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U. S. DEPARTMENT OF AGRICULTURE.

DIVISION OF VEGETABLE PHYSIOLOGY AND PATHOLOGY.

CEREAL RUSTS OF THE UNITED STATES:

A PHYSIOLOGICAL INVESTIGATION.

BY

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U. S. DEPARTMENT OF AGRICULTURE,
DIVISION OF VEGETABLE PHYSIOLOGY AND PATHOLOGY,
Washington, D. C., May 31, 1899.

SIR: I have the honor to transmit herewith a report on the cereal rusts of the United States, prepared by Mr. Mark Alfred Carleton, of this Division. Mr. Carleton has been engaged in an investigation of the diseases of cereals for several years and this report contains, in part, the results of the work. The several species of rusts affecting cereals in the United States are fully described, and the distribution of these rusts is given, together with a detailed statement of the results of extensive observations and experiments to determine the rust resistance of numerous varieties of wheat and oats. The life history of the rusts themselves has been very fully studied and the facts obtained from this work throw important light on problems connected with the breeding of rust-resistant varieties. In view of the wide distribution and the destructiveness of the rusts and the value of the results obtained, I respectfully recommend that the report be published as Bulletin No. 16 of this Division.

Respectfully,

B. T. GALLOWAY,
Chief of Division.

Hon. JAMES WILSON,
Secretary of Agriculture.

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CEREAL RUSTS OF THE UNITED STATES: A PHYSIOLOGICAL INVESTIGATION.

INTRODUCTION.

The investigator of grain rusts learns three important facts at the beginning of his work: (1) That these rusts are more or less distributed over all parts of the world where cereals are grown, (2) that the average annual losses they cause are very much greater than is generally supposed, and (3) that as yet little is known regarding their ontogenetic relations to each other and to their host plants. In view of the importance of rusts from a botanical standpoint, it is rather surprising that so little attention has been given to their study. In only two of the principal cereal-growing countries—that is, Australia and the United States—have any investigations of cereal rusts been made, and even in Australia, through the investigation of rust resistance, the matter has drifted into a study of the wheat plant itself rather than of the rusts that affect it. In the important cereal regions of Russia, India, and Argentina practically nothing is known about these rusts.

The only studies of the physiological relationships of the grain rusts outside of the writer's, most of which are reported in this bulletin, are those by Dr. Jakob Eriksson, of Sweden, whose researches will be described further on. Several investigations, relating almost wholly to the application of fungicides and the wintering of the parasite, have been made in this country. The most important are those reported by Bolley (6–10),[1] Kellerman and Swingle (41), Pammel (54, 56), Galloway (34), and Hitchcock and Carleton (38, 39).

A brief review of the work on grain rusts so far carried on shows that three distinct phases of the subject have been investigated: (1) The value of fungicides in preventing or checking rust, (2) rust-resistant varieties, and (3) the physiology of the rusts. Much of the work of the American writers above named pertains to the first phase. Besides the experimental work with the common fungicides, special attention was given to the preparation and application of new ones, particularly in the work in charge of the Department (34, Jour. Myc., pp. 199–203). In these trials the seed and soil were also treated with various compounds. The results of these various experiments showed that although

[1] For explanation of this and similar references in this bulletin, see corresponding numbers in bibliography, pp. 70–73.

Bordeaux mixture, ferric chloride, potassium bichromate, mercuric chloride, and perhaps one or two other compounds are quite effective in checking the spread of rust, yet, unless some great improvement is made in the method of applying fungicides, it would be practically impossible to spray a field of grain, owing to the great trouble in reaching all portions of the plants, and the difficulty, if not impossibility, of using any suitable kind of spraying apparatus in the field without destroying much of the grain. Besides, the expense of spraying large fields is an obstacle.

In Australia[1], as above stated, the careful and widespread attention given to the wheat-rust problem has resolved itself almost wholly into a study of rust-resistant varieties. McAlpine, Shelton, Pearson, and others have contributed much to the knowledge of rust-resistant varieties, but most of the work in this line has been done by Dr. N. A. Cobb as vegetable pathologist to the government of New South Wales, and William Farrer, a private breeder of rust-resistant varieties of wheat. An important concomitant result of the work in Australia is that the country now has wheat varieties that are vigorous, true to name, and of exceptional quality for the particular region in which they are grown.

Aside from the series of experiments reported in this bulletin, no systematic study of rust resistance has been made in this country, though from time to time observations in this line have been recorded by experiment station workers. Bolley (7, pp. 15, 16) refers to such observations made as far back as 1889, and farmers have long known that occasionally certain varieties of cereals are more exempt from rust than others. But in all such investigations as just mentioned the study of the rust itself is practically ignored, and hence much of the experimental work in spraying and selection of varieties is likely to be done blindly or needlessly and lead to unreliable conclusions. There would obviously be no necessity for combating a cereal rust every season if by knowing its life history it could be prevented from getting a start. Moreover, spraying experiments that prove successful in one season or in some certain locality may be an entire failure another season or in another locality, simply because different rusts are being treated in the different instances. So, also, it has been thoroughly demonstrated, as will be discussed further on, that certain varieties of wheat and oats are capable of the greatest variation in their powers of resisting rust, this resistance varying according to the kind of rust, the locality, and the season.

In the course of investigations reported by Hitchcock and the writer, the necessity of studying the physiological relationships of the rusts and the manner in which they winter over became more and more evi-

[1] The results of the Australian investigations were published in a series of reports of intercolonial wheat-rust conferences extending from 1890 to 1896, and also in the Agricultural Gazette of New South Wales and various special reports of different colonies.

dent.[1] The rusts had to be actually grown, and more diligent field observations became necessary. Everywhere the utmost confusion existed as to the distribution of cereal rusts on the different grasses, and frequently even the particular species occurring on any of the different cereals was only a matter of inference. By way of a beginning in clearing up these problems a series of inoculation experiments with uredospores was inaugurated by the writer on September 15, 1893, and carried on until February 1, 1894, the material used being taken from outdoors and propagated in the greenhouse during the winter. The results of these inoculations showed that the particular rust forms employed would not infect any cereal but the one from which they were taken, except *Uredo graminis* from wheat, which when used upon barley produced one rust spot (39, p. 3). It was also found that a uredo form found common on Kentucky blue grass would not infect wheat nor oats.[2] The conclusion was then expressed that "these experiments seem to show that the rusts of various cereals are probably physiological species." At the time this work was done the writer was not aware that Bolley had made some experiments of the same kind. Bolley, however, reached no conclusion (10, p. 263).

On March 1, 1894, the writer began work for this Department, consequently the inoculation experiments just described were dropped and were not resumed for nearly two years. In the meantime Eriksson, who in 1890 began experiments in the same line, published numerous articles[3] giving many results corresponding with those above mentioned and with others which have not yet been published. In some instances, however, the results differ.

Specialized forms of cereal rusts.—The species hitherto known all over northern Europe under the one name, *Puccinia rubigo-vera* (DC.) Wint., have been separated by Eriksson and Hennings into two distinct species, i. e., *P. glumarum* (Schmidt) Eriks. and Henn. (the "yellow rust)," and *P. dispersa* Eriks. and Henn. (the "brown rust") (30, pp. 197, 198, 257, 258). Three rusts, therefore, attack wheat in Sweden, the yellow rust being, it is said, the most common and destructive. So far as known this yellow rust does not occur in America, but the brown

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[1] Such ideas had already been expressed by the writer in Science, Vol. XIV, p. 63.

[2] On page 4 of the Kansas Agr. Expt. Sta. Bull. No. 46 it is stated that *Uredo graminis* of oats would not infect orchard grass, but subsequent investigations have shown that this grass is a common host for that rust.

[3] Eriksson, Jakob, *Die Getreideroste,* prepared in conjunction with Ernst Hennings and published originally in Swedish, comprises the details of Eriksson's investigations from 1890 to 1893. It did not reach America until the summer of 1896. The principal results were given in *Die Hauptresultate einer neuen Untersuchung über die Getreideroste* (Zeitschr. f. Pflanzenkrank., 1894, Vol. IV, pp. 66–73, 140–142, 197–203). The first part of this article appeared one month before the results obtained by Hitchcock and the writer were published, but was not seen by them for some time after. *Ueber die Specialisirung des Parasitismus bei den Getreiderostpilzen* (*Ber. d. Deutsch. Bot. Ges.*, 1894, Vol. XII, pp. 292–331) gave the results of his further experiments for 1894, and also references to the work of Hitchcock and the writer. Subsequent to 1894 Eriksson's researches have been reported in various papers.

rust is probably the same as our *P. rubigo-vera*. These authors also make the rust heretofore called *P. rubigo-vera simplex*, occurring on barley, a distinct species—that is, *P. simplex* (Kcke.) Eriks. and Henn. (30, p. 260). The writer has no reliable information as to the occurrence of this species on barley in this country, but what is possibly the same rust has been found occasionally on native species of Hordeum.

In his inoculation experiments Eriksson also has observed that forms of a certain rust species taken from certain hosts would not infect certain other hosts that are attacked by this same species. This may be true even where the hosts are of the same genus. On the other hand, infections will sometimes take place from the host species of one genus to the species of another genus. To such distinct forms of the same rust species he has given the name *forma specialis*. The form name is taken from the generic name of one of the hosts to which the form is restricted, preceded by the abbreviation f. sp. As there seems to be no good reason why the entire name should not be written as an ordinary trinomial, designating the variety, it will be so written in this bulletin. These forms are, as a rule, as good varieties as those established on morphological grounds by phanerogamic botanists.

Eriksson's researches have led him to conclude that so far as known there are at present ten forms of these cereal rusts in Sweden, that is, three black rusts, *Puccinia graminis secalis* on rye and barley, *P. graminis tritici* on wheat, and *P. graminis avenæ* on oats; three yellow rusts, *P. glumarum secalis* on rye, *P. glumarum tritici* on wheat, and *P. glumarum hordei* on barley; two brown rusts, *P. dispersa secalis* on rye and *P. dispersa tritici* on wheat; one dwarf rust, *P. simplex* on barley; and one crown rust, *P. coronifera* on oats. The writer's inoculation experiments in 1896 and 1897, several thousand in number, which will be described in detail further on, showed that there are now at least six distinct forms of cereal rusts in the United States, and probably a seventh, namely, two orange leaf rusts, *P. rubigo-vera tritici* on wheat and *P. rubigo-vera secalis* on rye; one crown rust, *P. coronata* on oats; three black stem rusts, *P. graminis tritici* on wheat and barley, *P. graminis secalis* on rye, and *P. graminis avenæ* on oats; and one maize rust, *P. sorghi* on maize.

In comparing the Swedish and the American rusts, it should be observed that Eriksson uses for the crown rust the name established by Klebahn (42, pp. 134–136), that is, *P. coronifera*. He justifies this upon the basis of his own (28) and upon Klebahn's experiments, which showed that in northern Europe *P. coronata* Corda is a collective species, of which one section has *Rhamnus cathartica* for its æcidial host and occurs on oats and other grasses, and another section has *R. frangula* for its æcidial host, but does not occur on oats. The former is called *P. coronifera* and the latter is called by the old name *P. coronata*. Each of these newly made species has also its specialized forms or varieties, there being eleven in all. As the writer has not yet determined the æcidial host of the crown rust of oats for this country,[1] it is deemed best to retain, for the present, the old name *P. coronata;* and while Eriksson and Hennings's division of *P. rubigo-vera* is undoubtedly correct, it seems, nevertheless, preferable to retain this well-known name[2] until it is positively determined whether our species is equivalent to *P. dispersa* or is a new one. It has already been stated that *P. glumarum* and probably *P. simplex* do not occur in this country, and of course *P. sorghi* does not occur in Sweden.

Common nomenclature of grain rusts.—The common nomenclature of these rust forms is a complex question. The names above given were decided upon, after much consideration, as being the most accurate and descriptive that could be used. In the case of *P. graminis* and *P. rubigo-vera* the names have been given in accordance with the most common and striking characteristics of the species. The former, when it occurs in abundance, exists principally upon the stems and in the black stage, while the latter is most strikingly exhibited on the leaves in the orange-colored uredo stage. The crown rust, although also an orange leaf rust, can not be spoken of as such, as it would thus be confused with the orange leaf rust of wheat, which is a different species. Of course, there need be no confusion in the case of the name of the maize rust, it being the only one on maize.[3]

The Department's work on grain rusts.—With a view to thoroughly investigating the cereal rust question, this Division in the spring of 1892 sent to crop reporters in the principal wheat-growing States a circular requesting information as to the distribution and abundance of the different rusts, the damage caused by them, etc. Owing to the press of other work, however, nothing further was done in this line, except the spraying experiments in 1892 and 1893, until the writer took charge of the work in the spring of 1894. A circular similar to the above was then prepared and sent to growers in all States where wheat and oats are grown to any extent, the information requested to be based on observations made during the season of 1894. The following table gives a combined summary of the answers received to the two sets

[1] Since the above was written a series of inoculation experiments have shown rather conclusively that *Rhamnus lanceolata* acts as an æcidial host of the crown rust in this country.

[2] The writer has recently had an opportunity to make personal observations on the rusts of wheat in northern Europe—that is, from England to Sweden and southward to southern Germany—and not only found these two to be very distinct, but also found that *P. glumarum* was far more common and injurious everywhere during the season of 1898. It seems strange that the two species should have been confounded for so long a time. However, there appear to be very good reasons for still retaining the name *P. rubigo-vera* for the species called *P. dispersa* by Eriksson and Hennings, as there is little doubt that it is the same as the one so well known under the former name in all other countries where rusts have been studied.

[3] The fact that Eriksson called *P. dispersa* brown rust—and, judging from his specimens, he seems correct—is the only reason for doubting that *P. rubigo-vera* of this country is equivalent to it, as our species is certainly orange color in the uredo stage. The uredo of the black stem rust would be more properly called brown.

of circulars. North Carolina and Georgia, though not important as wheat States, are included in the table to show the conditions respecting rust in such latitudes.

TABLE 1.—*Summary of reports on the cereal rusts received in 1892 and 1894 from twenty-three States.*

States from which reports were received.	Reports on wheat—		Per cent of damage.[1]	Part of plant chiefly affected by rust.			Reports on oats—		Part of plant chiefly affected by rust.		
	Injured by rust.	Free from rust.		Stems.	Leaves.	Both.	Injured by rust.	Free from rust.	Stems.	Leaves.	Both.
New York	9	43	23 (2)	1	1	2	27	12	1	13	2
Pennsylvania	7	61	30 (26)	1	4	1	53	11	2	9	2
Maryland[2]	1	7	17 (2)	......	4	....	4	....	......	3	2
North Carolina[2]	6	4	31 (7)	......	7	2	1	4	......	3	......
Ohio	27	73	20 (35)	3	6	4	63	28	1	11	3
Michigan	27	54	19 (35)	1	4	10	29	26	......	8	4
Indiana	47	87	24 (44)	4	13	2	72	44	1	10	2
Wisconsin	32	35	25 (30)	1	2	1	33	21	1	4	2
Illinois	34	90	26 (49)	......	14	3	69	22	......	2	......
Kentucky	43	22	40 (52)	1	8	6	40	19	......	4	4
Tennessee[2]	3	2	....	1	5	....	....	7	......	1	1
Georgia[2]	18	2	25 (10)	......	16	4	1	11	......	4	2
Minnesota[2]	5	12	....	......	2	....	4	12	......	4	4
Iowa	27	23	46 (16)	......	2	2	30	16	2	3	2
Missouri	38	48	26 (52)	1	8	1	46	23	......	5	3
North Dakota	7	26	11 (10)	......	......	1	21	5	1	2	1
South Dakota	12	43	21 (10)	1	1	2	20	10	......	1	2
Nebraska	30	77	28 (37)	......	1	2	67	32	1	5	4
Kansas	31	105	25 (38)	1	4	....	70	50	1	7	5
Texas[2]	4	10	12 (1)	......	3	5	3	6	1	2	2
Washington[2]	....	9	....	......	......	....	....	3	......	......	......
Oregon[2]	1	4	....	......	1	....	....	3	......	......	......
California	3	15	46 (3)	1	......	1	2	10	......	3	2

States from which reports were received.	Varieties of wheat free from rust.[3]	Varieties of wheat liable to rust.	Wheat most affected.	
			Early.	Late.
New York	Clawson (3), bearded varieties (2).	Clawson (3), white varieties (2).	4	32
Pennsylvania	Fultz (13), Red Lancaster (6)	Late varieties (5), bald varieties (3).	....	45
Maryland[2]	Fulcaster (2)	Fultz (2)	....	3
North Carolina[2]	Fulcaster (3), bearded varieties (1).	Ford (1), May (1)	2	5
Ohio	Early varieties (12), Fultz (9)	Late varieties (8), Clawson (7)	5	64
Michigan	Clawson (12), Fultz (7)	Clawson (14), Mediterranean (4).	3	61
Indiana	Fultz (27), early varieties (14)	Late varieties (20), bald varieties (9).	1	101
Wisconsin	Fultz (3), hard varieties (3)	Soft varieties (2), Fultz (2)	2	53
Illinois	Fultz (19), bearded varieties (10).	Fultz (10), bald varieties (8)	4	75
Kentucky	Fultz (10), bearded varieties (9).	Bald varieties (8), white varieties (6).	8	49
Tennessee[2]	Rice wheat (2), Missouri Red (1)	Bald varieties (2), soft varieties (1).	1	6
Georgia[2]	Blue Stem (3), Dallas (2)	Walker (1), Moore (1)	....	14
Minnesota[2]	Saskatchewan Fife (1), Blue Stem (1).	Soft varieties (1)	1	2
Iowa	Blue Stem (7), early varieties (3).	Bald varieties (3), soft varieties (2).	....	32
Missouri	Fultz (32), Mediterranean (21)	Walker (7), Fultz (7)	6	80
North Dakota	Blue Stem (4), hard varieties (3).	Scotch Fife (3), White Russian (2).	5	20
South Dakota	Blue Stem (14), hard varieties (4)	Soft varieties (5), Lost Nation (3)	1	23
Nebraska	Velvet Chaff (10), Blue Stem (6).	Bearded varieties (6), Grass (5).	3	63
Kansas	Turkey (32), Russian Bearded (11).	Soft varieties (15), May (8)	4	62
Texas[2]	Mediterranean (4), Nicaraguan (1).	Golden Chaff (1), bald varieties (1).	....	4
Oregon[2]	....	Red Chaff (1)	1	......
California	Sonora (2), Odessa (2)	White Club (2), White Australian (2).	1	3

[1] The figures in parentheses show the number of replies from which the average per cent was calculated.
[2] The report from this State is for 1894 only.
[3] The two varieties mentioned in each case were those given the greatest number of times in the replies. The figures in parentheses indicate the number of replies in which the variety was named.

The writer has visited, in some cases at different times, all the important wheat-growing States except Pennsylvania, Washington, Oregon, and California. The most extended tour was made in 1894, when all the wheat-growing States of the Great Plains and of the Mississippi Valley were visited. However, on account of the drought which prevailed during that season the conditions were in some respects most unfavorable for a study of the rusts. To gain a very accurate knowledge of conditions in the field a personal inspection of cereal districts for three to five successive years would be necessary; but, nevertheless, the observations just referred to, together with the replies from correspondents, have furnished valuable information and have made the situation much clearer than before.

GENERAL OBSERVATIONS ON CEREAL RUSTS IN DIFFERENT STATES.

New York.—Rust does not seem to be as prevalent in this State as in some others. Oats is often injured, especially in Erie and Wyoming counties. Considerable spring wheat is raised, and it is always more rusted than fall wheat, as are also late-sown wheat and oats. There is considerable stem rust, but to what extent it prevails over the State is not definitely known. Some counties in which rust is quite prevalent are Franklin, St. Lawrence, Cayuga, Schuyler, Wayne, Clinton, Greene, and Cattaraugus.

Pennsylvania.—The reports indicate that wheat is not extensively damaged by rust, but that oats is very commonly injured. It is quite probable, however, that much of the damage attributed to rust is due to "oat blight," a supposed bacterial disease occurring in this State, which gives the crop a yellowish red appearance. Fertilizers are supposed to materially aid the grain to escape rust by causing rapid growth and early maturity. The rust is always worst in the lowlands. Among the counties in which rust is especially prevalent are Columbia, Adams, Berks, Franklin, Northampton, Schuylkill, Forest, Sullivan, and Lackawanna. The standard varieties of wheat grown in this State are Fultz, Lancaster, and Fulcaster.

Maryland.—It is claimed that the application of fertilizers, especially phosphates, has materially decreased the losses from rust in this State in recent years. In the experiments conducted by the Department at Garrett Park during three seasons there was an abundance of orange leaf rust on wheat and crown rust on oats, but they did not appear to do any particular damage. Black stem rust was not observed. As in Pennsylvania, oat blight produces much of the injury commonly ascribed to rust. Much oat rust has been reported from Cecil County.

North Carolina.—Wheat is quite commonly injured by rust, but it is not grown extensively in this State. The orange leaf rust seems to be the prevailing species, though as yet it is uncertain whether it is the only one present in cases of severe injury. One peculiar fact of interest is that early wheat, such as Early May, is often more injured than late varieties, which is just the reverse of the rule. A probable reason for this is that early wheat is sometimes weakened by frosts or freezes and is thus rendered more liable to rust. In the Atlantic coast States the wild blackberry rust (*Cæoma nitens*) is extremely abundant, especially in the edges of clearings near fields of wheat—a fact which has given rise to the erroneous opinion in this State that this rust has some ontogenetic connection with the cereal rusts (53, p. 16). Three counties in which rust is quite prevalent are Randolph, Alexander, and Moore.

Ohio.—The black stem rust is occasionally very prevalent in this State. There is much more injury by rust to oats than to wheat. On account of early ripening, Fultz wheat is less liable to rust than other varieties. Here, also, fertilizers cause rapid growth and early maturity, and act to some extent as preventives of rust. The counties in which rust is reported to be especially injurious are Clark, Stark, Richland, Fayette, Hancock, Knox, Logan, Guernsey, Crawford, Scioto, Defiance, Greene, Medina, Mercer, Meigs, Miami, and Harrison.

Michigan.—In this State wheat is often badly damaged by rust, but, as in all the North Central States, oats suffers still more. Wheat is much more liable to rust injury after winterkilling, hence late varieties suffer more than the early varieties. The varieties of wheat most generally grown are Clawson and Fultz. Rust rarely occurs in the sandy districts. It is apparently most abundant in Antrim, Jackson, Wayne, Charlevoix, Cheboygan, Lapeer, Benzie, Alcona, Leelanau, Clinton, Shiawassee, Livingston, Washtenaw, Osceola, Midland, Saginaw, and Ingham counties.

Indiana.—Wheat is much injured and oats is commonly damaged in this State by rust. Late varieties are invariably much more liable to rust than the early varieties. Fultz wheat escapes rust, not because it is rust resistant, but because it ripens early. In some instances the growing of oats has been abandoned on account of rust. Grain is said to be free from rust in the warm, sandy soils. Some claim that it is very severe only once in two to five years. Black stem rust is the most injurious species occurring in this State. The counties in which the greatest amount of rust is found are Wayne, Vanderburg, Jennings, Pike, Sullivan, Greene, Ohio, Union, Lawrence, Posey, Gibson, Clinton, Ripley, Bartholomew, Huntington, Adams, Morgan, Wells, Clark, Delaware, Miami, Starke, and Johnson.

Wisconsin.—According to nearly half the reports received from this State, wheat is commonly damaged by rust. As in some other States, it is believed by many that an application of salt, lime, or ashes hastens ripening and makes stiffer and cleaner straw. It is claimed by some that White Russian oats possesses a considerable degree of rust resistance. Black stem rust constitutes a good proportion of the cereal rusts. Some of the counties in which there is much rust are Marathon, Pepin, Waukesha, Richland, Ozaukee, Brown, Waupaca, Adams, Marquette, Dunn, Waushara, Polk, Sauk, Outagamie, Juneau, Buffalo, Winnebago, Saint Croix, Jackson, and Sheboygan.

Illinois.—Oats is commonly and often seriously damaged by rust. The damage to wheat is much less, although it, too, often suffers severely. In 1890 and 1891 rust was unusually severe in some localities. It is always worst in fields of grain that have winterkilled. The damage is particularly severe once in three to five years. Wheat seems to suffer more in the extreme northern and southern portions of the State than in the central part—due in the southern part probably to the latitude and climate, and in the northern part to the large proportion of spring wheat grown there, but spring wheat is rapidly losing prestige and is not grown so extensively as formerly. Fultz wheat is a popular variety throughout the State. In some localities tile drainage is said to reduce the amount of rust. Some believe that although bearded varieties are less liable to rust on prairie lands, they are more liable to it on timber lands, but on what this belief is based the writer does not know. Some of the counties in which much rust seems to occur are Hardin, Morgan, Massac, Williamson, Whiteside, Edgar, Dekalb, Grundy, Cass, Menard, Cook, Boone, Lee, Carroll, Woodford, Stark, Pope, Lawrence, Stephenson, Pulaski, Johnson, and Jersey.

Kentucky.—The reports of correspondents, as well as the writer's observations, indicate that in this State wheat is very commonly and severely damaged by rust. In other States the complete destruction of the crop occurs occasionally, but in this State this is a common occurrence. Black stem rust is very common and, as it appears later than the orange leaf rust, the introduction of early-maturing varieties is a matter of much importance. Some make a practice of harvesting the grain while in the "dough" stage in order to escape the rust. Oats is also extensively injured. Some of the counties where the grain is most affected are Trigg, Harrison, Metcalfe, Simpson, Jackson, Caldwell, Henderson, Nelson, Allen, Garrard, Grayson, Adair, Magoffin, Crittenden, Fayette, Casey, Calloway, Webster, Christian, Livingston, Letcher, Grant, Graves, McLean, Ballard, Muhlenberg, Marshall, Martin, Lawrence, Estill, McCracken, Kenton, Montgomery, Knox, Clay, Monroe, Boone, and Ohio.

Tennessee.—The information concerning rust in this State is still quite meager, though the writer has made two trips of observation to different localities. However, the indications are that wheat is rather commonly injured by rust. The stem rust is very severe some years, but seems to be less common than in Kentucky. Little injury is done to oats. Rice wheat is considered by some to be a rust-resistant variety. Fultz and Fulcaster are favorite varieties in some localities. Stem rust becomes abundant from May 20 to June 1. Greene County seems to have considerable rust.

Georgia.—Very little wheat is raised in Georgia, but usually what is grown is badly injured by rust. Leaf rust is the species most prevalent, but frequently the grain is not severely injured until the stem rust appears. In this State, as in all the Gulf States, oats is seldom injured by rust. The variety of oats most commonly grown is the Texas Rust

Proof. Scarcely a county in the State is free from rust, but it appears to be most abundant in Lincoln, Jones, Milton, Catoosa, Hart, Randolph, Bartow, Henry, Marion, and Sumter counties.

Minnesota.—Not much information is at hand concerning rust in this State, but it is known that in certain years both wheat and oats are greatly injured. The Fifes and the Blue Stem are the standard varieties of wheat generally grown. White Russian oats is said by some to be rust resistant. Reports of rust have been received especially from Stearns, Fillmore, Renville, Ottertail, and Watonwan counties.

Iowa.—So great has been the damage from rust in this State that in some parts wheat growing has been gradually abandoned principally from this cause. In Buena Vista County it is reported that there has been an average annual loss of 10 per cent of the crop during the past twenty-two years. This severity of the rusts is doubtless due to the practice of spring sowing, so common in the State. The great desideratum for Iowa in the way of cereals is a good, hardy wheat like the hard red wheats from south central Russia, as the Ghirkas, Crimean, Yx, etc. The amount of oats sown in the State as compared with wheat is becoming quite large, but rust often destroys this crop also. It is always the black stem rust that is particularly injurious. Rust is pretty evenly distributed over the State, but it is probably particularly abundant in Fremont, Buena Vista, Des Moines, Dallas, Clay, Butler, Crawford, Cerro Gordo, Appanoose, Buchanan, Cedar, Cherokee, Greene, Franklin, Emmet, Allamakee, and Plymouth counties.

Missouri.—There is considerable rust in this State, but not much is known concerning the relative proportions of leaf rust and stem rust in cases of great injury. Mediterranean wheat is considered to be rather rust resistant. Oats is often much injured. Rust seems especially common in Christian, Crawford, Bollinger, Carroll, Atchison, Iron, Oregon, Dent, Dekalb, Franklin, Carter, Hickory, Livingston, Mercer, Sullivan, Daviess, Madison, Grundy, Nodaway, Gasconade, Linn, Jefferson, and Perry counties.

North Dakota.—Wheat does not seem to be commonly damaged in this State, although leaf rust is always present and is sometimes abundant. Oats, however, is often injured. White Russian oats is thought to be somewhat rust resistant. The Fifes and Blue Stem (Velvet Bald Blue Stem) are almost the only varieties of wheat known by the majority of the farmers. By far the greater proportion of the cereals of the State is, of course, grown in the extreme eastern part, in or near the fertile James River Valley, and the rusts naturally occur in greatest abundance in that region. Nevertheless the orange leaf rust and occasionally the stem rust also are found far westward. Much rust is reported, especially from Nelson, Grand Forks, Cass, Richland, Steele, McHenry, and Kidder counties.

South Dakota.—In this State, as in North Dakota, it is, as a rule, too dry, cool, and breezy for rusts to do much damage, but nevertheless they are occasionally quite injurious in places. The leaf rust is the species most common. The Blue Stem and various Fifes are the varieties of wheat generally grown. Oats, especially when planted late, is often badly rusted. Naturally rust is most abundant in the southeastern counties. Rust seems to be quite severe, at least occasionally, in Kingsbury, Clay, Deuel, Faulk, Brookings, Hanson, Minnehaha, Union, Douglas and Davison counties.

Nebraska.—Usually wheat is not badly damaged by rust in this State, although sometimes the injury is quite serious. The cereals in large portions of the State were badly injured in 1891, the black stem rust being abundant that year. In the sandy districts there is usually but little trouble with rust. As in Iowa, spring sowing is common, and is doubtless responsible for much of the injury. Fortunately, however, fall sowing is coming into vogue. As is usually the case, rust often accompanies winterkilling and poor drainage. In the eastern portion of the State oats is often severely damaged. The counties from which much rust is reported are Douglas, York, Loup, Dodge, Nuckolls, Blaine, Gage, Custer, Frontier, Nance, Perkins, Hamilton, Greeley, Howard, Adams, Wayne, Cuming, Boone, Seward, and Saline.

Kansas.—In the eastern half of the State the wheat crop is quite often injured by rust, but in the western half the damage is usually insignificant. Notwithstanding its comparative immunity, the writer once saw a field of White Michigan wheat in Cloud County totally destroyed by rust, the probable yield of the field having been estimated a few days prior to the attack at 25 bushels per acre. Turkey wheat is quite resistant to rust and is a general favorite in the State, particularly in the western part, and yet even in that section the writer has seen it severely attacked by the stem rust. Oats is often greatly damaged by stem rust in the eastern portion and is sometimes a total loss. The crop suffered greatly in 1893. Occasionally fields of late-sown oats are entirely destroyed before harvest. The counties in which rust seems to occur most frequently are Rice, Montgomery, Johnson, Stevens, Washington, Linn, Riley, Osage, Jewell, Reno, Marshall, Barton, Coffey, Bourbon, Ottawa, Shawnee, Decatur, and Miami.

Texas.—Reports received from the State during the dry season of 1894 indicate that grain is not usually attacked by rust. However, but little dependence can be placed upon so few reports from so large a State and only for one season, and moreover most of them were from northern Texas and the Panhandle, where there is always considerable drought. On the other hand, the writer knows from personal observation that in the east and south central portions of the State rust has been so detrimental to wheat that this crop has been practically abandoned over an extensive area of excellent wheat land. It is claimed that at the Texas Agricultural Experiment Station rye is actually injured by leaf rust even in midwinter. In fact, rye is often attacked by this rust in all the Southern States. Oats is seldom injured to any extent. Nicaragua wheat, a durum variety, was totally destroyed in 1896 at the Agricultural College farm in Brazos County. The part of the State in which rust seems to be most severe is that lying east of Gainesville, Fort Worth, and Austin.

Washington and Oregon.—Little information relative to cereal rusts has been obtained from these States, but as far as known they cause only slight damage, except in districts within reach of dampness from the ocean. On account of the growing season being also the dry season, the atmosphere is not usually favorable to rust propagation. Occasionally oats is considerably affected by the crown rust, as was the case in 1892 in Sherman County, Oregon.

California.—Though reports indicate that rust does not commonly injure the grain, still in some places both wheat and oats are severely damaged. The losses seem to be confined almost wholly to the coast districts within the influence of sea fogs. In other parts of the State the atmosphere is usually too dry for the rust to spread. In a few districts along the coast, in parts of Ventura County, for instance, wheat raising is said to have been abandoned on account of rust, but in some districts, as in Mono, Fresno, and San Bernardino counties, rust is extremely rare. Toward the north early wheat is reported by some to be more liable to rust than late, perhaps on account of weakness from winterkilling or frosts. Semihard or soft white wheats are generally raised. Sonora is a common variety and is said to be rather rust resistant. Black oats, it is claimed, is more resistant than white. Some of the counties in which rust seems to be especially plentiful are Santa Clara, Ventura, Sonoma, San Mateo, San Diego, and Santa Barbara.

Montana, Idaho, and Utah.—On account of the cool, dry atmosphere in these States, the rusts seldom occur in sufficient abundance to do any appreciable injury.

Virginia.—According to reports. wheat in the Shenandoah Valley is sometimes badly damaged by rust, and oats is damaged quite often. The rust is most abundant in the lowlands. Lancaster wheat is considered as rather rust resistant.

Oklahoma.—Within the past three years Oklahoma has become an important wheat-producing territory, and in the season of 1897 much injury resulted from rust. There was much rain near harvest time and rust doubtless materially lessened the yield, although it was still very large. In this region May wheat and soft varieties seem to be most subject to rust and Fulcaster and Turkey most resistant.

LOSSES CAUSED BY RUST.

Although several writers have discussed the question of financial losses from the grain rusts in different countries, including the United States, there are as yet no reliable estimates. Could even an approximate estimate of the losses in this country be made it would be very gratifying, but as yet even this can not be done. It would of course be impossible to make any general estimate from the per cents of damage given in Table 1, as they show the losses for only one or two seasons and in comparatively few localities. In the writer's opinion, however, the average annual loss from rust throughout the United States far exceeds that due to any other enemy, insect or fungous, and often equals those from all others combined.

ORANGE LEAF RUST OF WHEAT.

(*Puccinia rubigo-vera tritici*).

Physiological relations.—It was not until a late date in the writer's inoculation experiments that attention was given to this rust, most of the previous work having been with *P. graminis* and *P. coronata* of oats. Many observations made in the field have shown that the leaf rust of wheat and of rye probably do not pass from one host to the other, but are distinct specialized forms. Where wheat and rye are grown in adjoining fields, rust not only attacks them at different dates (which may be partially accounted for in that rye is in a condition most susceptible to rust earlier than wheat, maturing, as it does, earlier), but is occasionally very prevalent on one and not abundant or even present on the other during the entire season. Again, the writer has never been able to find any relation between the abundance of this rust on wheat and its occurrence on native grasses in the vicinity of the wheat fields.

The writer's first experiments, reported by Hitchcock and himself (39, pp. 3, 4), showed that uredospores of this rust would not infect oats, rye, or orchard grass, and that a uredo (supposed to belong to *P. rubigo-vera*) of Kentucky blue grass would not infect wheat or oats. The results of all subsequent inoculations[1] with this rust are summarized in the table following.

[1] Unless otherwise explained, all inoculation experiments reported in this bulletin consisted in treating one small pot containing from two to twelve seedling plants of the same kind 10 to 30 days old from the seed in case of cereals and 20 to 40 days in case of other grasses. An average of nine inoculations were made in each experiment, there being never less than six, and rarely more than twelve. The manner of performing the experiment is as follows: The plants to be inoculated are first wet with a very fine spray of water from an atomizer. Then by the use of a thin, narrow-bladed scalpel material is scraped from the diseased plants and is applied in spots here and there on the healthy ones, that is, on the upper surface, the lower surface, or on both, or on the stem also, depending on the particular experiment. No incisions are ever made. After another spraying the plants are covered with a bell jar, and the latter wet with cold water to aid in preserving a coating of moisture on the plants. On an average, the bell jar is not removed for two days, except just for an instant to allow a further spraying with water. During periods of hot sunshine a shade is used to shut off the sun's rays. These experiments are made in the greenhouse even during the summer, and the different rusts are kept growing the year through. All experiments of the same date are, as a rule, accompanied by one check experiment, in which inoculations are made upon plants of the same host as those from which the inoculating material was taken. All inoculations are made with uredospores unless otherwise stated.

TABLE 2.—*Inoculation experiments with Uredo rubigo-vera of wheat.*

Date of inoculation.	Place where experiments were made.	Origin of inoculating material.	Plant inoculated.	Period of incubation (days).	Result.
Jan. 19, 1897	Washington, D. C.	Wheat	Wheat	8	Successful.
Do	do	do	Missogen wheat	8	Negative.
Do	do	do	Rye	8	Do.
Feb. 1, 1897	do	do	Wheat	8	Successful.
Do	do	do	Rye	8	Negative.
Do	do	do	Barley	8	Do.
Do	do	do	Oats	8	Do.
Feb. 12, 1897	do	do	Wheat	11	Successful.
Do	do	do	Taganrog wheat	11	Do.
Do	do	do	Missogen wheat	11	Do.
Feb. 13, 1897	do	do	Wheat	15	Do.
Do	do	do	*Dactylis glomerata*	15	Negative.
Feb. 24, 1897	do	do	Akayemidashi wheat	11	Only one or two spots.
Do	do	do	California white wheat	11	Do.
Feb. 11, 1898[1]	Lincoln, Nebr	do	*Elymus canadensis*	13	Negative.
Do	do	do	*Elymus canadensis glaucifolius.*	7	Doubtful.
Do	do	do	*Elymus virginicus*	13	Do.
Do	do	do	*Agropyron richardsoni*	13	Negative.
Do	do	do	*Agropyron spicatum*	13	Do.
Do	do	do	*Agropyron tenerum*	13	Do.
Do	do	do	*Dactylis glomerata*	13	Do.
Do	do	do	*Panicum autumnale*	13	Do.

[1] Through inadvertence no check experiment was made.

Two of the experiments were doubtful on account of the slight infections, which were possibly accidental. Although under date of February 11, 1898, no check experiment of inoculations from wheat to wheat was made, in numerous other experiments with wheat alone the inoculations never failed to infect readily, where ordinary cultivated varieties of *Triticum vulgare* were used.[1]

Although the experiments carried on with *Uredo rubigo-vera* were not so numerous as those made with other rusts, they are nevertheless sufficient to show that the limits of this rust form are quite closely circumscribed by physiological conditions. Many more experiments with this rust would have been made during the winter of 1896–97 had it not been for the presence of wheat mildew, which tended to vitiate all work and which could not be got rid of without interfering with the experiments.

The time of incubation, or the interval between inoculation and appearance of rust in the case of *Uredo rubigo-vera* of both wheat and rye, is somewhat longer, as a rule, than that of the other cereal rusts, ranging under usual conditions in the greenhouse from seven to ten days.

The experiments so far made indicate that only varieties of the following species and subspecies[2] of the genus Triticum act as hosts for

[1] A fact of interest in this connection is that in one experiment Missogen, a hard wheat, of the subspecies *Triticum durum*, from Greece, showed no infection. Although this may not seem very significant at first, yet if considered in connection with facts shown in Table 8, it will be found to be in accord with the results of experiments on rust resistance of varieties given in Table 3, which show that durum and poulard wheats are more resistant to orange leaf rust than are the bread wheats.

[2] The classification of wheats followed in this bulletin is that of Koernicke and Werner (44).

the orange leaf rust of wheat in this country: *Triticum vulgare*, *T. compactum*, *T. turgidum*, *T. durum*, *T. spelta*, *T. dicoccum*, and *T. polonicum*. These are all cultivated varieties, but varieties of the three last named have been grown so far in this country only in an experimental way.

Occurrence and distribution.—It is a well-established fact that the orange leaf rust of wheat is the most common and widely distributed of all the cereal rusts in the United States, and is especially the most constant in occurrence from year to year. The stem rust and the crown rust do not occur on cereals in certain years and certain localities. The orange leaf rust of rye, although occurring wherever rye is grown, is still not common, because rye is not grown generally. Maize rust usually occurs wherever corn is grown, but is seldom abundant; but the orange leaf rust of wheat is not only never absent from the wheat field, being there the year through, but is sometimes abundant even in dry seasons. There is still so much uncertainty as to the identification of species that as yet it can not be definitely said whether this rust is the most common in foreign countries also, but the probabilities are that it is, at least in all except the countries of northern Europe. In Australia and India there is no doubt of its being the most common, provided that our leaf rust and the one in these countries are equivalent, which is almost certain. Barclay (5, Vol. XXVIII, p. 257; Vol. XXX, p. 46) is quite emphatic as to its being the most common in India.[1] In Sweden the conditions seem to be exceptional. The most common, as well as the most injurious rust in that country, according to Eriksson (31, pp. 208, 209, 331), is *P. glumarum*, while *P. dispersa* is rather insignificant both as to its occurrence and the injury it causes.[2]

Wintering of the uredo.—So much has already been written concerning the wintering of the uredo and the ability of the fungus to readily pass the winter in the uredo stage is so well established for this country that there is little further to add. However, it may perhaps be well to state that the conclusions of Bolley (7, pp. 13–15) and of Hitchcock and the writer (39, pp. 1, 2) have been confirmed and reconfirmed by the writer both in Kansas and Maryland. In the Southern States the leaf rusts of both wheat and rye not only live, but grow all winter. It is now conclusively proved that in latitudes below 40° in this country the leaf rust of wheat is able to pass a perpetual existence in the uredo stage on wheat alone, without the intervention of any other stage. This is evidently a matter of much economic importance, for if this method is not only possible, but should turn out to be the only one, it is easy to

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[1] Through the kindness of the Government officials of India the writer received specimens of rusted wheat straw from that country. The rust most abundant on the specimens seems to be morphologically enough like our own *Puccinia rubigo-vera* to be called the same, specimens showing the second and third stages of this rust being present. However, *P. graminis* was also found in considerable amount.

[2] At the writer's request Dr. Eriksson kindly sent him specimens of both *P. glumarum* and *P. dispersa*. An examination of these specimens showed that with the exception of a slight difference in color there is a very close resemblance morphologically betweeen the latter and our *P. rubigo-vera*.

see how the fungus might be easily overcome.[1] At all events the writer is convinced that the existence of volunteer wheat must have considerable bearing upon the distribution and propagation of this rust, and the conviction will be strengthened should further experiments fail to reveal other hosts besides wheat. There is still a possibility, however, that some native grass harbors the same rust form. In Australia it is generally accepted as a fact that both *Puccinia rubigo-vera* and *P. graminis* exist in the "red rust" stage all the year through, either on self-sown grain or on native grasses. Cobb (19, p. 29) and Lowrie (48, p. 51) make particular references to the matter. However, it should be remembered that identification on morphological grounds alone is not sufficient to prove that the grasses mentioned actually bore these cereal rusts and no mention is made of inoculation experiments.

The observations made thus far in India do not indicate that this rust lives the entire year in the uredo stage on any host. Barclay, after careful investigation, failed to discover a continuous repetition of uredospores (5, Vol. XXX, pp. 47, 48), though he admits the possibility of such. He thinks such an occurrence more improbable than "in Europe, where crops both of cereals and wild grasses overlap one another." Prain (60, p. 27) and Watt (70, pp. 54–56) discuss this question and accept Barclay's conclusions.

Eriksson has failed to discover that any one of the wheat rusts lives throughout the year in the uredo stage in Sweden. He claims to have shown, however, that *P. glumarum* is perennial within the wheat plant (25). To account for this he proposes a new theory, which will be

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[1] Dr. Geo. Watt, editor of the Agricultural Ledger of India, makes quite unfavorable criticisms (70, pp. 55, 56) of the conclusions reached by Hitchcock and the writer concerning this matter, as given on page 9 of our second report on rusts of grain. After quoting these conclusions he says: "The criticism would seem fairly justifiable, however, that these opinions are based on purely artificial experiments. The experiments may, in fact, be said to show what might occur, not by any means what occurs. It would, of course, be possible (under glass in cold countries or by reducing the temperature in tropical regions) to supply the parasite with continuous crops of its host, and thus to produce uredospores for an indefinite period. * * * The Kansas reports do not seem to afford sufficient evidence in support of the views advanced. * * * In countries that do not have a severe climatic isolation between the seasons of wheat cultivation, volunteer survivals of the crop might easily enough occur. Where this is met with the existence of uredospores might be made a matter of actual observation, and their vitality tested at repeated intervals, without having to call in the aid of improbable experiments." But a more careful reading of the bulletin will show that the "opinions" mentioned are not "based on purely artificial experiments," though greenhouse experiments were indeed employed to confirm field observations. It is distinctly stated on page 2 of the report named that the rust was observed in the field at different times, up to March 22, and of course after that date rust would continue to grow in that latitude. In the meantime, to prove that in these rust spots the spores were actually alive, many of them were brought in at various times and germinated and healthy plants infected with them, thus "testing their vitality" exactly as Dr. Watt suggests should be done. More than this, diseased plants were occasionally transplanted into the greenhouse, and as fresh uredospores were produced before a period of incubation from inoculations could have elapsed the mycelia were also shown to be alive (39, p. 2).

referred to further on. Sorauer (65, p. 216) states that the uredo mycelium of *Puccinia straminis* (*P. rubigo-vera*) winters over without injury. The inference is that the locality he has in mind is some portion of Germany, but whether he means *P. glumarum* or *P. dispersa* of Eriksson and Hennings, and whether the host plant is wheat or rye, is not known.

Liability of different varieties to this rust.—The study of the comparative liability of different wheat varieties to rust has in recent years developed to such an extent that an elaborate paper might be written on this topic alone. To investigate this phase of the subject the writer conducted a rather exhaustive series of field experiments during the seasons of 1895, 1896, and 1897, and as the orange leaf rust was the one mainly dealt with the question of rust resistance will be discussed at length here.

At the outset much time was required to learn what varieties are grown in different parts of the world and the sources through which they might be obtained. Efforts to obtain the varieties of each country were begun early in the spring of 1894, but many of those from distant parts did not arrive even in time for planting in the autumn of 1895. Peter Henderson & Co., of New York City, agreed to aid in obtaining foreign varieties through their foreign agents. In addition to those obtained in this way, samples were sent in direct by William Farrer, of New South Wales; Prof. E. M. Shelton, of Queensland; Prof. S. Tanaka, of the Imperial University, Tokyo, Japan; Carter Bros., of London, England; and Mr. H. Vagnon, Kherba, Clos des Bras, Algeria. In this country and Canada varieties were obtained from the agricultural experiment stations of Michigan, North Dakota, Nebraska, Kansas, and New Mexico; from Prof. William Saunders, of the Central Experimental Farm, Ottawa, Canada; and from Mr. A. N. Jones, of Newark, N. Y. Varieties were obtained from every important wheat country in the world. The record of experiments shows over 1,200 varieties, but of course many of these were duplicates, and about 75 were Farrer's unfixed crossbreds. Notwithstanding this, however, there were certainly over 900 good varieties tested during the three years of experiment. A very large number of these varieties, 463 in all, came from New Mexico through Prof. A. E. Blount, who has done so much work in breeding wheats, and who has collected a great many varieties from different countries. These were especially valuable in that they included a number of Blount's crossbreds and also many foreign varieties more or less acclimated to this country.

The experiments of 1895 were conducted at Garrett Park, Md., those of 1896 at Salina, Kans., and those of 1897 at Manhattan, Kans. The soil at Garrett Park was first treated with a fertilizer commonly used for wheat in that region and composed of South Carolina rock, bone dust, and kainit, the application being made at the rate of 500 pounds per acre while the ground was being harrowed. The different varieties were, as a rule, seeded in single alternate rows, these being 48 feet long and 12 inches apart at Garrett Park, 20 feet long and 12 inches apart at Salina, and 25 feet long and 20 inches apart at Manhattan. The time of seeding extended from October 17 to November 28, many of the foreign varieties being sown exceedingly late on account of their late arrival in this country. In the experiments at Garrett Park all the varieties, except those from New Mexico and Farrer's crosses, were seeded in two to four rows each.

The orange leaf rust was the only species that occurred at Garrett Park, but it was extremely abundant, and therefore there was an excellent opportunity of testing the resistance of the different varieties to this rust. After this year it was thought best to continue the experiments in the States of the Plains, as they more truly represent the conditions of the greater part of our wheat region, and, moreover, the stem rust as well as the leaf rust is nearly always present in that region. Hence the work was transferred to Kansas. Both rusts attacked the wheat at Salina and at Manhattan, the leaf rust being the more common. At Salina, as at Garrett Park, all varieties were planted rather late because of the drought, the dates of seeding extending from October 16 to November 4. At Manhattan all but about a dozen of the varieties were seeded in good time, that is, on September 22 and 23. The seeding of spring varieties was done each year at the average time for such seeding.

The winters of 1895–96 and 1896–97 were both unusually severe in the localities where the experiments were conducted, hence hundreds of the imported varieties failed entirely during these two seasons, and only a small proportion of the whole number tested during the three years withstood the climatic rigors and produced seed at the close of the season at Manhattan. It is interesting to note, however, that a number of sorts, especially those of Russian origin, passed the winter at Manhattan in much better condition than most of the varieties regularly grown there by the experiment station (36a, pp. 172–174).

The rust liability of the different varieties was determined by noting the per cent of rust on each at the date when the rust was most abundant.[1]

The experiments at Salina were conducted on the farm of Mr. B. B. Stimmel, who kindly gave the necessary ground free of charge. Through the courtesy of the board of regents of the State Agricultural College at Manhattan, the farm department cooperated with this Department in carrying on the experiments on its land and furnished certain aid in the prosecution of the work. For the successful accomplishment of the

[1] If no rust spot could be found on any plant in the row, the per cent of rust was of course zero; if only one or two spots were present on each of the plants in a half dozen or more places, the amount of rust was estimated as 1, 2, or 3 per cent, and so on; if nearly all the leaves in the row were about half covered with rust, it was estimated as 50 per cent; and if they were practically covered, it was estimated as 100 per cent. Of course the estimates were necessarily approximate and, moreover, the scale of rusts varies according to individual ideas. In this case the rust was so slight on the sheath that it was not considered.

work at Garrett Park great credit is due Mr. P. H. Dorsett, of this Division, who rendered valuable assistance.

The principal results of the three years' experiments are arranged in as condensed a manner as possible in the following table. In every case where the rust could not be graded for more than one season the variety is omitted from the table. Nearly every instance of this kind was in the case of a variety that winterkilled or failed otherwise after the first season, but in some cases they were simply not at hand for planting more than the one season. As a result of this disposition only about one-third of the varieties actually planted during the three years are represented in the table; hence it shows no varieties from Greece, England, Holland, India, Siberia, Argentina, or Algeria, although they were obtained from each of these countries. In the case of the varieties from Argentina and Algeria they were simply received too late to be tested except in the severe season of 1896–97.

Only those who have had similar experience can form any idea as to the work required to keep the nomenclature of varieties from being confused. It is not claimed that all the names in the table are right, for such a claim would be preposterous; but it is believed that nearly all are fairly reliable, or at least as correct as they can be in the present confused condition of our wheat nomenclature. Moreover, many apparent errors are really the correct names, the seeming discrepancy arising from translations of the original name into a different language, or they are cases of pure synonyms; for instance, Kaiser and German Emperor are very probably the same variety, while Kubanka and Beloturka, Black Sea and Arnautka, Thick-set and Cone Rivet, Club wheat and Oregon Club, Genealogic and Hallets Pedigree, Soules, Flint and Yorkshire, German Amber and Amber Winter, De Bordeaux and Rouge Inversible, etc., are all cases of synonyms. The peculiarity of some of the names is doubtless due also to bad orthography, as for example, a certain hybrid is not Tamed but Lamed. In French names incorrect spelling is common and in Russian names it is the rule. Sometimes such simple names as Gold Drop and Blue Stem are applied incorrectly to the most widely different varieties, and such names as Turkey and Russian Red either mean very little or may even be misleading, giving no clue to the origin of the varieties as one might suppose. A thorough revision of the nomenclature of our varieties of wheat is a most important desideratum for this country.

The two main obstacles to a successful comparison of the rustiness of a large number of varieties according to the method followed in the experiments, are (1) that the varieties being necessarily planted at different dates those equally susceptible to rust may nevertheless not be equally rusted at the time of grading, and (2) it is impossible to carefully grade the rustiness of more than one hundred varieties a day. However, in case of the experiments here described, both obstacles were overcome to a considerable degree by grading the varieties each season in the order in which they were sown; but notwithstanding this, many of them afterwards became more rusted than they were at the date of grading, though this did not occur to any great extent except in 1895. In that year, for example, though a few of the varieties showed no rust at all at the date of grading, yet only one variety, Einkorn, remained absolutely rust proof throughout the season. Much value would have been added to the experiments if they could have been continued in each locality during the three seasons, but under the circumstances this was impracticable. It is hoped, however, that they have settled a few things definitely and that they will furnish a valuable groundwork for future experiments in this country.

TABLE 3.—*Comparative amount of Uredo rubigo-vera on different varieties of wheat.*

Localities and names of varieties of—	Bald or bearded.	Per cent of rustiness of varieties in— 1895. May 23–25.	1895. June 13–17.	1896. June 15–16.	1897. June 22–25.	Average.	Remarks.
WINTER WHEATS.							
New Mexico:							
Algerian No. 1	Bearded	......	2	40	......	21	Durum wheat.
Algerian No. 3	do	......	3	20	......	12	Do.
American	do	x[1] m[2]	95	50	55	67	
Ames	do	m	0	50	......	50	Do.
Amethyst	Bald	x	10	50	......	30	Blount's cross.
Andrews	Bearded	m	92	20	......	56	
Andrus Black	do	......	5	15	......	10	
Aowse	Bald	m	70	50	......	60	
Armstrong	do	x m	88	30	......	59	
Arnolds Hybrid	do	x m	75	25	60	53	
Australian Indian	......	......	30	20	......	25	
Baltimore	Bald	m	90	25	......	58	
Banater	Bearded	m	5	20	......	13	
Bennett	do	......	60	50	......	55	
Berthoud	Bald	......	60	30	......	45	
Big English	do	m	93	10	55	53	
Black Chaff	Bearded	x m	40	35	......	38	
Blue Stem	Bald	x m	65	40	......	53	
Boyer	Bearded	x	70	50	20	47	
Buckeye	Bald	m	80	[3] *33	50	54	*Mean of two grades.
California Walker	do	......	75	55	60	63	
Canadian Wonder	Bearded	m	92	20	......	56	
Carters H	Bald	x m	5	50	......	28	
Carters I	Bearded	x m	20	60	......	40	
Carters J	Bald	x m	4	45	......	25	
Champion Amber	do	x	80	35	......	58	
China Red	Bearded	......	50	25	......	38	Hard wheat.
China Tea	do	......	20	55	......	38	Do.
China White	do	......	40	60	50	50	Do.
Clawson	Bald	......	15	40	57	37	
Cretan	Bearded	m	0	40	......	20	A durum wheat.
Dand Khan No. 2	Bald	......	5	30	......	18	White hard wheat.
Davis	do	......	65	40	......	53	
Deitz Amber	Bearded	......	82	60	......	71	
Dera	......	......	20	50	......	35	
Early Jasper	Bearded	......	60	45	......	53	
Early May	Bald	m	60	25	......	43	
Early Rice	......	......	97	30	......	64	
Early Ripe	......	m	88	50	55	64	
Earnhardt	Bald	m	65	50	50	55	
Egyptian F	do	......	40	55	......	48	
Egyptian No. 1	do	......	93	30	......	62	
Emporium	do	x	88	35	......	62	
Essex	do	m	40	*20	......	30	*Mean of two grades.
Fairchild	Bearded	m	98	20	......	59	
Farquhar	Bald	m	98	50	......	74	
Fleck	do	m	45	30	......	38	

[1] x indicates that such varieties were just beginning to rust at the date of grading.

[2] m indicates that the variety was badly attacked and sometimes severely injured by mildew (*Erysiphe graminis*) at the time of grading.

[3] Marks of reference (*, †) in this table call attention to explanations in last column.

TABLE 3.—*Comparative amount of Uredo rubigo-vera on different varieties of wheat*—Continued.

Localities and names of varieties of—	Bald or bearded.	Per cent of rustiness of varieties in— 1895. May 23–25.	1895. June 13–17.	1896. June 15–16.	1897. June 22–25.	Average.	Remarks.
WINTER WHEATS—continued.							
New Mexico—Continued.							
Flourelle	Bald	m	95	60	......	73	
Fluor Spar	do	m	50	50	......	50	Blount's cross.
Frances	do	m	75	50	......	63	
Frankenstein	do	m	60	40	......	50	
Freeling	do	m	30	50	......	40	
French Black Chaff	do	......	70	55	......	63	
Fulcaster	Bearded	......	92	35	......	64	Semihard wheat.
German Amber	Bald	......	80	60	40	60	
German Emperor	do	......	95	50	......	73	
Glass	do	......	45	30	......	38	
Gold Drop	do	m	60	35	70	55	
Golden Chaff	do	......	20	55	......	38	
Gold Premium	do	m	60	50	50	53	
Granite	do	m	30	50	......	40	Blount's cross.
Gypsum	do	m	15	50	......	33	Do.
Gypsy	Bearded	m	98	30	......	64	
Hard Australian	Bald	m	60	50	......	55	
Hard Manitoba	do	m	70	25	......	48	
Heiges Prolific	do	x m	75	45	......	60	
Hicks Prolific No. 1	do	m	75	40	......	58	
Hornblende	do	......	15	55	......	35	Do.
Hungarian	Bearded	m	72	50	......	61	
Hunters Winter	Bald	m	60	30	......	45	
Illinois Second Premium	do	x	75	35	......	55	
Improved Fife	do	m	20	40	......	30	
Improved Rice	do	......	85	40	......	63	
India Red	do	m	80	45	35	53	
Jacinth x Baart	Mixed	m	60	45	......	53	Farrer's cross.
Jennings	Bald	m	98	50	......	74	
Johnson	Bearded	m	92	50	......	71	
Jones Square Head	Bald	m	98	50	......	74	Jones's cross.
Kings Jubilee x Tourmaline	do	......	50	20	......	35	Farrer's cross.
Kivet	do	m	70	50	......	60	
Lairds Prolific	do	m	20	50	......	35	
Landreth	do	x m	95	35	......	65	
Leaks	do	......	10	30	......	20	From Australia.
Lehigh	Bearded	m	75	50	......	63	
Lincoln	Bald	m	95	30	......	63	
Little Wonder	do	m	25	40	......	33	
Longberry	do	m	98	65	55	73	
Mammoth	do	m	15	50	......	33	
Martins Amber	do	m	92	*45	......	69	* Mean of two grades.
McCreagan	do	m	96	30	......	63	
McGees Red	Bearded	......	60	35	......	48	
Mediterranean Hybrid	Bald	......	80	10	......	45	
Mediterranean Spring	Bearded	......	20	50	......	35	Hard wheat.
Mennonite	do	m	20	50	45	58	Do.
Michigan Amber	Bald	......	30	30	......	30	
Midge Proof	do	m	65	60	......	63	
Millers Prolific	do	m	98	50	......	74	
Minnesota Fife	do	......	5	40	......	23	Do.
Missouri Mediterranean	Bearded	......	70	25	......	48	Do.
Missouri Turkey	do	m	65	40	55	53	Do.
Monarch	do	m	95	55	......	75	
Moscow	do	m	25	50	......	38	Do.
Nashi	do	......	10	50	60	40	Very hardy.
Niagara	Bald	m	70	50	......	60	
Nigger	Bearded	m	85	15	65	55	Hardy.
North Champion	Bald	m	35	20	......	28	
Northcotes Amber	do	m	40	60	......	50	
Nox No. 3	do	m	40	10	......	25	
Oakshotts Champion	Mixture	m	55	30	......	43	
Odessa	Bald	m	1	40	45	43	Hard wheat.
Odessa No. 1	do	m	99	55	55	70	Hard-grained.
Odessa No. 2	do	m	97	65	65	76	Do.
Odessa No. 3	do	m	97	55	......	76	
Odessa No. 4	Bearded	m	90	50	......	70	
Osterey	Bald	m	95	20	......	58	Do.
Palestine	do	x m	10	20	......	15	A durum wheat.
Patagonia	do	m	94	60	......	77	
Platinum	do	m	40	......	70	55	Blount's cross.

TABLE 3.—*Comparative amount of Uredo rubigo-vera on different varieties of wheat*—Continued.

Localities and names of varieties of—	Bald or bearded.	Per cent of rustiness of varieties in— 1895. May 23–25.	1895. June 13–17.	1896. June 15–16.	1897. June 22–25.	Average.	Remarks.
WINTER WHEATS—continued.							
New Mexico—Continued.							
Pollard	Bald	......	50	60	......	55	
Pooles Red	....do	......	40	50	......	45	
Porcelain	....do	m	40	60	......	50	Blount's cross.
Powers	....do	m	95	30	......	63	
Pringles No. 5	....do	m	5	60	35	33	Hardy variety.
Propoe	....do	x m	60	30	......	45	
Prussian	....do	......	35	50	......	43	
Purple Straw	....do	x	55	70	......	63	
Quartz	Bearded	......	15	......	55	35	Blount's cross.
Raubs Prolific	Mixed	......	88	50	......	69	
Red Brazilian	....do	m	94	*20	......	57	* Selected bald.
Red May	Bald	x	88	*40	......	64	* Mean of two grades.
Rieti	Bearded	......	5	50	......	28	Hardy sort.
Rieti No. I	....do	m	40	30	......	35	
Roberts	Mixed	m	96	15	......	56	
Rocky Mountain	Bald	m	80	30	......	55	
Rogers	....do	m	80	50	......	65	
Roseworthy		......	30	45	......	38	Early variety.
Rudy	Bearded	m	98	35	......	67	
Rural	....do	......	0	5	......	3	Flinty-grained.
Russian	Bald	m	5	20	......	13	Hard-grained.
Russian Hard	Bearded	m	60	50	50	53	Hardy and hard-grained.
Rye Wheat	Bald	m	50	50	......	50	
Santa Fe	....do	m	92	*63	......	78	* Mean of two grades.
Scott	Bearded	......	80	55	......	68	
Sherman	....do	......	5	50	......	28	
Silver Chaff	Bald	x	65	55	......	60	
Small Frame	....do	x m	90	50	......	70	
Smoky	Bearded	m	25	45	......	35	
Soules	Bald	......	94	50	......	72	
Tappahannock	....do	m	90	45	......	68	
Touzelle	Bearded	......	5	50	......	28	
Treadwell	Bald	x m	93	*50	......	72	Do.
Triticum	Bearded	......	15	35	55	35	Hardy sort.
Tuskana	Bald	m	50	40	......	45	
Valley	Bearded	m	95	50	......	73	
Varesotto	....do	m	70	60	......	65	
Veneto	....do	m	65	60	......	63	
Verplank	Bald	m	85	65	......	75	
Walker	....do	x m	75	40	60	58	
Wards Prolific	....do	......	45	50	......	48	From Australia.
Wards White x Tourmaline	....do	......	65	50	......	58	Farrer's cross.
Weeks	Bald	m	75	60	......	68	
White Michigan	....do	......	5	35	......	20	
White Rose	....do	......	91	45	......	68	
White Russian	Bearded	......	5	40	......	23	Hard wheat.
Whites	....do	......	25	30	......	28	
White Velvet	Bald	m	40	20	......	30	
Wicker	....do	m	70	30	......	50	
Winnipeg	Bearded	......	0	15	......	8	A durum wheat.
Winter Australian	Bald	m	10	60	......	35	
Wintergreen	....do	m	75	55	......	65	
Winter Pearl	....do	......	97	50	......	74	
Witter	....do	m	97	55	......	76	
Yellow Missouri	....do	m	50	55	......	53	
Yuba	Bearded	m	98	50	......	74	
Kansas:							
Badger	Bald	x m	85	10	......	48	
Big English	....do	x m	75	40	......	50	
Big Frame	....do	x m	90	10	......	58	
Buckeye	....do	x m	75	30	60	55	Hardy wheat.
Currell	....do	m	50	40	......	45	
Dallas	Bearded	m	85	55	45	62	Hardy sort.
Deitz	....do	......	85	15	......	50	
Diehl Egyptian	Bald	m	96	45	......	71	
Early May	....do	x m	78	40	50	56	Early variety.
Farquhar	....do	m	90	20	75	62	Hardy.
Fultz	....do	x m	96	50	60	69	Hardy sort.
Improved Rice	....do	x m	94	50	......	72	
McCracken	....do	m	94	45	......	70	
McPherson	....do	m	90	45	......	68	

TABLE 3.—*Comparative amount of Uredo rubigo-vera on different varieties of wheat*—Continued.

Localities and names of varieties of—	Bald or bearded.	Per cent of rustiness of varieties in— 1895. May 23-25.	1895. June 13-17.	1896. June 15-16.	1897. June 22-25.	Average.	Remarks.
WINTER WHEATS—continued.							
Kansas—Continued.							
Nigger	Bearded	x m	96	30	65	64	Hardy.
Oregon Club	Bald	m	5	30	......	18	
Penquites Velvet Chaff	Bearded	m	80	25	......	53	
Ramsey	Bald	m	96	30	......	63	
Seneca Chief	Bearded	m	88	70	......	79	
Tasmanian Red	do	m	55	50	......	53	Hard wheat.
Velvet Chaff	do	x m	93	20	60	58	Fairly hardy.
White Blue Stem	do	x m	94	45	......	70	
Yellow Alabama	....	m	95	50	......	73	
Zimmerman	Bald	m	95	50	70	72	Hardy sort.
North Dakota:							
Glyndon No. 669	do	m	75	40	......	58	
Glyndon No. 692	do	m	74	30	......	52	
Glyndon No. 768	do	m	70	45	......	58	
Glyndon No. 775	do	m	70	50	......	60	
Powers Fife	do	m	70	35	......	53	
Red Fife	do	m	50	50	......	50	
Nebraska:							
Brazilian Red	Bearded	m	92	*28	......	60	*Mean of two grades.
Coryell	Bald	m	89	50	......	70	
Deitz Longberry	Bearded	m	87	50	......	69	
Golden Prolific	Bald	x m	95	65	......	80	
Ironclad	do	m	50	50	......	50	
Mediterranean	Bearded	x m	88	25	......	57	Hard wheat.
Miller	Bald	m	91	40	......	66	
Missouri Blue Stem	Bearded	m	92	50	......	71	
New Australian	Bald	x m	92	30	......	61	
Nigger	Bearded	x m	88	30	......	59	
Reliable	do	m	89	50	......	70	
Sea Island	....	m	70	50	......	60	Do.
Tasmanian Red	Bearded	m	91	20	......	55	Do.
Wellington Fife	Bald	x m	93	70	......	82	
			June 21-23				
Michigan:							
Budapest	....	......	......	*75	50	63	Do. *Spring sown.
Dawsons Golden Chaff	....	......	......	*75	(†)	75	Do. †Winterkilled.
Australia:							
Allora Spring	Bearded	......	*35	55	......	45	Early variety. *Mean of two grades.
Australian Talavera	Bald	......	*55	50	......	53	Do.
Battlefield	do	......	35	55	......	45	
Berthoud	do	......	10	50	......	30	
Blounts Lambrigg	do	......	*3	45	......	24	Do.
Brown-eared Mummy	Bearded	......	10	20	......	15	A poulard wheat.
Cape	Bald	......	65	50	......	58	
Clawson	do	......	92	50	......	71	
Dallas	Ba	......	10	20	......	15	
D'Arblays Hungarian x Improved Fife.	Mixed	......	*65	†50	45	53	*Rustiness not uniform. †Selected bearded.
D'Automne Rouge Barbu x 42 (A).	do	......	*70	......	†50	60	*Rustiness not uniform. †Selected bald.
Fill Bag	Bald	......	5	40	......	23	
Fluor Spar	do	......	*28	60	......	44	*Mean of two grades.
Fort Collins	do	......	60	80	......	70	
Frames Early	do	......	75	70	......	73	
French Early Bearded	Bearded	......	20	70	......	45	
High Grade	Bald	......	85	20	......	53	
Hudsons Early Purple Straw	do	......	55	40	......	48	
Improved Fife x Early Japanese.	Mixed	......	70	*30 †20	......	50 45	*Selected bald. †Selected bearded.
Jordans	Bald	......	*43	40	......	42	*Mean of two grades.
Northern Champion	do	......	25	75	......	50	
Pringles Defiance	do	......	30	50	......	40	
Pringles No. 5	do	......	*45	20	......	33	Do.
Rattling Jack	do	......	40	20	......	30	
Rattling Tom	do	......	60	70	......	65	
Red Provence	do	......	70	65	......	68	

TABLE 3.—*Comparative amount of Uredo rubigo-vera on different varieties of wheat*—Continued.

Localities and names of varieties of—	Bald or bearded.	Per cent of rustiness of varieties in— 1895. May 23–25.	1895. June 21–23.	1896. June 15–16.	1897. June 22–25.	Average.	Remarks.
WINTER WHEATS—continued.							
Australia—Continued.							
Red Tuscan	Bald	......	80	20	......	50	
Rieti	Bearded	......	15	20	......	18	
Robins Rust-resistant	Bald	......	*58	80	......	68	*Mean of two grades.
Saskatchewan Fife	do	......	75	50	......	63	Hard wheat.
Summer Club	do	......	*50	30	......	40	*Mean of two grades.
Tourmaline	do	......	*83	50	......	67	Do.
Vermont	do	......	*38	50	......	44	Do.
Victorian Defiance	do	......	*78	45	......	62	Do.
Wards Prolific	do	......	*55	50	......	53	*Mean of four grades.
White Hogan	do	......	20	50	......	35	
White Naples	do	......	80	75	......	78	
White Tuscan	do	......	30	40	......	35	
58 (A)	Bald	......	*50	50	......	50	*Mean of two grades.
58 (A) x Blounts Fife	do	......	40	70	......	55	Farrer's cross.
Japan:			June 28–July 1.				
Onigara	Bearded	......	15	75	......	45	Rather hardy.
Yemide	do	......	20	60	......	40	
Persia:							
Prophet	do	......	30	50	......	40	
Reddish White Bearded	do	......	30	50	......	40	
White Bearded	do	......	30	*30	......	30	*Mean of two grades.
Turkey:							
Haffkani	Bearded	......	5	5	......	5	Hard wheat.
Kastamuni	Bald	......	*20	55	......	38	*Mean of two grades.
Germany:							
Bart März	do	......	60	30	......	45	
Best Summer Club	Bald	......	60	40	......	50	Much mildewed in 1895.
Blanc a Duvet Veloute	do	......	40	75	......	57	Velvet ears.
Buca Nera	Bearded	......	0	5	......	3	*Mean of two grades.
California Spring	Bald	......	60	40	30	43	
Dattel	do	......	*38	*45	......	39	Do.
Dividenden	do	......	*35	50	......	43	Much mildewed in 1895. *Mean of two grades.
Egyptian Bearded	Bearded	......	40	40	......	40	Mildewed in 1895.
Fern	Bald	......	5	50	......	28	
Gallician Spring	do	......	50	50	......	50	
Geant du Milanais	Bearded	......	*2	10	......	6	*Mean of two grades.
Goldene Aue	Bald	......	50	30	......	40	
Hickling	do	......	*13	50	......	32	Much mildewed in 1895. *Mean of two grades.
Igel mit Grannen	Bearded	......	*10	40	......	25	Do.
Kaiser	Bald	......	30	40	......	35	Badly mildewed in 1895.
Mai	Bald	......	*3	20	......	12	*Mean of two grades.
Mirado	Bearded	......	0	5	......	3	Poulard wheat.
Probsteier	Bald	......	2	55	......	29	Badly mildewed in 1895.
Regenerirter	do	......	40	60	......	50	Do.
Romanello	do	......	30	45	......	38	
Rouge de St. Laud	do	......	25	50	......	38	Much mildewed in 1895.
Russian	Bearded	......	40	40	......	40	Mildewed in 1895.
Rye Wheat	Bald	......	40	*52	......	46	*Mean of two grades.
Sandomir	do	......	10	50	......	30	Much mildewed in 1895.
Smogger	do	......	50	45	......	48	Do.
Taganrog	Bearded	......	1	5	......	3	Macaroni variety. Badly mildewed in 1895.
Talavera de Bellevue	do	......	10	50	55	38	Hardy variety.
Urtoba	Bald	......	*16	55	......	36	*Mean of two grades.
Victoria de Mars	Bearded	......	*40	20	......	30	Do.
Spelts, emmers, etc.:							
Bearded White Spring	Bearded	......	60	60	......	60	
Black Velvet Compound Emmer.	do	......	5	15	......	10	
Black Velvet Emmer	do	......	40	25	......	33	
Blue Velvet Bearded	do	......	30	50	......	40	Badly mildewed in 1895.

TABLE 3.—*Comparative amount of Uredo rubigo-vera on different varieties of wheat*—Continued.

Localities and names of varieties of—	Bald or bearded.	Per cent of rustiness of varieties in— 1895. May 23-25.	1895. June 28-July 1.	1896. June 15-16.	1897. June 22-25.	Average.	Remarks.
WINTER WHEAT—continued.							
Germany—Continued.							
Spelts, emmers, etc.—Continued.							
Einkorn	Bearded	......	0	0	......	0	Absolutely rust proof.
Red Tyrol	Bald	......	30	30	......	30	
Red Winter Club	do	......	50	15	......	33	
Schlegel Dinkel	do	......	40	30	......	35	Much mildewed in 1895.
Triticum spelta æstivum	do	......	50	*50	......	50	Mean of two grades.
Triticum spelta dasyanthum	Bearded	......	50	51	......	51	Badly mildewed in 1895.
Vögeles Dinkel	Bald	......	70	50	......	60	Do.
White Winter Bearded	Bearded	......	50	50	......	50	
Italy:							
Bianchetto	Bald	......	70	*30	55	53	Hardy variety. Mean of two grades.
Bordeaux	Mixed	......	50	45	......	48	
Cologna	Bearded	......	60	50	......	55	
Di Noé d'Umbria	Bald	......	70	45	......	58	
Duro di Apulia	Bearded	......	0	50	......	25	
Duro Riscole	do	......	50	45	......	48	
Lutaba	Mixed	......	70	60	......	65	
Majorica Cianco	Bald	......	80	20	......	50	
Marzuolo	Bearded	......	60	40	......	50	
Precocissimo di Giappone	do	......	75	50	......	63	
Prolifero	do	......	60	40	20	40	Good, hardy variety.
Rieti	do	......	40	40	......	40	
Rieti (prima reproduzione)	do	......	60	40	......	50	
Tangarotto	do	......	0	40	70	37	Hardy sort.
Triminia	do	......	10	20	......	15	
Varesotto	do	......	80	50	......	65	
Vulgo Granillo e Salerno Misto.	Mixed	......	40	20	......	30	
France:							
A Six Rangs	Bearded	......	2	50	......	26	
Blanc de Flandres	Bald	......	65	30	......	48	
Chiddam d'Automne a Epi Rouge.	do	......	50	50	......	50	
Chiddam de Mars	do	......	30	50	......	40	
D'Australie	Bearded	......	0	40	......	20	Poulard wheat.
De Noé	Bald	......	40	10	......	25	
Hybride de Bordier	do	......	40	40	......	40	
Hybride Hatif (Rimpau)	do	......	50	15	......	33	
Pétanielle Noire de Nice	Bearded	......	0	20	......	10	Do.
Richelle Blanche de Naples	Bald	......	65	50	......	58	
Touzelle Rouge de Provence	do	......	70	50	......	60	
Victoria d'Automne	do	......	30	50	......	40	
Spain:							
Candeal Desraspado de Murcia.	Bearded	......	60	40	......	50	
Cartagena Rojo Aristado	do	......	50	40	......	45	Semihard wheat.
Jejar de Valencia	do	......	65	30	......	48	Very hard-grained.
Sweden:							
Kubb	Bald	......	70	40	......	55	
Russia:							
Banatka	Bearded	......	......	50	20	35	Hard wheat.
Bearded Winter	do	......	......	50	50	50	Hardy sort and hard wheat.
Champion	......	......	......	55	60	58	
Crimean	do	......	......	55	40	48	Hardy sort and hard-grained.
Donka	......	......	......	40	50	45	Hard wheat.
Genealogic Red	......	......	......	*50	45	48	Hard wheat. *Mean of two grades.
Kalinovka White	Bearded	......	......	*45	60	53	*Mean of two grades.
Pulavka	do	......	......	50	50	50	Hard wheat.
Red Bearded	do	......	......	*53	60	57	Hard wheat. *Mean of two grades.
Red Winter	Bald	......	......	*55	60	58	Hard-grained. *Mean of two grades.
Russian-English	do	......	......	*65	50	58	Hard wheat. *Mean of two grades.

TABLE 3.—*Comparative amount of Uredo rubigo-vera on different varieties of wheat*—Continued.

Localities and names of varieties of—	Bald or bearded.	Per cent of rustiness of varieties in— 1895. May 23–25.	1895. June 28–July 1.	1896. June 15–16.	1897. June 22–25.	Average.	Remarks.
WINTER WHEAT—continued.							
Russia—Continued.							
Swedish				50	50	50	
Theiss	Bearded			*45	*55	50	Hard wheat. *Mean of three grades.
Winter Ghirka	Bald			*53	*63	58	Hard-grained. *Mean of two grades.
Vyssoko-Litovsk	do			*45	70	58	Hardy sort. *Mean of two grades.
Yx	Bearded			60	65	63	Hard-grained and hardy sort.
SPRING WHEATS.			June 21–23	June 29–30			
North Dakota:							
Glyndon No. 669	Bald		70	50		60	
Glyndon No. 673	do		60	60		60	
Glyndon No. 675	do		65	50		58	
Glyndon No. 747	do		65	60		63	
Glyndon No. 775	do		65	50		58	
McKissicks Fife	do		60	50		55	
Russia:							
Alsace	do		6	50	15	24	Hard wheat; some loose smut in 1895.
Arnautka	Bearded			15	5	10	A durum wheat.
Byelokoloska	Bald		3	60		32	Much loose smut in 1895.
Byelokoloska (Kursk)	do		5	60	10	25	Mildewed in 1895.
Chernuska	Bearded		3		5	4	A durum wheat. Mildewed in 1895.
Chernokoloska	do			25	5	15	A durum wheat.
Gharnovka	do		1	20		11	Badly mildewed in 1895.
Imperial	do		55	55		55	Hard wheat; some loose smut in 1895.
Krasnokoloska	Bald		20	50		35	Hard wheat; much mildewed in 1895.
Polish	Bearded		5	15		10	Flinty hard.
Saxonka	Bald		5	60		33	Hard wheat; mildewed in 1895.
Spring Ghirka (Ekaterinoslav).	do		15	65		40	Do.
Spring Ghirka (Samara)	do		5	60		33	Do.

A careful study of the table will show what a great variation there is in the ability of the same variety to resist or escape rust under different conditions. Some varieties that were almost rust free in 1895 were badly rusted in 1896 and 1897, while others rusted less during the last two years than in 1895. Another important conclusion to be drawn from the experiments is that no ordinary variety of wheat is absolutely rust proof. Even the variety Einkorn above mentioned, which is not really a true wheat, succumbed to the stem rust (*P. graminis*) in 1896. Nevertheless the fact remains that some varieties are better able to escape or resist rust than others under the same conditions and in the same locality, and that some are quite resistant, at least comparatively speaking, in all localities and under all conditions, and it behooves the grower to know these varieties.

Characteristics of wheats resistant to orange leaf rust.—This is a subject of great interest and has already been discussed to some extent by different writers. So far as the ordinary wheats are concerned, the resistant varieties are as a rule somewhat dwarfed, are close and compact, and stool but little. The leaves, comparatively few in number, are stiff, narrow, and erect, with a more or less tough, dry cuticle, often with a glaucous or waxy surface; heads compact and narrow; and grains hard, red, small, and heavy.[1] In other words, the characteristics of these wheats are about the same as those of the wheats of semiarid regions. This is a fact of much significance, being a further argument that more attention should be given to the cultivation of varieties particularly adapted to the black soils and climate of dry steppes, such as those successfully grown in southeastern Russia, parts of Siberia, and in our own States of the Plains. Fortunately such varieties produce the finest grain and most nutritious flour known, and are usually hardy, drought-resisting sorts. However, under the influence of certain conditions of climate or locality, even these varieties, as above suggested, are likely to prove capricious as regards freedom from rust. In fact, no matter what the other conditions, every variety will rust, even considerably, if it matures late, and for this reason nearly all the hard Russian varieties mentioned in Table 3 rusted considerably. Early maturity is therefore another important quality. For rust freedom and for other purposes an early-maturing, hard, red, frost-resistant, and drought-resistant winter sort is the ideal one for the greater portion of our wheat region.

The foregoing remarks apply only to the varieties of *Triticum vulgare* and to some extent perhaps to those of *T. compactum*. But the varieties that are almost rust proof, as shown by the table, belong mostly to the subspecies *T. durum* and *T. turgidum*, though a few of them belong to *T. dicoccum*, *T. monococcum*, and *T. polonicum*. Those of the first two subspecies, called respectively durums and poulards, although very rich in gluten content, are seldom used in bread making, on account of coarseness and hardness of the grain and the dark color of the flour produced. They are extensively used, however, in the manufacture of certain pastries and macaroni. Much of the latter is made in this country, and the cultivation of such wheats should be encouraged. As these wheats are natives of hot, dry countries, they ought to do well, it seems, in the southern part of the Great Plains. If they could be matured sufficiently early (which was not possible in the experiments by this Department) they would certainly be very free from orange leaf rust, which seems to be especially bad in the South.

It will be seen that only a few of Farrer's crossbreds are included in the table. The chief reason for this is that those not included simply winterkilled before the conclusion of the three years' experiments, and the amount of seed obtained being exhausted, they could not be tried further. However, nearly all the crosses showed evidence of their

[1] Varieties resistant to this rust are also often bearded; therefore in the second column of Table 3, it is indicated whether varieties are bearded or bald.

high breeding and careful selection and some proved to be quite rust resistant, but as most of them were unfixed crossbreds their rust resistance could be fairly determined only by several years' trial and careful elimination of the most rust liable and less hardy plants. As shown by the table, it was found that almost invariably selections from the sporting progeny of unfixed crosses of bald and bearded varieties produced in the following years plants which showed that the bearded sorts are much more resistant to rust than the bald.

In addition to the experiments made by the writer, several were made in cooperation with the Department by persons in different States, the object being to test a few of the same varieties in different localities to determine their rust resistance and adaptability to such regions. Owing to various causes, chiefly lateness of seeding and drought, many of the experiments were entire failures, and in some cases the occurrence of rust was not carefully recorded. Only four were reported upon, these having been carried on by Prof. R. C. Kedzie, at the Michigan Agricultural College in 1896; Mr. B. F. Snyder, at Liberty, Indiana, in 1896; Mr. J. E. Payne, superintendent of the Rainbelt Experiment Station, at Cheyenne Wells, Colorado, in 1897; and by Mr. S. I. Wilkin, at Bow Creek, Kansas, in 1897. The following table gives a summary of the four reports:

TABLE 4.—*Report on Uredo rubigo-vera on wheat tested in four localities.*

Names of varieties.	Bald or bearded.	Wheat grown at—				
		Agricultural College, Michigan, 1896.	Liberty, Indiana, 1896.		Cheyenne Wells, Colorado, 1897.	Bow Creek, Kansas, 1897.
			Winter sown.	Spring sown.		
Banatka	Bearded	Slightly rusted.		Badly rusted		
Barletta	Bald					
Bearded Winter	Bearded				A failure	Nearly every blade rusted.
Budapest				Some rusted	No rust	
Chernokoloska	Bearded	Slightly rusted.				
Chubut	do			Some rusted		
Crimean	do	A failure	A failure	Badly rusted		
Genealogic Red					do	
Genealogic White					do	50 per cent rusted.
Gray Winter		Slightly rusted.	A failure			
Imperial	Bearded					
Kuyavka		Much rusted				
Little Head	Bald		A failure	Badly rusted		
Melka	do		do	do		
Red Bearded	Bearded	Slightly rusted.				
Red Ghirka			A failure		A failure	Every blade rusted.
Red Winter	Bald			Badly rusted	No rust	75 per cent rusted.
Theiss	Bearded	A failure		do	No rust	80 per cent rusted.
White Kalinovka	do			do		
Winter Ghirka	Bald		A failure		No rust	30 per cent rusted.
Yx	Bearded				do	

Although this table gives but little information, still it is of some interest in connection with Table 3.

No rust was observed at Cheyenne Wells, either on the varieties from the Department or on any others tested at that station in 1897. The atmosphere at that place is exceedingly dry, but nevertheless attempts are being made to grow crops without irrigation.

The field experiments described have thrown much light on another problem of even greater practical importance than the liability of varieties to orange leaf rust; that is, the comparative adaptability of the different sorts and varieties to the conditions of our wheat regions. However, this question does not properly belong in these pages and consequently must be discussed in another place.

Besides the experiments above reported, certain observations have been made by others in this country on the rust resistance of different varieties of wheat, especially as regards the orange leaf rust, and a few will be mentioned here. According to Pammel (55, p. 500), the following varieties were badly rusted at the Iowa Experiment Station in 1889: Fife, Black Sea, White Fife, Manitoba Fife, Golden Globe, and Lost Nation. Velvet Chaff and Blue Stem were slightly rusted, but Saskatchewan "showed little tendency to rust." He also states that in 1890 all the spring wheat was more or less severely injured by rust, and that some of the varieties were entirely worthless, but that rust did but little injury to the following winter wheats: Turkish Wheat, Golden Cross, Red Fultz, Ontario, New Monarch, Fulcaster, and Deitz Longberry. "The Turkish Wheat yielded 24 bushels."

Latta (45, p. 87) in 1892 reported, by percentages, the proportion of stalks rusted in various sorts at the Indiana Agricultural Experiment Station, and named Jones Winter Fife and Willitts as being rusted 100 per cent and Early Amber as rusted only 10 per cent. Latta and Ives (46, p. 62) in 1894 found in the same way that 100 per cent of the stalks of the following varieties were rusted: Fulcaster, Velvet Chaff (white bearded), Red Clawson, Rochester Red, Beal, Johnson, Willitts, Jones American Bronze, New Monarch, and Early Genesee Giant; but only 20 per cent of the stalks of Ohio Blue Stem and Nigger were rusted. These estimates of course do not give the actual degree of rustiness. In 1892 Georgeson, Burtis, and Shelton (36, pp. 14–50) published notes on rustiness of over 200 varieties grown at the Kansas Agricultural Experiment Station farm. The varieties which remained quite free from rust were Arnolds Hybrid, Currell, Oregon Club, and Siberian. Those "very badly rusted" were Centennial, Red Fultz, Roscoe, Walker, Wayne County Select, and Wintergreen.

Prof. W. M. Hays has been doing much work for several years in breeding and improving wheat varieties at the Minnesota Agricultural Experiment Station, and during that time has made notes on the degree of rustiness of different sorts. He has kindly given the writer permission to use some of his notes for the year 1897, which are as follows:[1] The highest per cent of rustiness, according to these notes, was 35 in case of Ladoga and the lowest 7 in the case of Glyndon No. 761. The

[1] The percentages of rustiness are in all cases means of two estimates made by Professor Hays and an assistant.

varieties rusted 8 per cent and under are Haynes Blue Stem,[1] Ristings Fife, Glyndon No. 761,[2] and Haynes Blue Stem x Glyndon No. 761; those rusted 20 per cent and over are Rio Grande, Preston, Percy, Countess, Ladoga, Dawn, Alpha, and Progress. The last seven, which were most rusted of all the varieties, are Professor Saunders's new crossbreds sent from Canada.

Some observations made in the Southern States are of special interest, because of the usual abundance of orange leaf rust in that region. Tracy (68, pp. 23–25; 69, pp. 44–46) writes that the varieties Defiance and Beloturka, received from Australia, were strongly rust resistant in Mississippi and promise well for that region. Canning Downs, received at the same time, winterkilled. Twelve varieties obtained from England ripened very late and were almost destroyed by rust. Two varieties from France, White Naples and Rieti, made very good yields. In Louisiana, where rust is very abundant, Stubbs (66, pp. 556–561) tested quite a number of varieties at Calhoun and Baton Rouge, most of them having been obtained from California. At Baton Rouge all the varieties failed completely. At Calhoun the following varieties were badly damaged by rust:

Four-rowed Imported Winter.
Red Wheat Gold Finder.
Halletts Red Winter.
Hundred Fold.
Arizona Indian.
Carters Queen.
Common March.
Holburn Wonder.
Thuring Row.
Halletts Genealogic.
Spauldings Prolific.
Mammoth.
Hybrid Lamed.
Egyptian.

Those entirely free from rust or only slightly affected were—

Indian Three Months.
Molds White Winter.
Russian Red Bearded.
Fulcaster.
Big Long Bearded Club Brenner.
Sibleys No. 1.
Mediterranean.
Red Russian.
Purple Straw.
California Spring.
Winter Genoese.
Ghirka.
Harris.
Diehl Mediterranean.
White Russian.
White Boughton.
Golden Cross.
Tuscan Island.

According to Kellner (41a, pp. 138–143), out of 151 varieties of wheat and spelt tested at the California Agricultural Experiment Station in 1892, only the following were practically rust free: Arizona Indian, Big Long Bearded Club, Blue Grass, F. Gates, Missogen, Nicaragua, Russian Durum, Russian Red Bearded, Red Sonora, Sicilian, Solid Straw Poulard, White Crimean, and Red Emmer.

In Australia the subject of rust resistance has, as already stated, been investigated more, or at least by a greater number of investigators, than in any other country. Several elaborate series of such experiments have been made with different varieties and these have

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[1] In duplicate plats rusted as high as 10 per cent.

[2] In duplicate plat rusted 11 per cent.

been reported by Pearson (57 and 58), McAlpine (51 and 52), Shelton (62 and 63), Lowrie (48 and 49), and others. It is impracticable to quote results from these different writers, but it will perhaps suffice to give the following list of varieties, which the last International Conference on Rust in Wheat[1] agreed upon as likely to be freest from rust in Australia and at the same time more or less desirable in other respects:

(1) *Rust-resistant varieties:*

Wards Prolific.
Marshalls No. 8.
Robins Rust-resistant.
Marshalls No. 3.
Australian Wonder.

For cooler districts Defiance wheats, such as—

Wheatons Rust-resistant.
Pringles Defiance.
Smiths Nonpareil.
Blounts Lambrigg.
Tunnack.

For cooler and moister districts Fife wheats, such as—

Improved Fife.
Hornblende.

(2) *Varieties escaping rust on account of early ripening:*

Allora Spring.
Early Para.
Early Baart.
Budds Early.
Canning Downs.
Rust-resistant.

(3) *Prolific and moderately rust-resistant varieties:*

Talavera.
Leaks.
White Lammas.

During 1893 and 1894 Maddox (50, pp. 14–23) made observations at Eastfield, Tasmania, on the occurrence of rust on over two hundred varieties, including seventy-five or more crossbreds from Farrer. The following varieties and also 28 of Farrer's crossbreds were free or practically free from rust:

Wards Prolific (white).
Manitoba.
Wards Prolific (red).
Pringles No. 5.
Bearded Herisson.
D'Arblays Hungarian.
Bald Herisson.
Improved Fife.
Fultz.
Niagara.
Summer Club.
Robins Rust-resistant.
Hornblende.
Medeah.

The following varieties were free, or practically free from rust during 1893 and 1894:

Anglo-Australian.
Blounts Fife.
White Fife.
Anglo-Canadian.
Bega.
Tourmaline.
Sicilian Square-headed Red.
Saskatchewan.

[1] Agr. Gaz., July, 1896, Vol. VII, pp. 438–442.

Two of Farrer's crosses and the following other varieties were rusted 50 per cent in 1894:

Bellevue Talavera.	Kings Jubilee
Quartz.	Clawson.
Hudsons Early Purple Straw.	Lazistan.
Rattling Jack.	Frames Early.
American Champion Head.	Red Tuscan.
Victorian Defiance.	High Grade.
White Naples.	Urtoba.
Early Baart.	Cape Wheat.
California Spring.	

The following varieties were rusted 75 per cent in 1893:

Square-head.	Red St. Laud.
Count Walderdorffs.	Frames Early.
Carters Stand-up.	Red Tuscan.
Boutchers Velvet.	High Grade.
Golden Drop.	Urtoba.
Bestehorns.	Cape Wheat.

In Sweden, according to Eriksson (31, pp. 340, 341), there was until recently but little difference noted in varieties as regards liability to brown rust (*Puccinia dispersa*), although his experiments showed great differences with respect to yellow rust (*P. glumarum*). However, in 1896, when the brown rust was unusually abundant and severe in that country, and when the teleutospores were for the first time observed on the stems (sheaths), at least to any great extent, there was a great difference in the amount of this rust on the different varieties. In another account of the rust that year (27, pp. 248–251) Eriksson divides the varieties tested into three classes, according to their degree of rustiness. Class 1 includes the varieties free from rust, at least as far as the sheaths are concerned; class 2 includes the varieties sparingly or considerably rusted; and class 3 includes those badly rusted. Examples of class 1 are—

Horsefords Pearl.	Michigan Bronze.
Scholeys Square-head.	Kinver Square head.
Blé a Epi Carré.	Count Walderdorffs.

Examples of class 3 are—

Frankenstein.	Manchester.
Grevenhagen.	Shireffs Square-head.
Hickling.	Blood Red.
Red Chaff Danzig.	Beselers Brown Thick-head.
Hungarian White.	White Club Spelt.

In India very little has been demonstrated concerning the liability of different varieties to rust, though various experiments with wheat have been conducted for many years in different provinces of that country. In the Central Province, where *P. rubigo-vera*, or "gerwa," as the natives call it, is said to be the principal disease with which farmers have to contend. the wheats generally regarded as rust proof are Mundia Pissi and Bansi, but the former is not a very marketable sort. At the Nagpur Experimental Farm experiments were made in 1895 (12, pp. 19–21) to test the comparative liability to rust of four varieties, including Mundia Pissi, and a similar series was planned in 1897 (13, pp. 22–24) with eight varieties, including Mundia Pissi and Bansi. As but little rust occurred on any of these varieties experimented with, no conclusions could be drawn. Twenty-nine of Farrer's crosses were tried in 1897. The 26 of these that came to maturity were very late in ripening and rusted badly, though no other varieties were rusted. The rust, however, did not injure the grain.

A variety, supposed to be from America, was tested at the Cawnpore Experimental Farm in 1896 (37, pp. 22, 23) and remained entirely free from rust, while the common sort, Muzaffarnagar, beside which it was grown, rusted here and on other fields of the farm. Judging from the description of the variety, however, it is probably not of American origin, but a durum wheat, perhaps from the Mediterranean region.

Rust-free varieties for the United States.—Before leaving this subject some suggestions may be given concerning rust-free varieties for this country. By reference to Table 3 it will be seen that after discarding all that are not true bread-wheat varieties there is really little difference, so far as rust is concerned, in the sorts tested by this Department in 1896 and 1897 or in many of those tested in 1895. This is due chiefly, if not wholly, to the late seeding. Nevertheless, in case of most of the varieties in 1895, and even in the next two years, if the maximum of rustiness to be tolerated is raised considerably (to about 40 per cent), a number of bread wheats remain fairly rust resistant.

Judging from all the experiments and observations discussed, the following varieties, already well known and good standard sorts in other directions, may be recommended as likely to prove considerably resistant to orange leaf rust in every part of this country, provided, of course, that they are sown in time:

Winter wheats:

Turkey.	Rieti.
Mennonite.	Odessa.
Pringles No. 5.	Pringles Defiance.

Spring wheats:

Haynes Blue Stem.	Saskatchewan Fife.

The following varieties seem to be resistant, but have not yet been well established as such:

Theiss.	Fulcaster.
Oregon Club.	Deitz Longberry.
Sonora.	Arnolds Hybrid.
Diehl Mediterranean.	California Spring.[1]

[1] Although according to name a spring variety, it withstands the winter quite well.

Some of the hardy prolific sorts not yet well known in this country, but likely to be more or less rust resistant after thorough acclimation and selection, are—

Winter wheats:

Prolifero.
Banatka.
Red Winter.
Nashi.
Tangarotto.
Bearded Winter.
Winter Ghirka.
Budapest.
Crimean.
Yx.
Bellevue Talavera.

Spring wheats:

Alsace.
Spring Ghirka.

Two varieties which are quite susceptible to rust, but which usually ripen early enough to escape the worst effects of it, are—

Early May.
Zimmerman.

Some others not quite so well known, but probably worthy of trial as rust-escaping sorts, are—

Early Baart.
Allora Spring.
Kathia.
Roseworthy.
Japanese No. 2.
Yemide.
Canning Downs.

These last varieties, however, are not likely to withstand very severe winters, and are therefore best adapted to southern districts, where they may perhaps in time become acclimated. Yemide and Kathia are probably the most hardy of the six. As already stated, Canning Downs winterkilled in one trial even in Mississippi.

The following durum and poulard wheats adapted to hot districts and under most conditions extremely resistant to the orange leaf rust, are suggested as being well worthy of trial as macaroni wheats in the Southern States.

Arnautka.
Taganrog.
Beloturka.
Nicaragua.
Medeah.
Petanielle Noire de Nice.
Gallands Hybrid.
Chernuska.
Cretan.
Missogen.

Two varieties of the emmer and monococcum groups from Germany that are recommended for further trial as stock feed are—

Einkorn.
Black Velvet Compound Emmer.

These are very resistant to rust, Einkorn remaining absolutely proof against the orange leaf rust during two years when it was very severe.

Damage.—In previous publications (16 and 17, p. 497) the writer expressed his opinion that after all the orange leaf rust, as a rule, does very little, if any, damage to wheat, even during periods when it is quite abundant. Although further investigations have confirmed this belief, he is now inclined to think that occasionally, under certain conditions and in certain localities, considerable injury may ensue if the rust occurs much in advance of harvest. In all instances, however, where the wheat is a total loss, which often occurs in such States as Kentucky, Indiana, Texas, Michigan, and Ohio, the black stem rust is found to be the chief, if not the only, rust present; and in all the writer's experience he has not met with a single well-authenticated case in this country where the leaf rust caused actual shriveling of the grain.[1]

In recent years botanists of all countries except England and Sweden seem to agree that *P. rubigo-vera* is not only the common rust, which is true, but also the one of economic importance, as will be seen by consulting the writings of Arthur (1), Bolley (7, pp. 13, 14), Barclay (5, Vol. XXX, pp. 46, 47), and Cobb (18, p. 34),[2] and in view of the limited amount of field work done it is natural that such an idea should prevail. The error arises from confusing the abundance of orange leaf rust every year with the destructive effects of black stem rust in certain years. Farmers, however, universally fear "black rust on the stems." It is significant in this connection that Barclay (5, Vol. XXX, p. 47), after admitting that the natives in India recognize the difference between "rolli" (*P. graminis*) and "rolla" (*P. rubigo-vera*), yet says that a "Zemindar" who sent him specimens stated that "rolla" is less destructive than "rolli."

Farrer (33, p. 36; 33*a*, pp. 163, 164) has for some time maintained that in Australia *P. rubigo-vera* does but little damage. McAlpine (51, pp. 27, 28; 52, p. 26) also seems to believe the damage is commonly done by *P. graminis*. The writer's experiments at Garrett Park, Md., afforded an excellent opportunity to test the matter thoroughly, *P. graminis* being entirely absent there in 1895, while *P. rubigo-vera* was about as abundant as it could well be. As shown in Table 3, a majority of the varieties were very much rusted, yet the very sorts rusted most produced perfectly plump grains. On the other hand, curiously enough, it is constantly maintained that wheat is badly damaged by rust in the Southern States and in nearly all cases the orange leaf rust is the one reported to be present. However, the matter should be looked into more carefully in that region. In several cases of complete destruction of the grain personally investigated by the writer in the southeastern part of Texas, *P. graminis* was undoubtedly the real cause.

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[1] Barclay (5, Vol. XXX, pp. 4, 5) gives two instances in which he weighed the grains of samples of wheat affected with *P. rubigo-vera* received from different places in India, and found that those of one sample weighed one-sixth as much as correspondingly healthy ones and those of the other sample weighed one-half as much. However, nothing is said as to whether the healthy grains were of the same variety of wheat as the injured ones or whether *P. graminis* was not also present on the rusted specimens.

[2] It is admitted by Cobb that *P. graminis* perhaps did the damage to wheat in Australia in 1889, and that it may be the injurious species in some other years, as it is "a very vigorous rust."

Certain instances seem to show that occasionally, when this rust appears suddenly or unusually early in dry seasons, it is capable of doing some injury indirectly, either by preventing the leaves (its chief point of attack) from elaborating sufficient food material for the plant, or by causing too great transpiration through injury of the leaves, or in both ways. Galloway (35, pp. 445–452), in his article on leaf casting of *Pinus virginiana*, records important experiments, which show the increase of transpiration in rust-injured leaves of the pine. In the experiments at Manhattan, Kans., in 1897, the grain of many experimental varieties of wheat was considerably injured, and seemingly, in part, at least, by this rust. Just after the appearance of the rust in great abundance a dry period set in and continued until harvest. But even in this case *P. graminis* was also present in considerable quantity, and may really have caused the injury. Eriksson (27, pp. 245–248) claims that the first instance of any injurious occurrence of *P. dispersa* that he observed in Sweden was in the season of 1896, the first twenty days of June of this year being drier and hotter than any corresponding period in seven years.

Certain phenomena observed during the experiments at Garrett Park led the writer to think that in very wet seasons this rust may be actually of some benefit to the grain by preventing too much growth of the vegetative parts of the plant at the expense of the reproductive portions. Though many varieties produced shriveled grain in these experiments, those most severely affected with rust produced good grain. Little (47, p. 640), in his discussion of wheat "mildew" in England, also refers to this. He notes that "in the Fen districts, which suffer most from mildew, the prevalence of this spring rust (*Uredo rubigo-vera*) is believed to be rather beneficial than otherwise, as it reduces the excessive luxuriance, which is usually the result of a mild winter, and which is popularly supposed to make the wheat crop more liable to mildew."

ORANGE LEAF RUST OF RYE.

(*Puccinia rubigo-vera secalis*).

Physiological relations.—Although this rust strongly resembles the orange leaf rust of wheat, inoculation experiments have shown that there is not only no physiological connection between them, but that the orange leaf rust of rye can not, so far as the writer has yet determined, be transferred by inoculation to any grass, wild or cultivated, except *Secale montanum*. Experiments with the uredo of this rust were begun in the spring of 1896 with material which was kindly sent to the writer by Prof. F. S. Earle, of the Alabama Agricultural Experiment Station.

These experiments are summarized in the following table:

TABLE 5.—*Inoculation experiments with Uredo rubigo-vera secalis.*

Date of inoculation.	Place where experiments were made.	Origin of inoculating material.	Plant inoculated.	Period of incubation (days).	Result.
1896.					
May 20	Washington, D. C	Rye	Rye	14	Successful.
Do	do	do	*Elymus canadensis*	14	Negative.
Do	do	do	*Elymus americanus*	14	Do.
Do	do	do	*Elymus virginicus*	14	Do.
Do	do	do	*Elymus condensatus*	14	Do.
Do	do	do	Wheat	14	Do.
Do	do	do	Japanese wheat	14	Do.
Do	do	do	Persian Red Spring wheat	14	Do.
Do	do	do	*Poa nemoralis*	14	Do.
Do	do	do	*Dactylis glomerata*	14	Do.
Do	do	do	*Hordeum murinum*	14	Do.
Do	do	do	Rye	11	Successful.
Do	do	do	Early Baart wheat	11	Negative.
Do	do	do	Oats	11	Do.
Do	do	do	*Poa pratensis*	11	Do.
May 27	do	do	Siberian rye	12	Successful.
Do	do	do	Wheat	12	Negative.
Do	do	do	Oats	12	Do.
Do	do	do	Barley	12	Do.
Dec. 21	do	do	Rye	16	Successful.
Do	do	do	Wheat	16	Negative.
Do	do	do	*Elymus americanus*	16	Do.
Do	do	do	Oats	16	Do.
Do	do	do	Barley	16	Do.
Do	do	do	*Kœleria cristata*	16	Do.
Do	do	do	*Poa pratensis*	16	Do.
Do	do	do	*Dactylis glomerata*	16	Do.
Do	do	do	Rye	9	Successful.
Do	do	do	Wheat	9	Negative.
Do	do	do	Rye	18	Successful.
Do	do	do	Wheat	18	Negative.
1897.					
Jan. 7	do	do	Rye	12	Successful.
Do	do	do	*Elymus virginicus*	12	Negative.
Do	do	do	*Dactylis glomerata*	12	Do.
Feb. 1	do	do	Rye	13	Successful.
Do	do	do	Barley	13	Negative.
Do	do	do	Wheat	13	Do.
Do	do	do	Oats	13	Do.
Do	do	do	*Dactylis glomerata*	13	Do.
Do	do	do	*Sporobolus asper*	13	Do.
Do	do	do	*Anthoxanthum odoratum*	13	Do
Do	do	do	*Phleum pratense*	13	Do.
Do	do	do	*Melica altissima*	13	Do.
Do	do	do	*Poa pratensis*	13	Do.
Do	do	do	*Poa nemoralis*	13	Do.
Do	do	do	*Elymus virginicus*	13	Do.
Do	do	do	*Festuca gigantea*	13	Do.
Do	do	do	Corn	13	Do.
Feb. 20	do	do	Rye	12	Successful.
Do	do	do	*Secale montanum*	12	Do.
Do	do	do	*Agropyron repens*	12	Negative.
Do	do	do	*Agropyron tenerum*	12	Do.
Do	do	do	*Triticum villosum*	12	Do.
Do	do	do	*Elymus canadensis*	12	Do.
Do	do	do	*Dactylis glomerata*	12	Do.
Mar. 30	do	do	Rye	33	Successful.
Do	do	do	*Agropyron caninum*	33	Negative.
Do	do	do	*Lolium perenne*	33	Do.
Nov. 3	Manhattan, Kans	do	Rye	9	Successful.
Do	do	do	Wheat	9	Negative.
Do	do	do	Barley	9	Do.
Do	do	do	*Agropyron tenerum*	9	Do.
Do	do	do	Rye	9	Successful.
1898.					
Jan. 5	Lincoln, Nebr	do	Rye	21	Do.
Do	do	do	*Elymus virginicus*	21	Negative.

The period of incubation for the orange leaf rust of rye is apparently a little longer than for the orange leaf rust of wheat, ranging from eight to twelve days with ordinary greenhouse conditions. In a few cases where, as the table shows, this period was extremely long, time was allowed for the rust to infect other plants if it would, the rye itself having become infected at a much earlier date.

The experiments thus far made show that orange leaf rust of rye may occur in this country on cultivated varieties of *Secale cereale* and on *S. montanum*. It was actually found on the latter host at Lincoln, Nebr., November 16, 1897.

Occurrence and distribution.—As previously stated, this rust is always present where rye is grown, but its distribution is limited in this country because rye is not extensively grown here. Like the corresponding rust of wheat, it seems to be more abundant in the Southern States. According to Humphrey (40, pp. 228, 229) and Thaxter (67, p. 98), it also occurs in considerable abundance in Massachusetts and Connecticut. What is said of its distribution in this country is true of it also in foreign countries, except in Russia and Germany, where rye is grown to a great extent, and where it is probably a much more prominent rust.

Wintering of the uredo.—In the Southern States this rust, like the leaf rust of wheat, not only lives over, but propagates through the winter in the uredo stage. As rye is rather hardy, the writer's opinion is that the rust readily passes the winter as a uredo in all parts of the United States, but owing to the small extent to which the crop is grown he has not been able until very recently to demonstrate its ability to do so in any locality, and Humphrey (40, p. 229) failed to find any evidence that it does so in Massachusetts. However, in November, 1897, the writer found the uredo in great abundance in a patch of volunteer rye at Lincoln, Nebr., and afterwards, in midwinter, it was seen in the same place on green leaves. On April 15, 1898, it was still present in considerable quantity, but was confined entirely to the leaves of the previous autumn's growth and had without question lived through the winter, though the leaves were still somewhat green. Some of the uredospores placed in water-drop cultures germinated, a few of them producing very long germ tubes. Two days afterwards, that is, April 17, the uredo was again found in considerable quantity several miles from the other locality in a large field of rye seeded for pasturage, being, as before, confined entirely to the leaves of the previous autumn's growth. In neither case was there any production of new spores, and yet the spring was so far advanced that there could be no question about the continued growth of the rust. The weather was unusually cold in November and December, the temperature falling to —$27\frac{7}{9}$ C. on the 18th of the latter month at the State University, but on the whole the winter was not particularly severe.

The uredo of this rust probably winters over in most other countries also, but in nearly all observations so far made by others concerning the matter it is impossible to determine whether this rust or the leaf rust of wheat is referred to.

The economical bearing of this subject is most important. A fact of much significance is that the leaf rusts of wheat and rye are the only cereal rusts that winter their uredos in this country and are at the same time the only ones that can not be transferred by inoculations to any other host except species of the same genera. The obvious inference is that these rusts perpetuate themselves from year to year principally by means of their uredos, but that occasionally the teleutospores probably bridge over unusually severe winters, either by means of some æcidium as yet unsuspected or by direct infection of the young plant early in the spring through the germinating sporidia. There is still the possibility, however, that other uredo hosts may be found. Of course if these three alternatives were absent these rusts could be readily eradicated by the concerted action of farmers in keeping their farms rigidly clean of volunteer grain.

Liability of different varieties to this rust.—On account of so few sorts of rye being grown in this country, no particular attention has been given to the subject of rust liability of varieties. However, it may be said that all fields of rye, without exception, are usually more or less affected.

In the experiments at Salina a number of packages of spring rye ("yaritsa" in Russian), received from the region near Nerchinsk, Siberia, were tested, some of them being planted in the autumn and some in the spring. All the plants were rusted, the rustiness ranging from 60 to 80 per cent.

Damage.—The damage to rye from this rust is very little, as a rule, as in the case of leaf rust of wheat. According to Humphrey (40, pp. 228, 229) and Thaxter (67, p. 98), it occasionally causes considerable injury in Massachusetts and Connecticut, and it is also said to be quite injurious at times in the Southern States. According to Prof. J. H. Connell, director of the Agricultural Experiment Station, College Station, Tex., rye in the experimental plats of the station is occasionally injured by this rust even in January.

CROWN RUST OF OATS.

(*Puccinia coronata* Corda.)

Physiological relations.—The fact that this rust occurs on oats only, and that its appearance, both superficially and microscopically, is very different from that of the black stem rust, together with the peculiar form of its teleutospores, make it the most distinct of all the cereal rusts. The uredospores are so much like those of the leaf rusts of wheat and rye, however, that when only these were present the writer could not be certain that the crown rust and the leaf rusts did not exchange hosts until he determined the matter by inoculation. There is evidence, too, that many identifications of cereal rusts have been made simply at random. Though the crown rust of oats is recorded as occurring on a great many wild grasses, the writer has made but two collections of rust on such grasses which he could demonstrate, even on morphological grounds, to be this rust.

The writer has made more inoculation experiments with oat rusts than with any of the other cereal rusts. The following table gives a summary of his experiments with the crown rust:

TABLE 6.—*Inoculation experiments with Uredo coronata.*

Date of inoculation.	Place where experiments were made.	Origin of inoculating material.	Plant inoculated.	Period of incubation (days).	Result.
1896.					
Feb. 6	Washington, D. C	Oats	Siberian oats	8	Successful.
Do	do	do	Black Tartarian oats	8	Do.
Feb. 14	do	do	Siberian oats	10	Do.
Do	do	do	Black Tartarian oats	10	Doubtful.
Do	do	do	Early Para wheat	10	Negative.
Do	do	do	Siberian wheat	10	Do.
Do	do	do	Siberian barley	10	Do.
Do	do	do	Siberian rye	10	Do.
Do	do	do	Nebraska White Prize corn	10	Do.
Feb. 24	do	do	*Hordeum murinum*	17	Only one or two spots.
Mar. 4	do	do	Siberian wheat	35	Negative.
Do	do	do	do	29	Do.
Do	do	do	Siberian rye	35	Do.
Do	do	do	do	29	Do.
Do	do	do	Early Para wheat	35	Do.
Do	do	do	do	29	Do.
Do	do	do	Siberian barley	35	Do.
Do	do	do	do	29	Do.
Do	do	do	Corn	35	Do.
Do	do	do	do	29	Do.
Do	do	do	Rieti wheat	12	Do.
Do	do	do	Siberian millet	12	Do.
Do	do	do	Safeed wheat	12	Do.
Do	do	do	Persian Red Spring wheat	12	Do.
Do	do	do	Beloturka wheat	12	Do.
Do	do	do	Shirosawa wheat	12	Do.
Do	do	do	Persian Black barley	12	Do.
Do	do	do	Rieti wheat	13	Do.
Mar. 11	do	do	Six-rowed barley	7	Do.
Do	do	do	*Avena fatua*	7	Successful.
Do	do	do	Hungarian White oats	7	Do.
Do	do	do	Donka wheat	7	Negative.
Do	do	do	Siberian oats	7	Successful.
Do	do	do	Pied de Mouche oats	7	Do.
Do	do	do	Chinese barley	7	Negative.
Do	do	do	*Agrostis alba vulgaris*	7	Do.
Do	do	do	*Dactylis glomerata*	7	Do.
Do	do	do	*Elymus virginicus*	7	Do.
Do	do	do	Nackter Kleiner Fahnen oats	7	Successful.
Mar. 12	do	do	Siberian millet	12	Negative.
Do	do	do	Safeed wheat	14	Do.
Do	do	do	Haffkani wheat	12	Do.
Do	do	do	Etampes oats	12	Do.
Do	do	do	Nebraska White Prize corn	12	Do.
Do	do	do	Persian Black barley	12	Do.
Do	do	do	*Dactylis glomerata*	12	Do.
Do	do	do	Etampes oats	11	Successful.
Mar. 18	do	do	Late Danish oats	11	Do.
Mar. 30	do	do	*Hordeum murinum*	10	Do.
Apr. 6	do	do	*Avena pratensis*	10	Do.
Do	do	do	*Koeleria cristata*	10	Negative.
Do	do	do	*Phleum pratense*	10	Successful.
Apr. 9	do	do	*Bromus unioloides*	13	Negative.
Do	do	do	*Agropyron repens maritimum* !	13	Do.
Do	do	do	*Agrostis alba vulgaris*	19	Do.
Do	do	do	*Lolium perenne*	13	Do.
Do	do	do	*Dactylis glomerata*	13	Do.
Do	do	do	*Koeleria cristata*	13	Do.
Apr. 11	do	do	*Avena pratensis*	9	Successful.
Apr. 17	do	do	Fentons Rust Proof oats	15	Do.
Do	do	do	*Avena pratensis*	15	Do.

TABLE 6.—*Inoculation experiments with Uredo coronata*—Continued.

Date of inoculation.	Place where experiments were made.	Origin of inoculating material.	Plant inoculated.	Period of incubation (days).	Result.
1886.					
Feb. 17	Washington, D. C	Oats	*Bromus unioloides*	15	Negative.
Do	do	do	Oats	15	Successful.
Do	do	do	*Hordeum jubatum*	15	Negative.
Do	do	do	*Arrhenatherum elatius*	15	Do.
Do	do	do	*Lolium perenne*	15	Do.
Do	do	do	*Dactylis glomerata*	11	Successful.
Do	do	do	Amurskii oats	11	Do.
Do	do	do	*Aira cæspitosa*	11	Only one or two spots.
Do	do	do	*Poa pratensis*	11	Negative.
Do	do	do	*Holcus mollis*	11	Doubtful.
Do	do	do	Fentons Rust Proof oats	11	Successful.
Do	do	do	*Eatonia sp. indet*	11	Do.
Apr. 18	do	do	Ligowo oats	7	Do.
Do	do	do	*Dactylis glomerata*	7	Do.
Do	do	do	*Koeleria cristata*	7	Do.
Do	do	do	*Anthoxanthum odoratum*	7	Do.
Apr. 22	do	do	*Festuca sp. indet*	11	Do.
Do	do	do	*Alopecurus alpestris*	11	Do.
Do	do	do	*Phalaris arundinacea*	11	Do.
Do	do	do	*Polypogon monspeliensis*	11	Do.
Do	do	do	*Trisetum subspicatum*	11	Only one or two spots.
Do	do	do	*Poa pratensis*	11	Negative.
Do	do	do	*Sporobolus asper*	11	Do.
Do	do	do	*Aira cæspitosa*	11	Do.
Do	do	do	*Brizopyron siculum*	11	Doubtful.
Do	do	do	*Andropogon halapense*	11	Negative.
May 1	do	do	Ligowo oats	14	Successful.
Do	do	do	*Triticum spelta æstivum*	14	Negative.
Do	do	do	*Sporobolus cryptandrus*	14	Do.
Do	do	do	*Panicum crus-galli*	14	Do.
May 6	do	do	*Ammophila arundinacea*	12	Do.
May 7	do	do	Dun oats	13	Successful.
Do	do	do	*Avena sterilis*	13	Only one or two spots.
Do	do	do	*Phleum asperum*	13	Successful.
Do	do	do	*Poa annua*	13	Only one or two spots.
Do	do	do	*Ammophila arenaria*	13	Do.
Do	do	do	*Eatonia dudleyi*	13	Negative.
Do	do	do	*Brachypodium distachys*	13	Do.
Do	do	do	*Scheдonnardus paniculatus*	13	Do.
Do	do	do	*Panicum crus-galli*	13	Do.
Do	do	do	*Eleusine egyptiaca*	13	Do.
Do	do	do	*Eragrostis purshii*	13	Do.
Do	do	do	*Sporobolus cryptandrus*	13	Do.
Do	do	do	*Eragrostis abyssinica*	13	Do.
May 20	do	do	*Triodia cuprea*	12	Do.
Sept. 23	Manhattan, Kans	do	Oats	7	Successful.
Dec. 15	Washington, D. C	do	do	11	Do.
Dec. 21	do	do	do	17	Do.
Do	do	do	*Anthoxanthum odoratum*	17	Negative.
1897.					
Feb. 12	do	do	*Arrhenatherum elatius*	18	Do.
Mar. 30	do	do	Oats	12	Successtul.
Do	do	do	*Eatonia obtusata*	12	Negative.
1898.					
Mar. 12	Lincoln, Nebr	do	Oats	25	Successful.
Do	do	do	*Phalaris caroliniana*	25	Negative.
Do	do	do	*Agrostis alba vulgaris*	25	Do.
Do	do	do	*Arrhenatherum elatius*	25	Do.

A peculiar feature of these experiments is that although the rust does not seem to actually occur on many native grasses, yet the cases of successful infections of grasses in the greenhouse are rather numerous. Aside from the fact that some of the grasses may yet be found to be hosts in nature, there are two possible explanations of this peculiarity: (1) The inoculations were made as a rule on young plants, which, having less resistant constitutions, are always more susceptible to disease than older ones; and (2) as the experiments were made in the greenhouse the conditions were, of course, somewhat more favorable to rust propagation than those outdoors. As to the condition of the host, the matter was tested in a few cases by inoculating at a more advanced age certain plants that had been successfully infected when quite young, the result being that infections did not occur at all or were very slight and evidently took place with difficulty. In the experiments with the leaf rusts of wheat and rye young plants were also used as hosts, but the results were quite different. The crown rust, it seems, is not yet sharply limited in its adaptability to particular hosts.

The table shows that although rust from oats infected a number of wild grasses, no case is recorded of an infection of oats from a wild grass; hence it has not been demonstrated that the crown rust of oats is equivalent to the rust of any wild grass, although it is of course quite probable that the same rust occurs on several species of the genus Avena and perhaps on other grasses. In the writer's opinion the identity of a rust of any grass with that occurring on any cereal is not established until reverse infections have been produced.

Another important question that yet remains unsettled is whether there is an æcidial host for this rust of oats in the United States. True, an æcidium on a species of Rhamnus has been collected in a number of places, but as yet no inoculation experiments have been made with it, and it will require many to determine accurately the status of the crown rust in this country.[1]

The usual incubation period to produce infections on oats in case of inoculations with this rust is from seven to ten days, but to infect certain other plants, such as *Hordeum murinum* and *Dactylis glomerata*, a longer time is required, and when plants are rather old scarcely any infection results.

From experiments so far made, only cultivated varieties of the following subspecies of *Avena sativa* can be considered to be hosts of this rust in the United States: *Avena sativa patula*, *A. sativa orientalis*, and *A. sativa nuda*.[2] Other species of Avena that will probably yet be found to act as hosts are *A. fatua*, *A. pratensis*, *A. hookeri*, and *A. sterilis*. Of course there is the possibility also that this rust will be found to have several specialized forms in this country, as Eriksson (28, p. 302) has already found to be the case in Sweden.

Occurrence and distribution.—The crown rust in its distribution seems to be quite analogous to the leaf rust of wheat, and in that regard both bear somewhat similar relations to the black stem rusts of the same

[1] Since this bulletin was prepared the writer has made a number of inoculation experiments with the æcidium of *Rhamnus lanceolata* at Lincoln, Nebr., which resulted in the infection of oats, *Phalaris caroliniana*, and *Arrhenatherum elatius*.

[2] *Phalaris caroliniana* and *Arrhenatherum elatius* must now also be included as probable hosts (see preceding footnote).

hosts. It is the more common of the two oat rusts in the United States. So far as locality is concerned, there seems to be little difference in its distribution, but compared with the stem rust it seems to be especially prevalent in the Atlantic and Southern coast States. Apparently it is not as constant in its occurrence from year to year as the leaf rust of wheat, though the writer is not certain of any instance where it was entirely absent during the entire summer. Although one of the most prominent rusts in the United States, it is, strange to say, so far as yet known, rather insignificant in most other countries. According to Barclay (5, Vol. XXX, p. 46), it does not occur on any cereal in India, but a variety, *P. coronata himalayensis*, occurs on *Brachypodium sylvaticum*. The writer has not been able to find any record of its occurrence in Australia, and although found on European oats, it is apparently not very abundant.

Wintering of the uredo.—Although the writer's opinion is that this rust passes the winter in the uredo stage in the warmer latitudes of the United States, there is as yet no good evidence that it does. A case where volunteer oats bore this rust in both the uredo and teleuto stages was called to the writer's attention by Mr. M. B. Waite, of this Division, the first week of March, 1894, at Washington, D. C. The uredospores were found to be in apparently good condition on leaves not yet dead. Uredospores of both crown and stem rusts of oats were observed on volunteer oats at Manhattan, Kans., up to November 2 of the season of 1896, but there was no opportunity of determining whether they lived longer.

Liability of different varieties to this rust.—There is not as much known regarding the liability of varieties of oats to rust as there is relative to liability of varieties of wheat. One reason for this is, probably, that there is less difference in the structure and physiological constitution of the former. In Australia, where the subject of liability of varieties to rust has received most attention, neither the oat crop nor rust of oats seem to be of much importance. However, the farmers of the United States and of northern Europe know quite well that certain varieties of oats, as well as of wheat, are more exempt from rust than others. In some parts of the country, especially in California, black oats is said to be freer from rust than the white oats, and in the North the White Russian is said to be quite rust resistant. Although this rust is quite abundant in the Southern States, a certain variety of oats, known most generally, perhaps, as Texas Rust Proof, is universally claimed to be rust resistant, but the writer has had no opportunity of personally determining this matter. When this variety is grown in the North, however, it invariably rusts and sometimes badly. As usual, in none of these reports of rust on oats is there any statement as to the species of rust that was present, though a matter of the utmost importance. According to Professor Hays's notes for 1897 on the varieties of oats grown at the Minnesota Experiment Station, Winter Turf, Siberian White, Black

Etampes, Black Houdan, and Houstons Silver White were rusted only 7 to 10 per cent, and Black America, Rust Proof, Monarch, White Bedford, White Superior Scotch, and Centennial were rusted 27 to 30 per cent.

While conducting the field experiments on rust liability of varieties of wheat, the writer also tested a number of varieties of oats in the same way during the first two years, and as the crown rust was the only one present at Garrett Park and the principal one at Salina, the experiments will be discussed under this head. The varieties of oats used in these experiments were obtained through the same sources as were the wheats, although, of course, they were not obtained from so many countries. They represent nearly all the cultivated subspecies and varieties of *Avena sativa*. The results of the experiments are arranged in the following table, to which the explanations of Table 3 also apply. The varieties were all sown in the spring at the usual time, although a few of them were winter sorts. The methods of seeding, etc., employed were the same as in the case of the wheats.

TABLE 7.—*Uredo coronata on varieties of oats.*

Localities and names of varieties.	Subspecies.[1]	Per cent of rustiness at— Garrett Park, July 16, 1895.	Per cent of rustiness at— Salina, June 30, 1896.	Average.	Remarks.
North Dakota:					
Black Prolific	s	2	92	47	
Early White Russian	p	0	93	47	
Fentons Rust Proof	p	2	91	47	
Giant Side	s	3	91	47	
Giant Yellow	p	4	89	47	
Golden Giant Side	s	5	70	38	
Great Northern	p	1	91	46	
Lincoln	p	4	92	48	
Race Horse	p	3	[2] 95	49	[2] Mean of two grades.
Tartarian	s	1	88	45	
Wide Awake	p	5	95	50	
Scotland:					
Barbachlow	p	7	90	49	
Black Tartarian	s	1	( )	1	Not planted in 1896.
Blainslie	p	5	94	50	
Dun	p	1	91	46	Either winter or spring variety.
Early Angus	p	4	90	47	
Hamilton		6	90	48	
Hopetoun	p	5	90	48	
Long Fellow	p	5	97	51	
Potato	p	5	93	49	
Providence	p	5	85	45	
Sandy	p	1	96	49	
Tom Finlay	p	5	95	50	Same as White Polish.
Sweden:					
Black Tartarian	s	3	93	48	
Ligowo	p	2	60	31	
Svalöfs		3	93	48	
Germany:					
Anderbeck		11	97	54	
Angus	p	10	92	51	
Australian (Port Adelaide)	p	5	80	43	
Barbachlow		13	90	52	
Berwick	p	12	94	53	
Bestehorn		8	85	47	
Black Hungarian	s	12	92	52	
Black Nubian		10	93	52	

[1] *p* means panicled oats, *s* side oats, *n* naked oats, and refer, respectively, to the subspecies *patula*, *orientalis*, and *nuda* of *Avena sativa*.

[2] The reference marks call attention to notes in the last column.

TABLE 7.—*Uredo coronata on varieties of oats*—Continued.

Localities and names of varieties.	Subspecies.	Per cent of rustiness at— Garrett Park, July 16, 1895.	Salina, June 30, 1896.	Average	Remarks
Germany—Continued.					
Black side oats	s	10	90	50	
Black Tartarian (Hallett's pedigree).	s	8	85	47	
Black Tartarian side oats	s	10	90	50	
Brie	p	10	90	50	
Brown Panicled	p	10	90	50	
California Prolific	....	7	85	46	
Dun	p	12	95	54	
Early Schlesian	p	7	80	44	
Etampes	p	10	90	50	
Flanders	....	11	91	51	
Georgian	p	12	94	53	
Grey Winter	p	12	94	53	
Houdan	p	13	94	54	
Joanette	p	9	90	50	
Lentewitzer	....	40	91	66	
Ligowo	p	10	90	50	
Nackter Kleiner Fahnen	n	20	80	50	Small grain and short straw.
Nilson	....	20	95	58	
Pied de Mouche	....	10	85	48	
Podolia	p	5	92	49	
Probsteier	p	10	92	51	
Providence	....	5	94	50	
Riesen Fahnen	....	40	95	68	
Rousse Couronnée	p	12	91	52	
Rügenscher	p	10	90	50	
Sandy	p	10	90	50	
Siberian	....	12	95	54	
Swedish	....	40	91	67	
Thüringer	p	13	92	53	
Ueberfluss	....	12	93	53	
Victoria	....	8	85	45	
Waterloo	p	40	85	63	
White Australian	p	12	95	54	
White Canadian (Hallett's pedigree).	p	10	90	50	Same as Georgian oat.
White Hungarian	s	8	70	39	
White Polish	p	12	90	51	
White Tartarian	s	5	92	49	
Russia:					
Amurskii	p	4	85	45	Very tall and heavy straw.
Anderbeck	....	5	93	49	Mean of two grades.
Australian	p	3	92	48	
Australian (Groïno)	p	4	92	48	
Chernii	....	4	90	47	Late, but drought resistant.
Danois	....	3	90	47	
Double-fruited	....	5	92	49	
Grey Winter	p	4	90	47	
Kursk	....	5	94	50	
Nagii	n	3	92	48	Rather large grains.
Odnogrivii Byelii	s	1	85	43	
Odnogrivii Chernii	s	4	93	49	
Orlovskii	....	3	90	47	
Probsteier	p	5	94	50	
Race Horse	p	4	94	49	
Shatilovskii	....	5	95	50	Mean of two grades.
Tsobiliye	....	4	92	48	
Ueberfluss	....	3	91	47	
Victoria	....	4	90	47	Do.
Welcome	....	1	80	41	
White Canadian	....	1	80	41	Same as Georgian.
White Danish	p	4	91	48	
Zhelannuii	....	5	92	49	
Italy:					
Bianca di Canada	....	3	90	47	
Casertana Grossa	....	1	88	45	
Comune di Viterbo	p	4	92	48	
Di Ruvo di Puglia	p	2	85	44	
Gentile Prima Verite del Umbria.	....	4	90	47	A very early variety.
Gigante a Grappola	....	3	90	47	
Nera di Tartara	s	5	96	51	
Precoce Detta Nuova Zelanda.	....	5	93	49	
Tardiva Danese	....	5	94	50	
Veneziana	....	5	96	51	

TABLE 7.—*Uredo coronata on varieties of oats*—Continued.

Localities and names of varieties.	Subspecies.	Per cent of rustiness at— Garrett Park, July 16, 1895.	Salina, June 30, 1896.	Average.	Remarks.
France:					
Belgian Black Winter		2	93	48	
Black Hungarian	s	3	95	49	
D'Etampes	p	2	94	48	A black chaff sort.
Grey Houdan	p	3	95	49	
Grey Winter	p	1	88	45	
Jaune de Flandre	p	3	90	47	The Flemish oat.
Joanette	p	3	92	48	Short straw.
Noire de Brie	p	1	88	45	
Rousse Couronnée	p	4	92	48	
White Hungarian	s	3	92	48	
Siberia:					
Siberian (Nerchinsk)		( )	70	70	Not planted in 1895.
Siberian No. 7		( )	60	60	Do.
Spain:					
Civada Blanca Granja de Barcelona.	p	0	95	95	
Portugal:					
Abrantes	p	1	88	45	

There was little difference in the amount of rust on different varieties during the second season, all being very badly affected. As the black stem rust also was present, it was very difficult to grade, even approximately, the amount of crown rust alone. It is believed that had the varieties been sown quite early in the case of the experiment at Garrett Park many of them would have escaped entirely, as the rust did not appear until very near harvest time, and only four varieties were rusted as much as 40 per cent. On the whole, the two years' experiments do not show much difference in the comparative liability of varieties of oats to the crown rust.

Damage.—The writer knows of no instance where it could be proved that this rust caused any really serious damage to oats, under ordinary conditions, when the black stem rust was not also present; but nevertheless it is quite possible that it may occasionally cause considerable injury. In any event it seems to be of more economic importance in this than in most other countries.

BLACK STEM RUST OF WHEAT.

(*Puccinia graminis tritici* Eriks. and Henn.).

Puccinia graminis has always served as a convenient species in which to include such grass rusts as show no particular morphological individuality, but which resemble this species, and as a result it is credited with more host plants than any other rust. The writer has found at least 38 different grasses given as hosts for this rust in America, and Eriksson states (31, p. 119) that 105 are recorded in the herbarium of the division of plant physiology of the experiment station at Stockholm as hosts for this species in Sweden. Nearly all such identifications are of little value from an economic standpoint, many of them are wrong morphologically, and some of them are little better than guesswork. Errors in identification often arise from the fact that the specimens show but one stage of the rust, usually the uredo stage.

The number of host plants has been considerably reduced in recent years by the separation of a number of new species, and also by more correct identifications. Some of the new species occurring in this country are *P. amphigena* Diet., *P. subnitens* Diet., *P. distichlidis* Ell. and Ever., *P. agropyri* Ell. and Ever., and *P. jubata* Ell. and Barth., but whether these are all good species the writer is not yet prepared to say. The last one, however, he believes is not.[1]

Physiological relations.—Long before the writer's inoculation experiments were begun he often noticed, as doubtless others have also, a considerable difference between the general appearance of the black stem rust of wheat and of oats. In fact the uredo stages on the two hosts, at least on the leaves, appear to differ from each other more than the uredo stages of *P. rubigo-vera* and *P. coronata*. The sori are longer, larger, and seemingly a little darker on oats than on wheat, and usually there is proportionally more of the uredo present on the former than on the latter, though this latter feature is quite variable. Of course such differences may be due to differences in constitution of the host plants, but this is not necessarily so, for the leaf rust and crown rust on the same hosts behave differently.

Believing such work would be of particular interest, the writer inaugurated some inoculation experiments with this widely distributed rust species, the experiments with the form on oats being started sooner and carried on to a greater extent than those with the form on wheat, which latter, on account of lack of inoculating material, were not begun until April 20, 1896. The sources of inoculating material were *Uredo graminis* of wheat, kindly sent in by Prof. R. H. Price, April 14, 1896, from the Texas Agricultural College farm, and barberry rust, furnished through the kindness of Prof. C. F. Wheeler, May 9 and 14, 1896, from the Michigan Agricultural College. These experiments are very incomplete, but are still under way. The following table gives a summary of the work so far done:

TABLE 8.—*Inoculation experiments with Uredo graminis tritici and Æcidium berberidis.*

Date of inoculation.	Place where experiments were made.	Origin of inoculating material.	Plant inoculated.	Period of incubation (days).	Result.
1896. May 1	Washington, D. C	Wheat	Australian Glory wheat	11	Only one or two spots.
Do	do	do	Shirosawa wheat	11	Negative.
Do	do	do	Ligowo oats	11	Do.
May 9	do	do	Wheat	11	Successful.
Do	do	do	Blounts Lambrigg wheat x Hornblende.	11	Only one or two spots.
Do	do	do	Wheat	11	Successful.
Do	do	do	Banatka wheat	11	Do.
Do	do	do	Wheat	11	Do.
Do	do	do	Oats	11	Negative.
Do	do	do	do	11	Do.
May 20	do	do	Wheat	12	Successful.

[1] More recent experiments made by the writer show conclusively that *P. jubata* is not only the same as *P. graminis*, but is identical with the form *tritici* of wheat and barley.

TABLE 8.—*Inoculation experiments with Uredo graminis tritici and Æcidium berberidis*—Continued.

Date of inoculation.	Place where experiments were made.	Origin of inoculating material.	Plant inoculated.	Period of incubation (days).	Result.
1896.					
May 29	Washington, D. C	Wheat	Oats	12	Negative.
Do	do	do	Wards Prolific wheat	12	Successful.
May 27	do	*Berberis vulgaris.*	Persian Red Spring wheat	18	Negative.
Do	do	do	Ligowo oats	18	Do.
Do	do	do	Wheat	18	Do.
Do	do	do	*Berberis vulgaris*	18	Do.
Do	do	do	*Berberis thunbergii*	18	Do.
Do	do	Wheat	Wheat	14	Successful.
Do	do	do	do	14	Do.
Do	do	do	Barley	14	Do.
Do	do	do	do	14	Do.
Do	do	do	*Hordeum murinum*	14	Do.
Do	do	do	*Holcus mollis*	14	Negative.
Do	do	do	*Agrostis alba vulgaris*	14	Do.
Do	do	do	*Phleum pratense*	14	Do.
Do	do	do	*Kœleria cristata*	14	Successful.
Do	do	do	*Lolium perenne*	14	Negative.
Do	do	do	Oats	14	Do.
Do	do	do	do	14	Do.
Do	do	do	*Dactylis glomerata*	14	Do.
Do	do	do	Rye	14	Do.
Do	do	*Berberis vulgaris.*	Barley	13	Successful.
Do	do	do	Rye	13	Only one or two spots.
Do	do	do	Wheat	13	Negative.
Do	do	do	do	13	Do.
Do	do	do	Oats	13	Do.
Sept. 26	Manhattan, Kans	Wheat	Wheat	7	Successful.
Dec. 21	Washington, D. C	Barley	Barley	18	Negative.
Do	do	do	Rye	18	Do.
Do	do	do	Oats	18	Do.
Do	do	do	Wheat	18	Do.
Do	do	do	Corn	18	Do.
Dec. 24	do	Wheat	Wheat	9	Only one or two spots.
Do	do	do	Barley	9	Do.
Dec. 30	do	Barley	Wheat	13	Successful.
Do	do	do	Barley	13	Do.
Do	do	Wheat	Wheat	15	Only one or two spots.
Do	do	do	Barley	15	Do.
1897.					
Jan. 9	do	do	Wheat	10	Do.
Do	do	do	Kastamuni wheat	10	Successful.
Do	do	do	Taganrog wheat	10	Do.
Do	do	do	Missogen wheat	10	Do.
Do	do	do	Rye	10	Negative.
Do	do	do	Barley	10	Do.
Do	do	do	Oats	10	Doubtful.
Do	do	do	do	10	Do.
Do	do	do	*Sporobolus asper*	10	Negative.
Do	do	do	*Phleum pratense*	10	Do.
Do	do	do	*Festuca gigantea*	10	Successful.
Do	do	do	*Elymus virginicus*	10	Do.
Jan. 22	do	do	Wheat	11	Doubtful.
Do	do	do	Missogen wheat	11	Successful.
Do	do	do	Rye	11	Negative.
Do	do	do	Barley	11	Do.
Do	do	do	Corn	11	Do.
Do	do	do	*Melica altissima*	11	Do.
Do	do	do	*Anthoxanthum odoratum*	11	Do.
Do	do	do	*Poa nemoralis*	11	Do.
Do	do	do	*Poa pratensis*	11	Do.
Do	do	do	*Agropyron spicatum*	11	Do.
Do	do	do	*Agropyron richardsoni*	11	Successful.
Do	do	do	*Dactylis glomerata*	11	Do.
Do	do	do	*Elymus virginicus*	11	Do.
Feb. 1	do	do	Wheat	11	Only one or two spots.
Do	do	do	Barley	11	Negative.
Do	do	do	Oats	11	Do.
Feb. 12	do	do	*Dactylis glomerata*	18	Only one or two spots.
Feb. 13	do	do	Wheat	12	Negative.
Do	do	do	Taganrog wheat	12	Successful.

TABLE 8.—*Inoculation experiments with Uredo graminis tritici and Æcidium berberidis*—Continued.

Date of inoculation.	Place where experiments were made.	Origin of inoculating material.	Plant inoculated.	Period of incubation (days).	Result.
1897.					
Feb. 13	Washington, D. C.	Wheat	Missogen wheat	12	Successful.
Do	do	do	Barley	12	Only one or two spots.
Mar. 16	do	do	Wheat	16	Negative.
Do	do	do	Rye	16	Do.
Do	do	do	Barley	16	Do.
Do	do	do	Wheat	16	Do.
Do	do	do	do	16	Do.
Do	do	do	Akayemidashi wheat	16	Successful.
Do	do	do	do	16	Do.
Mar. 30	do	do	Einkorn (*Triticum monococcum*)	13	Do.
Do	do	do	*Elymus virginicus*	13	Negative.
Aug. 16	Stillwater, Okla.	*Agropyron tenerum.*	Wheat	12	Only one or two spots.
Aug. 23	do	do	do	13	Negative.
Sept. 7	Manhattan, Kans.	Wheat	do	8	Only one or two spots.
Do	do	do	Barley	8	Successful.
Do	do	do	Oats	8	Doubtful.
Sept. 13	do	Barley	Barley	10	Successful.
Oct. 5	do	*Hordeum jubatum.*	Rye	11	Negative.
Do	do	do	Wheat	11	Successful
Do	do	do	Barley	11	Do.
Do	do	do	Oats	11	Negative.
Do	do	do	*Arrhenatherum elatius*	11	Do.
Do	do	do	*Triticum villosum*	11	Do.
Do	do	do	*Dactylis glomerata*	11	Do.
Oct. 14	do	do	Wheat	11	Successful.
Do	do	do	Barley	11	Do.
Do	do	do	Corn	11	Negative.
Oct. 21	do	Barley	Wheat	16	Doubtful.
Do	do	do	Barley	16	Only one or two spots.
Do	do	do	*Hordeum nodosum*	16	Negative.
Nov. 6	do	*Hordeum jubatum.*	Wheat	6	Successful.
Nov. 12	do	do	Wheat	11	Successful.
Do	do	do	Barley	11	Only one or two spots.
Do	do	do	Rye	11	Negative.
Do	do	do	Oats	11	Do.
Do	do	do	*Hordeum nodosum*	11	Do.
1898.					
Jan. 5	Lincoln, Nebr.	*Elymus canadensis glaucifolius.*	Wheat	21	Successful.
Do	do	do	Barley	21	Do.
Do	do	do	Oats	21	Negative.
Do	do	do	Rye	21	Do.
Do	do	do	*Agropyron richardsoni*	21	Do.
Jan. 21	do	Wheat	Wheat	10	Successful.
Do	do	do	Barley	10	Do.
Feb. 11	do	*Elymus canadensis glaucifolius.*	Wheat	14	Do.
Do	do	do	Barley	14	Do.
Do	do	do	Rye	14	Negative.
Do	do	do	Oats	14	Do.
Do	do	do	*Elymus canadensis glaucifolius*	14	Successful.
Do	do	do	*Elymus virginicus*	14	Negative.
Do	do	do	*Agropyron tenerum*	14	Do.
Do	do	do	*Agropyron spicatum*	14	Do.
Do	do	do	*Elymus hirsutiglumis*	14	Do.
Do	do	do	*Elymus virginicus muticus*	14	Do.
Do	do	do	*Dactylis glomerata*	14	Do.
Do	do	do	*Agrostis alba vulgaris*	14	Do.
Feb. 21	do	do	*Elymus canadensis*	7	Successful.
Feb. 25	do	do	*Hordeum jubatum*	11	Do.
Feb. 28	do	do	Wheat	9	Do.

The results above given show that as a rule this rust form passes readily from wheat to barley and from barley to wheat, the exceptions not being more numerous than the failures from wheat to wheat, and such exceptions were probably generally caused by the presence of mildew or some other unusual condition. Indeed, it usually seemed that the transfers from wheat to barley and from barley to wheat, especially the latter, resulted more easily than did transfers from wheat to wheat or from barley to barley. As shown by the writer's investigations, it is the only cereal rust that readily infects more than one of the five cereals. In a few instances there were apparently slight infections of oats, but it was evident, if they were not accidental from *Uredo graminis* of oats, that the infections took place with difficulty.

One interesting feature of the experiments is that although the barberry rust in one set of experiments readily infected barley, it failed to infect wheat or oats and produced but one spot on rye. If the barberry rust was originally produced by the sporidia of teleutospores from wheat, which is not known, the failure to infect oats would be in accord with Eriksson's experiments (20, pp. 304, 305; 29, pp. 200–202), which showed that rust of barberry would infect only that cereal the rust form of which originally produced the barberry rust. On the other hand, the fact that it also failed to infect wheat, and infected rye but slightly, can not be thus explained; and this, with a few other peculiar results obtained, has led the writer to suspect that in this country there may be two distinct forms of the black stem rust on barley, one of which also infects rye but not wheat, and the other wheat but not rye. Like barley, *Hordeum jubatum* seems to also act as a host for both forms. Similarly peculiar results were obtained with certain other wild grasses and need to be further investigated.

As previously stated, the leaf rust seemed to infect the true bread wheats more readily than it did the durums and poulards, but in these experiments the reverse was true, the stem rust infecting durums and poulards more easily than it did the bread wheats. Moreover, larger and darker sori seemed to be formed on the durums and poulards than on the other wheats (Pl. IV, fig. 18)—an interesting fact in connection with the subject of rust resistance of varieties.

For the inoculations from the wild grasses *Hordeum jubatum*, *Agropyron tenerum*, and *Elymus canadensis glaucifolius*, material was of course obtained in the field on these hosts. Two rusts are found on *A. tenerum*, both of which seem to produce the same sort of sori on wheat, but only one is believed to be *P. graminis*. The spore forms were quite different.

Under ordinary greenhouse conditions the period of incubation for this rust in the uredo ranges from eight to twelve days. Under dates of September 26, 1896, November 6, 1897, and February 21, 1898, the shorter periods noted include only the time until signs of rust appeared, the epidermis not being broken until one or two days afterwards.

From experiments and observations so far made, the following may be considered as established hosts for the black stem rust of wheat in this country: *Triticum vulgare*, *T. compactum*, *T. turgidum*, *T. durum*, and *Hordeum vulgare*—cultivated varieties, and *T. monococcum*, *T. polonicum*, and *H. jubatum*.

It is almost certain that the following species also act as hosts for this rust form: *Triticum spelta* and *T. dicoccum*—cultivated varieties, and *Agropyron richardsoni*, *A. tenerum*, *Elymus canadensis*, and *E. canadensis glaucifolius*.

Occurrence and distribution.—As to the occurrence of this rust in the United States, little need be added to what has already been said. A fact of particular importance is that the stem rust, unlike the leaf rust, is not constant in occurrence, but will occasionally miss one or two years in five or six, depending, however, pretty much upon the locality. Although sometimes very destructive in any part of the United States except the irrigated districts, it probably produces serious damage most frequently in the Central States, between New York and Missouri, and in certain portions of Texas and California. In foreign countries this rust is especially common in northern Europe, and in certain seasons it is quite abundant also in Australia and Tasmania. According to Barclay (5, Vol. XXX, pp. 45–47), it is comparatively unimportant in India.

Wintering of the uredo.—Australia is the only country in which it has been demonstrated that the uredo winters over. Here, according to Cobb (19, p. 29), *P. graminis* lives the entire year in the uredo stage, either on self-sown grain or on certain native grasses, but whether he refers to one or to both of the forms of the rust on wheat and oats is not known. The writer has made a number of investigations to determine the question for this country, giving considerable time to the matter each winter, but has not yet been able to trace uredospores through the winter, although the form on oats has been found to live much longer than that on wheat.

Failing to find that the uredo winters over in Kansas, the writer thought that it might do so farther south, where the winters are milder, and that as spring advances the uredospores would be wafted northward from field to field and produce infection in their line of progress. In the hope of settling this point, therefore, he made a two-weeks' tour in December, 1895, through the State of Texas, from Indian Territory to the Mexican line. All the small grains except barley were closely examined in numerous fields around Fort Worth, Austin, Laredo, Houston, Beaumont, College Station, and McKinney, but it was rather surprising to find not only no trace of *Uredo graminis* either on wheat or winter oats, but also no *Uredo rubigo-vera* on wheat or rye. Winter oats was seen growing as far south as Laredo, but no trace of rust or of any other fungus could be found on any of the plants, although in examining old straw at several different places plenty of evidence was found that all the rusts of wheat and of oats were present during the preceding summer.

The latest date at which the writer observed the uredo on wheat at Manhattan was August 27. A case observed as late as September 19, supposed to be this rust, was afterwards found to be *Uredo rubigo-vera*. At Lincoln, Nebr., the uredo was found to be still active on *Hordeum jubatum* as late as October 25, and if identical with the form on *Elymus canadensis glaucifolius*, *Agropyron tenerum*, and *A. richardsoni* it was found on these hosts at the same place as late as November 16, 1897.

Liability of different varieties to this rust.—The series of experiments for testing rust liability of wheat varieties made by McAlpine (51, pp. 27, 28; 52, p. 26) in 1893 and 1894 and by Eriksson (31, pp. 333–341) in 1890–93 are the only ones reported in which it was stated that *P. graminis* was the chief species concerned. There is no means of knowing from the reports of any other experiments, whether in Australia or elsewhere, which rust was most abundant or whether both were present. However, in the reports of certain experiments, especially those conducted by Maddox (50, pp. 8–23), it is frequently stated what part of the plant was affected, that is, whether the stem or the leaves. In such cases it may be inferred that both rusts were present, but as to which one predominated only a guess, based on the comparative amounts of rust recorded on the leaves and stems, can be hazarded.

As already stated, this rust was present in the writer's experiments at Salina and Manhattan, but appeared so late in the season that at the latter place no satisfactory estimate of the rustiness of different varieties could be made, and at the former, for the same reason, the rustiness of spring varieties only could be graded. The following table shows the percentages of rust on the spring varieties:

TABLE 9.—*Comparative amount of Puccinia graminis on different varieties of spring wheat at Salina, Kans., in 1896.*

Localities and names of varieties.	Bald or bearded.	Per cent of rustiness.	Localities and names of varieties.	Bald or bearded.	Per cent of rustiness.
North Dakota:			Siberia—Continued.		
Glyndon 669	Bald	Traces.	Melka (Nerchinsk)	Bald	Traces.
Glyndon 673	do	Traces.	Australia:		
Glyndon 675	do	Traces.	Blounts Gypsum	do	Traces.
Glyndon 747	do	Traces.	(Carre de Sicile Rouge x Hourblende) x Improved Fife.		Traces.
Glyndon 775	do	Traces.			
McKissicks Fife	do	Traces.			
Russia:			14 x ([300 x Medeah] x 14).		Traces.
Alsace	do	10			
Arnautka	Bearded	5	Gypsum x (Improved Fife x Gypsum.)		Traces.
Byelokoloska	Bald	40			
Byelokoloska (Kursk)	do	25	Ladas (=42 a x Ladoga)	Bald	5
Chernokoloska	Bearded	10			
Gharnovka	do	10	Pringles Defiance	do	Traces.
Ghirka	Bald	45	Argentina:		
Ghirka (Samara)	do	30	Bahia Blanca	Bearded	5
Ghirka (Ekaterinoslav)	do	15	Barletta	Bald	5
Imperial	Bearded	20	Barletta (Santa Fe)	do	15
Krasnokoloska	Bald	15	Candeal Redondo		10
Polish	Bearded	25	Chubut	Bearded	15
Saxonka	Bald	30	Chubut Spielart	do	10
Siberia:			Entre Rios	do	Traces.
Beloturka	Bearded	5	Frances	Bald	15
Byelaya		15	Russo		15
Chernokoloska		5 to 15	Saldomé	Bearded	20
Kitaiska	Bearded	15	Tusela	Bald	20

As will be seen by comparing the figures in this table with those in Table 3 for the same varieties and the same year, (1) all the varieties were as a rule more affected with the leaf rust than with the stem rust; (2) Polish, Gharnovka, and other varieties that are quite resistant to leaf rust seemed to be about as badly affected with the stem rust as any of the others, while the North Dakota wheats and a few others that were badly affected with leaf rust were almost wholly free from stem rust; and (3) the Australian varieties, which were all sent in by Mr. Farrer, of New South Wales, and which are supposed to be bred and selected with especial regard to resistance to this rust, performed their mission quite well, all but Ladas showing only slight traces of the stem rust. Another fact of importance in regard to the durum wheats is that the stem rust affected all portions of the plant except the seed. The bread wheats were not so completely affected except in a few cases.

Pammel (55, pp. 498, 499) states that at the Iowa Agricultural Experiment Station, in 1892, when this rust "was very destructive," the

FIG. 1.—Healthy and shriveled grains of Jones Winter Fife harvested the same season in different parts of Kentucky.

following varieties were badly rusted: Velvet Chaff, Johnson, Early Red Clawson, Golden Cross, James White Fife, and Poole, while Turkish Red was, on the other hand, but slightly affected.

Farrer (33, p. 36) noted several years ago that the same varieties resist the two rusts in different degrees. Eriksson (31, pp. 340, 341; 27, p. 249) also found in his experiments that often those varieties most susceptible to *P. glumarum* were most resistant to *P. graminis* and *P. dispersa*. In Victoria in the season of 1893–94 McAlpine tried a number of varieties sent to him by Eriksson from Sweden, and the results he obtained showed well the differences in susceptibility of the same varieties to different rusts. Though the varieties were recommended as being quite resistant to *P. glumarum* in Sweden, they were badly affected with *P. rubigo-vera* in Victoria. The matter was discussed in detail by McAlpine before the Fourth Intercolonial Rust-in-Wheat Conference of Australia (52, p. 27), and also by Eriksson in an article in *Zeitschrift für Pflanzenkrankheiten* (23, pp. 141–144). However, in many cases where one rust is always present the differences noted in resistance of the same variety to different rusts may be, in great part, more apparent than real. If one rust attacks certain varieties severely, another one, the conditions being the same, will naturally work most on those varieties where there is least competition, while if the former rust were not present at all or present only in small quantities the latter might affect other varieties as much.

Damage.—The damage to wheat from this rust has, perhaps, been sufficiently discussed already under orange leaf rust of wheat, hence suffice it to repeat here that it is the destructive wheat rust of the United States. The damaging effects of this rust in Kentucky are shown in fig. 1. Such effects seem to be of common occurrence in the State.

BLACK STEM RUST OF RYE.

(*Puccinia graminis secalis* Eriks. and Henn.).

It has not yet been determined whether there is a distinct form of *P. graminis* on rye in this country.[1] True, there are in different herbariums in the United States various specimens of rust on rye collected here and labeled *P. graminis*, but many of these identifications are known to be wrong, and as the writer has no practical experience with such a rust either in the greenhouse or in the field, he can as yet make no definite statements in regard to it. In a few experiments, however, he made successful infections on rye and barley, but not on wheat, with what seemed to be uredospores of *P. graminis* from *Hordeum jubatum*. These experiments, as already mentioned, seem to show that *H. jubatum* supports two distinct forms of *P. graminis*, but there is yet quite a possibility of error because the number of experiments was small.

BLACK STEM RUST OF OATS.

(*Puccinia graminis avenæ* Eriks. and Henn.).

Physiological relations.—The apparent differences between this rust and the form on wheat have already been discussed. Besides these differences it has occasionally been seen in cases of adjoining fields of wheat and of oats that one of the cereals was affected with the stem rust while the other remained entirely free from it. The writer has made more inoculation experiments with this rust than with any other, the work having been inaugurated about the same time as that with *P. coronata*. The results of the experiments are presented in the following table:

[1] Further observations and facts that have come to hand very recently make it certain that black stem rust occurs on rye, but whether it is identical with the form on wheat and barley is yet to be determined.

TABLE 10.—*Inoculation experiments with Uredo graminis avenæ.*

Date of inoculation.	Place where experiments were made.	Origin of inoculating material.	Plant inoculated.	Period of incubation (days).	Result.
1896.					
Feb. 6	Washington, D. C.	Oats	Siberian oats	7	Successful.
Do	do	do	Black Tartarian oats	7	Do.
Feb. 14	do	do	Siberian oats	11	Do.
Do	do	do	Black Tartarian oats	11	Do.
Do	do	do	Early Para wheat	11	Negative.
Do	do	do	Siberian wheat	11	Do.
Do	do	do	Siberian barley	11	Do.
Do	do	do	Siberian rye	11	Do.
Do	do	do	Nebraska White Prize corn	11	Do.
Feb. 17	do	do	*Hordeum murinum*	10	Successful.
Feb. 19	do	do	Pied de Mouche oats	8	Do.
Do	do	do	Imperial wheat	8	Negative.
Feb. 20	do	do	Amurskii oats	8	Successful.
Do	do	do	Dun oats	8	Do.
Feb. 24	do	do	Nackter Kleiner Fahnen oats	9	Do.
Feb. 25	do	do	Black Tartarian oats	9	Do.
Mar. 4	do	do	Persian Black barley	15	Negative.
Do	do	do	Persian Red Spring wheat	15	Do.
Do	do	da	Spring rye	15	Do.
Do	do	do	Frances wheat	21	Do.
Do	do	do	Imperial wheat	21	Do.
Do	do	do	Japanese wheat No. 1	21	Do.
Do	do	do	Dur de Volos wheat	21	Do.
Do	do	do	Corn	21	Do.
Do	do	do	Sugar cane	21	Do.
Do	do	do	Imperial wheat	19	Do.
Do	do	do	Byelokoloska wheat	18	Do.
Do	do	do	Crimean wheat	18	Do.
Do	do	do	Siberian wheat	12	Do.
Do	do	do	Chinese barley	18	Do.
Do	do	do	*Triticum spelta amyleum*	18	Do.
Do	do	do	Saldomé wheat	18	Do.
Do	do	do	Einkorn	18	Do.
Do	do	do	Kathia wheat	18	Do.
Do	do	do	Banatka wheat	18	Do.
Do	do	do	Safeed wheat	14	Do.
Do	do	do	Varesotto wheat	14	Do.
Do	do	do	Australian Glory wheat	14	Do.
Do	do	do	Lal wheat	14	Do.
Do	do	do	*Elymus sp. indet*	14	Do.
Do	do	do	Corn	34	Do.
Do	do	do	Siberian rye	34	Do.
Do	do	do	Siberian barley	34	Do.
Do	do	do	Siberian wheat	34	Do.
Do	do	do	Early Para wheat	34	Do.
Do	do	do	Siberian rye	20	Do.
Do	do	do	Siberian wheat	20	Do.
Do	do	do	Siberian barley	20	Do.
Do	do	do	Early Para wheat	20	Do.
Do	do	do	Corn	20	Do.
Do	do	do	do	12	Do.
Do	do	do	Siberian millet	14	Do.
Do	do	do	Muzaffarnagar wheat	14	Do.
Do	do	do	Shirosawa wheat	14	Do.
Mar. 11	do	do	*Avena fatua*	7	Successful.
Mar. 12	do	do	Siberian millet	12	Negative.
Do	do	do	Safeed wheat	14	Do.
Do	do	do	Haffkani wheat	12	Do.
Do	do	do	Etampes oats	12	Do.
Do	do	do	Nebraska White Prize corn	12	Do.
Do	do	do	Persian Black barley	12	Do.
Mar. 13	do	do	*Dactylis glomerata*	9	Successful.
Mar. 18	do	do	Tardiva Danese oats	9	Do.
Mar. 19	do	do	*Dactylis glomerata*	10	Do.
Mar. 21	do	do	*Agrostis alba vulgaris*	12	Negative.
Do	do	do	*Elymus virginicus*	12	Do.
Do	do	do	*Phleum pratense*	12	Do.
Do	do	do	*Triticum villosum*	12	Do.
Mar. 23	do	do	*Hordeum murinum*	9	Successful.
Mar. 26	do	do	*Triticum villosum*	17	Only one or two spots.
Mar. 28	do	do	*Hordeum murinum*	10	Successful.
Mar. 30	do	do	do	9	Do.
Do	do	do	Amurskii oats	9	Do.
Do	do	do	Shirosawa wheat	9	Negative.
Apr. 2	do	do	*Dactylis glomerata*		Successful.
Apr. 6	do	do	*Avena pratensis*	10	Do.
Do	do	do	*Koeleria cristata*	10	Do.
Do	do	do	*Phleum pratense*	14	Negative.

TABLE 10.—*Inoculation experiments with Uredo graminis avenæ*—Continued.

Date of inoculation.	Place where experiments were made.	Origin of inoculating material.	Plant inoculated.	Period of incubation (days).	Result.
1896.					
Apr. 9	Washington, D. C	Oats	Fentons Rust Proof oats	10	Successful.
Do	do	do	*Lolium perenne*	10	Negative.
Do	do	do	*Arrhenatherum elatius*	10	Successful.
Do	do	do	*Hordeum jubatum*	10	Negative.
Do	do	do	*Bromus unioloides*	10	Only one or two spots.
Do	do	do	*Avena pratensis*	10	Successful.
Do	do	do	*Agrostis alba vulgaris*	10	Negative.
Apr. 13	do	do	*Phleum pratense*	14	Only one or two spots.
Apr. 14	do	do	*Lolium perenne*	15	Do.
Apr. 17	do	do	*Hordeum murinum*	11	Successful.
Do	do	do	*Dactylis glomerata*	11	Do.
Do	do	do	Shirosawa wheat	11	Negative.
Do	do	do	*Trisetum subspicatum*	8	Successful.
Do	do	do	*Alopecurus alpestris*	8	Do.
Do	do	do	*Holcus mollis*	8	Do.
Do	do	do	*Agrostis scabra*	8	Do.
Do	do	do	Fentons Rust Proof oats	8	Do.
Do	do	do	*Polypogon monspeliensis*	8	Do.
Do	do	do	*Festuca sp. indet*	8	Do.
Do	do	do	*Eatonia sp. indet*	8	Do.
Apr. 22	do	do	*Brizopyron siculum*	13	Negative.
Do	do	do	*Sporobolus asper*	13	Do.
Do	do	do	*Poa pratensis*	13	Do.
Do	do	do	*Andropogon halapense*	13	Do.
Do	do	do	*Phalaris arundinacea*	13	Do.
Do	do	do	*Anthoxanthum odoratum*	13	Do.
May 1	do	do	Ligowo oats	14	Successful.
Do	do	do	*Triticum spelta æstirum*	14	Negative.
Do	do	do	*Sporobolus cryptandrus*	14	Do.
Do	do	do	*Panicum crus-galli*	14	Do.
Do	do	do	*Hordeum murinum*	13	Only one or two spots.
Do	do	do	Australian Glory wheat	13	Negative.
Do	do	do	*Kœleria cristata*	13	Do.
May 6	do	do	*Ammophila arenaria*	12	Successful.
May 7	do	do	Dun oats	15	Do.
Do	do	do	*Avena sterilis*	15	Do.
Do	do	do	*Phleum asperum*	15	Do.
Do	do	do	*Ammophila arenaria*	15	Do.
Do	do	do	*Eatonia dudleyi*	15	Negative.
Do	do	do	*Panicum crus-galli*	15	Do.
Do	do	do	*Poa annua*	15	Do.
Do	do	do	*Brachypodium distachys*	15	Do.
Do	do	do	*Sporobolus cryptandrus*	15	Do.
Do	do	do	*Eleusine egyptiaca*	15	Do.
Do	do	do	*Bouteloua curtipendula*	15	Do.
Do	do	do	*Eragrostis purshii*	15	Do.
Do	do	do	*Schedonnardus paniculatus*	15	Do.
May 20	do	do	*Triodia cuprea*	12	Do.
May 27	do	do	Oats	7	Successful.
Do	do	do	do	7	Do.
Do	do	do	Barley	7	Negative.
Do	do	do	Rye	7	Do.
Do	do	do	Wheat	7	Do.
Dec. 21	do	do	Oats	10	Successful.
Do	do	do	do	9	Do.
1897.					
Feb. 24	do	do	*Avena pratensis*	13	Do.
Do	do	do	*Avena hookeri*	13	Do.
Do	do	do	*Dactylis glomerata*	13	Do.
Do	do	do	*Eatonia obtusata*	13	Do.
Do	do	do	*Bromus ciliatus*	13	Do.
Do	do	do	*Triticum villosum*	13	Negative.
Do	do	do	*Hordeum nodosum*	13	Do.
Mar. 30	do	do	*Avena fatua*	12	Successful.
Do	do	do	*Festuca ovina*	12	Negative.
Do	do	do	*Festuca arundinacea*	12	Do.
Do	do	do	Oats	12	Successful.
Do	do	do	*Festuca rubra glaucescens*	12	Negative.
Do	do	do	*Festuca gigantea*	12	Do.
Aug. 23	Stillwater, Okla	*Dactylis glomerata.*	Wheat	13	Do.
Do	do	do	Oats	13	Do.
Sept. 7	Manhattan, Kans	do	Wheat	8	Do.

TABLE 10.—*Inoculation experiments with Uredo graminis avenæ*—Continued.

Date of inoculation.	Place where experiments were made.	Origin of inoculating material.	Plant inoculated	Period of incubation (days).	Result.
1897.					
Sept. 7	Manhattan, Kans	*Dactylis glomerata.*	Oats	8	Successful.
Do	do	do	*Dactylis glomerata*	8	Do.
Dec. 23	Lincoln, Nebr	*Arrhenatherum elatius.*	Oats	12	Do.
Do	do	do	Rye	12	Negative.
1898.					
Jan. 5	do	Oats	Oats	21	Successful.
Do	do	do	Wheat	21	Negative.
Jan. 24	do	do	Oats	12	Only one or two spots.
Do	do	do	Wheat	12	Negative.
Do	do	do	Oats	9	Successful.

Inoculations with this rust were successful on a greater number of hosts than inoculations with any other rust. Of course, as in the case of *Uredo coronata*, some of the experiments might not have proved successful with older plants, but nevertheless a number of inoculations on older plants also produced infections. On the other hand, in the case of Etampes oats, under date of March 12, 1896, and in a few other cases, the plants were inoculated just after germination upon damp cotton, but evidently were too young to be affected, the germ threads of the spores having ceased to grow before the first leaf was accessible.

An interesting feature of these experiments is the number of infected plants that belong to species of allied genera or to species that are rather similar in structure, and their close correspondence with those infected with *Uredo coronata*, as shown in Table 6.

The first forage grass proved to be a host for this rust in this country was *Dactylis glomerata*. On account of its susceptibility to infection, both when young and in an advanced stage, the writer for some time believed it to be a host for this rust. On August 2, 1897, both uredospores and teleutospores of the rust were found in great abundance on this grass on the grounds of the agricultural college at Stillwater, Okla.[1] A rusted plant was transferred from these grounds to the greenhouse of the Agricultural College at Manhattan, Kans. Material from this plant easily infected other plants of orchard grass and oats, producing sori on oats more vigorous than those from material of the same rust taken from oats. The rust was found on *Arrhenatherum elatius* at Lincoln November 16, 1897, and the reverse infections on oats from this material were produced December 23, 1897.

On the basis of experiments and observations made so far the following may be named as well-established hosts for the black stem rust of

[1] He had, of course, seen the rust on orchard grass several times before, as it is rather common, but had always supposed it to be equivalent to the form on wheat.

oats: *Avena sativa patula*, *A. sativa orientalis*, and *A. sativa nuda*—cultivated varieties, and *Dactylis glomerata*, and *Arrhenatherum elatius*. The following species may at present be considered as probable hosts: *Avena fatua*, *A. hookeri*, *A. pratensis*, *A. sterilis*, *Koeleria cristata*, and *Lolium perenne*.

Occurrence and distribution.—The black stem rust of oats is certainly more common than the black stem rust of wheat, owing probably to the fact that oats matures later than wheat and the stem rusts occur later than the other rusts. However, it is not known whether the stem rust of oats is generally commoner than the crown rust, although definite statements on this point might be made in the case of certain localities—locality apparently being an important feature in this connection.

As in the case of stem rust of wheat, this rust is not constant in occurrence, although perhaps more so than the former. Reports indicate that in the Southern States it is neither so common as it is in the Northern States nor so common as the crown rust. No trace of it was seen in Maryland during two successive seasons of observations by the writer. His examination of old straw at the Texas Agricultural College in December, 1895, showed that the crown rust was quite abundant the preceding summer, but none of the stem rust was observed.

Wherever oats is grown in foreign countries the distribution of the stem rust of oats seems to be quite general, but in some regions it is said to be of little economic importance.

Wintering of the uredo.—So far as yet known, this rust does not winter its uredo in this country. The following table gives a summary of the writer's observations of the occurrence of the uredo in late summer and autumn:

TABLE 11.—*Summary of observations on late occurrence of Uredo graminis avenæ.*

Host plant.	Date of observation.	Place of observation.
Oats	Sept. 17, 1896	Manhattan, Kans.
Do	Nov. 2, 1896	Do.
Do	Aug. 27, 1897	Do.
Dactylis glomerata	Aug. 23, 1897	Stillwater, Okla.
Do	Oct. 8, 1897	Do.
Oats	Oct. 12, 1897	Payne County, Okla.
Dactylis glomerata	Nov. 12, 1897	Manhattan, Kans.
Oats	Nov 14, 1897	Lincoln, Nebr.
Arrhenatherum elatius.	Nov. 16, 1897	Do.

The fact that the uredo was found on other hosts than oats, and especially the fact that these hosts are perennial, strengthens the probability that the uredo winters over, but at the same time weakens the probability that it winters on oats. At any rate, it is easily seen that orchard grass and tall meadow oat grass are not likely to prove desirable neighbors for the oat field.

As already stated, Cobb (19, p. 29) mentions that *P. graminis* winters over in the uredo stage in Australia, but he is not sufficiently explicit to justify the conclusion that he includes this form on oats.

Liability of different varieties to this rust.—But little information exists as to the liability of different varieties of oats to rust in this country based on any case in which it was definitely known that the stem rust was the chief one under observation. In the season of 1894 the writer assisted Prof. J. H. Shepperd in grading the rustiness of varieties of oats grown at the North Dakota Agricultural Experiment Station, *P. graminis* being the dominant rust on oats that season, not only there but also throughout the North and West. The following season Prof. H. L. Bolley, of that station, graded the rustiness of the same varieties, and in a recent letter received from him he states that *P. graminis* was the chief rust present that year, but that the presence of *P. coronata* accounts for the small percentages of rust noted for certain varieties. The results of the two years' grading were reported by Professor Shepperd in a bulletin issued March, 1896 (64, pp. 38–40). The percentages for the same varieties for the two seasons correspond quite well as a rule, and show almost entire freedom from rust in the case of Early White Russian, Fentons Rust Proof, Tartarian, and Great Northern, and an abundance of rust on Giant Yellow, American White, Badger Queen, and North Star.

This rust occurred to a small extent on the varieties of oats in the field experiments at Salina, but on account of its late appearance and the great abundance of the crown rust it was impracticable to grade the amounts on the different varieties.

In Australia, where so much has been written on rust-resistant wheats, apparently no attention has been given to rust-resistant oats, probably for the reason that oat rust is of little economic importance in that country. In 1893 Eriksson made some observations (31, pp. 348–350) on rust liability of varieties of oats in Sweden, especially as regards the black stem rust, and concluded that in Sweden there is no particular difference in the susceptibility of different sorts of oats to this rust.

Damage.—The damage which this rust causes to oats in this country is even greater than that produced by the form occurring on wheat. In fact almost every year thousands of acres are totally destroyed in some portions of the country by this parasite, the damage being greatest north of the thirty-seventh degree of north latitude and east of the ninety-fifth degree of west longitude. According to Eriksson (31, p. 386), it is also very destructive at times in Sweden, the damage to oats in that country from this cause in 1889 amounting to 16 million crowns (about 4½ million dollars).

MAIZE RUST.

(*Puccinia sorghi* Schw.).

Physiological relations.—The fact that the maize rust bears some morphological resemblance to the rusts of certain grasses, particularly to *P. graminis* of wheat and oats, led the writer to suspect that it might be equivalent to one or more of these, and it was for this reason especially that in the inoculation experiments with the rusts of the other four cereals Indian corn was employed several times, as were also other grasses. A few experiments were also made with the uredo of maize rust itself. The following results were obtained:

TABLE 12.—*Inoculation experiments with Uredo sorghi.*

Date of inoculation.	Place where experiments were made.	Origin of inoculating material.	Plants inoculated.	Period of incubation (days).	Result.
1896.					
Sept. 17	Manhattan, Kans	Corn	Corn	5	Successful.
Sept. 24	do	do	do	7	Do.
Dec. 22	Washington, D. C.	do	do	7	Do.
1897.					
Apr. 10	do	do	*Euchlæna mexicana*	11	Do.
Oct. 13	Manhattan, Kans	*Euchlæna mexicana.*	Corn	11	Do.

The time of incubation for this uredo is shorter than that of any other cereal rust, varying from five to eight days, under ordinary greenhouse conditions.

Until recently it was not known that maize rust occurred on any host in this country except Indian corn. In pursuance of an idea long entertained that teosinte (*Euchlæna mexicana*), on account of its close relation to corn, might also be a host for the maize rust, the writer planted some teosinte seed (obtained from the Division of Agrostology, which kindly supplied seeds of various grasses used in the writer's experiments) in the greenhouse in the spring of 1897, and successfully inoculated the resulting plants, a longer period of incubation being required, however, than in the case of corn. On August 21, 1897, he found both the uredo and teleuto stages on teosinte growing on the grounds of the Agricultural College at Stillwater, Okla., and later successfully inoculated corn with uredospores from the teosinte, vigorous sori being produced.

It is a curious fact that while inoculations with this rust resulted in adding another host for it, similar experiments with the other cereal rusts have shown that the number of their hosts is much smaller than had been supposed. The established hosts for this rust in the United States, as determined by experiments so far made, are *Zea mays* (cultivated varieties of the groups *saccharata*, *dentiformis*, and *vulgaris*) and *Euchlæna mexicana*.

Occurrence and distribution.—Maize rust occurs in all parts of the United States where the ordinary varieties of field corn, sugar corn, and pop corn are grown, but it is rarely found in great abundance in any locality. It attains its maximum abundance on ordinary field crops about October 1, or about three months later than any other rust of cereals. Whether the introduction of teosinte as a forage crop will have any effect in facilitating the spread of the rust remains to be seen.

This rust is also reported from South America, Germany, France, Italy, Portugal, India, and south Africa; but owing to the facts that the genus Sorghum is included with its hosts and that Barclay has shown (5, Vol. XXVIII, pp. 257–259; 3, pp. 214, 215) that the rust on *Sorghum vulgare* in India is a distinct species, which he called *P. penniseti*, it is questionable whether it actually occurs in all these countries.

Wintering of the uredo.—This rust is not yet known to winter its uredo in any country, and as no æcidial stage has been discovered, the manner of its perpetuation throughout the year is entirely unknown.

Liability of different varieties to this rust.—There is as yet no difference known in the susceptibility of different varieties of corn to this rust, but so far no investigations have been made to determine this point. The rust seems to be of but little economic importance.

Damage.—The writer has occasionally seen patches of very late corn injured by this rust. If corn is sown broadcast as a forage crop late in the season it is likely to be badly damaged, but as a rule the rust does little or no damage. Pammel mentions (56a, p. 851) that in Iowa the yield of corn, especially of sweet corn, is sometimes materially lessened because of rust.

GENERAL REMARKS.

Many inoculation, germination, and other physiological experiments not mentioned in this bulletin but bearing closely on the cereal rust problem, will be discussed in other publications of this Division. These experiments, like those made by Eriksson, show that in addition to the forms herein described, the cereal rusts have also distinct specialized forms on various grasses, but as these forms do not occur on the cereals they are usually of no economic importance. In addition to the experiments already reported in a former publication (15, pp. 448–452), numerous others were made by the writer to determine the behavior of the uredospores from a chemical standpoint. Also hundreds of inoculations on cereals with the æcidia of various plants other than barberry have been made for the purpose of discovering, if possible, other æcidial hosts for the cereal rusts, but so far none have been found. Again, the morphological differences between the different forms of the cereal rusts are, in a few cases at least, of considerable importance, but it is thought best, under the circumstances, to discuss them in another publication.

Something should be said concerning the value of the inoculation experiments reported in this bulletin. It may be claimed by some that the experiments which proved successful in the greenhouse and on young plants would probably result negatively in a greater number of cases if made out of doors on more mature plants. This is not only possible, but, as already shown, the writer's results make it very probable; and thereby the experiments are all the more valuable, as in the greenhouse they are more exclusive in nature and in no case is an infection likely to take place out of doors if it can not be produced in the greenhouse. In case there is an error, therefore, it is on the safe side, and the number of possible host plants is gradually more and more limited, until finally, by reverse infections, the actual host plants are established. As already stated, a number of instances of repeated experiments on older plants resulted negatively, although they had been successful in the first experiments.

The "mycoplasmatic" theory, advanced by Eriksson (25, pp. 475–477) to explain the manner of perpetuation of *Puccinia glumarum* from one season to another, has already been mentioned. A description of Eriksson's experiments with this rust seems to reveal conditions different from those existing in the case of any other cereal rust. Barley plants grown from the seed and completely shut off from external influences showed rust after a time. The seed was sown in sterilized soil and grown in glass houses, into which air could pass only through cotton-wool filters. From other statements and illustrations in *Die Getreideroste*, it seems probable that we have here at last an instance of the propagation of grain rust through the medium of the germinating seed of the host, as in some of the smuts. Eriksson claims that, as he found no mycelium present, the rust exists in the form of a mycoplasma in the cells of the embryo in a latent symbiotic state during the interval between harvest and seeding time. As the rust in question does not exist in this country, the writer has had no opportunity to investigate the matter. No other cereal rust is known to live within the seed in any form or manner.[1]

SUMMARY.

(1) At least six and probably seven distinct rusts affect the cereals of the United States. They are as follows: Orange leaf rust of wheat (*Puccinia rubigo-vera tritici*), orange leaf rust of rye (*P. rubigo-vera secalis*), crown rust of oats (*P. coronata* Corda), black stem rust of wheat and barley (*P. graminis tritici* Eriks. and Henn.), black stem rust of rye (*P. graminis secalis* Eriks. and Henn.), black stem rust of oats (*P. graminis avenæ* Eriks. and Henn.), and maize rust (*P. sorghi* Schw.).

(2) Though all these rusts except that on maize probably cause some injury occasionally, the black stem rusts of wheat and of oats are by far the most destructive.

(3) All the rusts are pretty evenly distributed over the United States, wherever their respective hosts are grown, except the stem rusts, which are perhaps most prevalent in the region between the Alleghanies and the ninety-fifth degree of west longitude north of the

[1] Cases where rusts other than those of cereals live over in the seed are not, however, unknown. The actual peridia of the æcidium of *Uromyces euphorbiæ* C. and P. may often be seen within the seed of *Euphorbia dentata*. The writer's investigations concerning this rust are yet to be published. In 1890 Ralph (61, p. 18) also described an æcidium affecting the seed of *Senecio vulgaris* in Australia, which seems to furnish one other instance.

thirty-seventh degree of north latitude and in portions of Texas and California. The leaf rusts and the crown rust are proportionally more important in the Atlantic and the Southern coast States.

(4) The damage to wheat and oats from rust in this country probably exceeds that caused by any other fungous or insect pest, and in some localities is greater than that caused by all other enemies combined.

(5) As yet there is but little certainty concerning rust resistance, which varies continually under different conditions. Heretofore in testing varieties for rust resistance, little attention has been paid to the species of rust concerned.

(6) The following hardy prolific varieties of wheat can usually be depended upon to resist orange leaf rust to a considerable degree: Turkey, Mennonite, Odessa, Rieti, Pringles No. 5, and Pringles Defiance, and for early spring sowing Haynes Blue Stem and Saskatchewan Fife. Some of these varieties may be resistant to the black stem rust also, but this has not been definitely determined.

(7) The following varieties also resist leaf rust, probably in nearly all cases: Theiss, Fulcaster, Oregon Club, Deitz Longberry, Sonora, Diehl Mediterranean, Arnolds Hybrid, and California Spring.

(8) Durum and poulard wheats are very resistant to the leaf rust, but so far have been used chiefly in making macaroni. A few of the most important of these wheats are, Arnautka, Taganrog, Beloturka, Medeah, Gallands Hybrid, Petanielle Noire de Nice, Chernuska, Cretan, Missogen, and Nicaragua.

(9) During two years when rust was very severe Einkorn, a variety of *Triticum monococcum*, used for stock feed, remained absolutely proof against the leaf rust.

(10) So far as known, any ordinary variety of wheat may rust badly if sown late, but the following, although susceptible to rust, may sometimes escape it because of early maturity: Early May, Zimmerman, Early Baart, Allora Spring, Roseworthy, Yemide, Kathia, Canning Downs, and Japanese No. 2. However, four of these—Early Baart, Allora Spring, Roseworthy, and Canning Downs—are probably not sufficiently hardy for northern latitudes.

(11) Of the varieties of oats, Texas Rust Proof is commonly considered rust resistant in the Southern States, but to which of the rusts is not known. In the Northern States the varieties more or less resistant to black stem rust are Early White Russian, Great Northern, Tartarian, and Fentons Rust Proof.

(12) Experiments so far made with uredospores show that the orange leaf rusts of wheat and rye do not transfer to hosts outside of the genera Triticum and Secale, respectively, but that, on the other hand, their uredo stages winter over readily in this country, beginning first on self-sown grain and probably later transferring to the regular fall-sown crop. All farms should therefore be kept constantly and rigidly free of volunteer wheat and rye.

(13) The crown rust of oats is not yet known to winter its uredo nor to transfer to any other hosts than species of Avena.[1]

(14) The black stem rust of wheat occurs also on barley and *Hordeum jubatum*. So far as known it does not winter its uredo in this country.

(15) It has not yet been definitely determined whether there is a distinct form of the black stem rust on rye in this country, but it is very probable that there is.

(16) The uredo of the black stem rust of oats is not yet known to winter in the United States, but it has been found alive very late in the autumn. The rust, however, is also common on the two grasses, *Dactylis glomerata* and *Arrhenatherum elatius*, hence oats may be easily infected with it when grown in close proximity to these grasses.

(17) Maize rust occurs also on teosinte in this country, but does not winter its uredo. It is of little economic importance.

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[1] As already mentioned, later experiments show that the æcidium of *Rhamnus lanceolata* infects oats, *Phalaris caroliniana, and Arrhenatherum elatius.*

[2] Since this bulletin was prepared Dr. H. Klebahn has published in Zeitschr. für Pflanzenkrank., Feb. 4, 1899, Bd. VIII, Heft 6, pp. 321–342, a lengthy article entitled "Ein Beitrag zur Getreiderostfrage." It consists chiefly in an account of experiments made with the different grain rusts, and of the results, which seem to conflict more or less with those obtained by Eriksson. In Centralbl. f. Bakt., Parasit., u. Infekt., Dec. 19, 30, and 31, 1898, Abt. II, Bd. IV, pp. 855–859, 887–896, 913–919 (6 illus.) appears an article by Prof. H. L. Bolley, entitled "Einige Bemerkungen über die symbiotische Mykoplasmatheorie bei dem Getreiderost," in which the author, on the basis of his own experiments, also criticises Eriksson's theory, and gives the results of other investigations, which show the great vitality of uredospores and æcidiospores and the possibility of uredospore germ tubes passing through the actual epidermis of the leaf as well as the stomata. The original of this paper (in English) was presented before the Boston meeting of the American Association for the Advancement of Science, August, 1898.

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EXPLANATION OF PLATES.

PLATE I.—Comparative rustiness of four varieties of wheat from *Uredo rubigo-vera tritici*, Garrett Park, Md. *1* Buckeye: *a* lower surface of leaf, *b* upper surface of leaf; *2* Golden Prolific; *3* Gallands Hybrid: *a* lower surface of leaf, *b* upper surface of leaf; *4* Beloturka. The brown spots on *3* and *4* were not caused by rust.

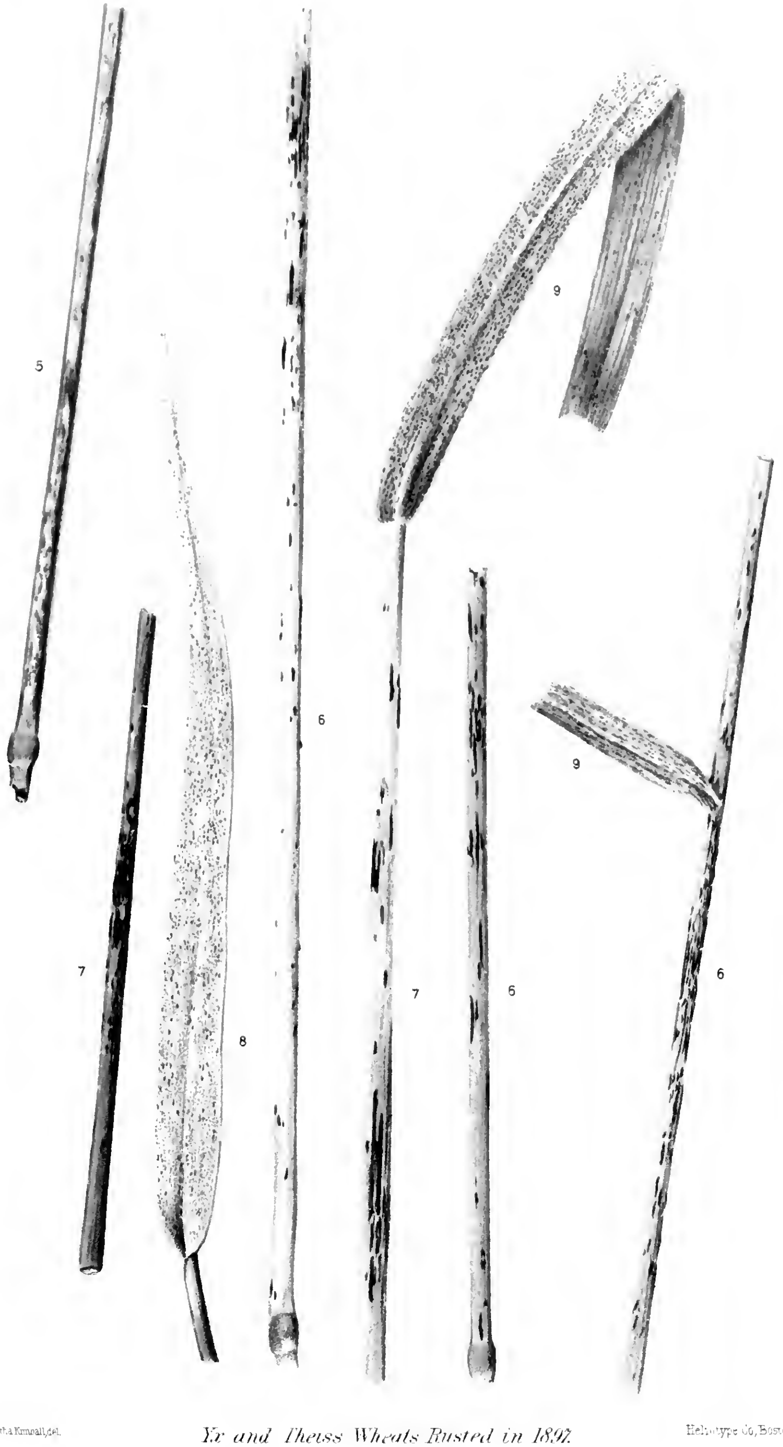
PLATE II.—Yx and Theiss wheats rusted with *Puccinia graminis tritici* and *P. rubigo-vera tritici* at Manhattan, Kans. *5* uredo of *P. graminis; 6* uredo and teleuto stages of *P. graminis; 7* teleuto stage of *P. graminis; 8* uredo and teleuto stages of *P. rubigo-vera; 9* teleuto stage of *P. rubigo-vera.*

PLATE III.—Cereal rusts produced by artificial infection on young plants. *10 Uredo rubigo-vera secalis* on rye; *11 U. rubigo-vera secalis* on rye, showing how the chlorophyll remains about rust spots during changes of the coloring matter; *12 U. rubigo-vera secalis* on *Secale montanum; 13 U. rubigo-vera tritici* on wheat; *14 U. coronata* on oats.

PLATE IV.—Cereal rusts produced by artificial infections on young plants. *15 Uredo coronata* (*a*) and *U. graminis avenæ* (*b*) produced on the same leaf of oats; *16 U. graminis avenæ* on oats; *17 U. graminis avenæ* on *Kæleria cristata; 18 U. graminis tritici* on Taganrog wheat; *19 U. graminis* on the leaf of barley; *20 U. graminis* on the sheath of barley; *21 U. sorghi* on corn leaf; *22 U. sorghi* on corn, but with teleuto stage also.

D. G. Passmore, del. Heliotype Co. Boston.

Comparative Resistance of four varieties of wheat from Orange Leaf Rust.



Bertha Kimball, del.

Yx and Theiss Wheats Rusted in 1897.

Heliotype Co., Boston.

D. G. Passmore del.

Cereal Rusts from Artificial Infections.

Heliotype Co., Boston.

D. G. Passmore, del.

Cereal Rusts from Artificial Infections.

Heliotype Co. Boston

BULLETIN No. 17.

U. S. DEPARTMENT OF AGRICULTURE.

DIVISION OF VEGETABLE PHYSIOLOGY AND PATHOLOGY.

B. T. GALLOWAY, Chief.

WILT DISEASE

OF

COTTON, WATERMELON, AND COWPEA

(*Neocosmospora* nov. gen.).

BY

ERWIN F. SMITH,

PATHOLOGIST.

Issued November 22, 1899.

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1899.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
DIVISION OF VEGETABLE PHYSIOLOGY AND PATHOLOGY,
Washington, D. C., July 15, 1899.

SIR: I respectfully transmit herewith a report embodying the results of some investigations of a disease which has caused serious loss to the growers of cotton and other Southern crops. The report is technical, and will form a basis for further work looking toward the restriction and prevention of the disease. I respectfully recommend that the report be published as Bulletin No. 17 of this Division.

Respectfully,

B. T. GALLOWAY,
Chief of Division.

Hon. JAMES WILSON,
Secretary of Agriculture.

CONTENTS.

ILLUSTRATIONS.

WILT DISEASE OF COTTON, WATERMELON, AND COWPEA.

(*Neocosmospora* nov. gen.)

The fungus here described has been under nearly continuous observation for five years. A number of points in its life-history remain to be worked out, but as a year or two must necessarily elapse before the investigation is completed, it is thought best to put the main facts on record at this time, particularly as more material has been accumulated than is usually considered ample for the description of a genus or species.

This material has been accumulating during so long a period that it now amounts to a very considerable mass of correspondence, notes, slides, photographs, drawings, etc., and only a condensed account is here possible. The facts are set forth in as few words as possible, but each one depends on more than a single observation or experiment, and often statements which occupy only a word or two or a line or two are based on scores of observations. Whenever the writer has been in doubt, and that was often, he has repeated the experiment or made additional observations. The long delay in publication is due to the fact that he was disappointed at the result of the cross-inoculations and over certain other failures which are mentioned in their proper place.

DESCRIPTION OF THE FUNGUS.

Ascomycetous stage.—Perithecia on the roots (Pl. I, *1*) more rarely on the parts above ground, superficial, resting on a slight subiculum, sometimes developing in the earth near the roots, or underneath the loose bark of the host plant, or deep in cavities or rifts of the decomposing root or stem, but always free from the tissues of the host and not borne on any distinct stroma,[1] infrequent or numerous, scattered or several to many together; ovate, slightly higher than broad, of quite variable size, ranging from 210 to 400 μ in height by 150 to 328 μ in diameter, mostly 250 to 350 by 200 to 300 μ.[2] Peridium about 20 μ thick, coral red to vermilion red, or in water under a cover glass, of a uniform purplish red, when fully ripe becoming orange vermilion (Ridgway's

[1] When cultivated on slices of cooked potato the perithecia are usually developed from a more or less elevated, tough (fleshy), grayish-white stromatic surface of quite different appearance from the ordinary mycelium.

[2] One hundred and eleven measurements.

Nomenclature of Colors, 1st ed., Pl. VII, No. 12), owing perhaps to the brown ascospores which can be seen through the translucent walls; collapsing irregularly (more or less) when empty, but not sinking in regularly about the ostiolum after the manner of many Nectrias; surface slightly irregular and a little papillate, especially toward the apex, by reason of the slight projection of single cells, not scaly, pruinose, or hairy; wall distinctly parenchymatic, the irregularly polyhedral cells with rounded angles and in the ventral portion about 8 to 16 μ in diameter (Pl. II, *5*); usually no distinct neck until fully ripe, then frequently a short neck (generally 30 to 40 μ long, but shorter or longer, sometimes even as long as 80 μ, but never hairy or fimbriate at the apex);[1] ostiolum closed by special cells (Pl. II, *1*) and indistinct until fully ripe, then opening by solution, 30 to 50 μ or more broad, bordered by narrower cells: the neck lined internally by numerous hairs (periphyses), 20 to 30 μ long, which project into the throat leaving only a small opening (Pl. II, *2*). Asci 8-spored, numerous (75 to 100 or more), cylindric, stipitate, the somewhat narrowly constricted base of variable length, but usually equal to about one-eighth to one-third the length of the spore-bearing part, the latter 70 to 100 μ long by 11 to 14 μ broad (usually 12 μ broad), with apices rounded and very slightly, if at all, thickened (Pl. I, *2*, *3*: Pl. V, *2*); usually crushing out of the immature perithecium with some part of the hypothecium in one or more adherent masses (Pl. I, *4*), becoming so thin-walled as to be scarcely visible, and when fully ripe frequently dissolving, leaving the free spores (Pl. II, *4*) to escape through the stoma or through any part of the accidentally ruptured wall as the gelatinous débris in the interior of the perithecium expands by absorption of water, in which case the spores often adhere to the exterior of the perithecium for some time in little irregular brown masses (Pl. I, *1a*). In other cases (even on the same culture), the asci retain their form and elasticity and the ripened ascospores are shot out through the ostiolum to the distance of 3 to 8 millimeters. Paraphyses present (Pl. I, *2*; Pl. V, *2*) and often two or three times the diameter of the asci, each composed of several roundish, oblong, or irregular, thin-walled, loosely connected cells, nearly destitute of protoplasm and readily overlooked (unstained, they are best seen by viewing the sections or crushed out material in water with a very narrow pencil of rays).[2] Ascospores (Pl. I, *2*, *3*, *5*, *6*; Pl. V, *2*) in one row, when ripe closely filling the ascus, globose to short elliptical, rarely ovate or considerably longer than broad, continuous, rather thick-walled, colorless until ripe, then light brown, in mass mummy brown (Ridgway's Nomenclature, Pl. III, No. 10), with a thick, distinctly wrinkled exospore (more rarely smooth), variable in size, usually 10 to 12 μ in diame-

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[1] Pure cultures from the same ascospore yielded ripe perithecia with and without beaks.

[2] Similar organs are present in many Nectriaceous fungi which have been described as destitute of paraphyses.

ter, if globose, and 8 to 12 by 11 to 14 μ if ellipsoidal,[1] contents hyaline, one to several guttulate; germinating readily on potato or in nutrient agar (Pl. I, *6*), producing a white, immediately much branched, many septate mycelium which by interweaving soon conceals the ascospore and in a short time (cowpea fungus) reproduces perithecia, first, however, and usually within thirty-six hours, producing from the ends of short branches or from terminal hyphae (Pl. I, *7*) numerous, colorless, oval to narrowly elliptical conidia which are mostly 8 to 16 by 3 to 6 μ, straight or curved, continuous (or occasionally one-septate after falling off) and indistinguishable from those of the internal fungus (see below). Mycelium on slightly alkaline meat infusion peptone agar at first pure white, then grayish white (stromatic), producing immature but nearly full-grown perithecia in large numbers within a week of the sowing of the ascospore. Mycelium on steamed potato cylinders in test tubes at

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[1] Altogether 244 ascospores have been measured directly from the plant, and all of the sizes observed are recorded below in microns, together with the plants from which taken and the number of each size. P=Cowpea; W=Watermelon; C=Cotton:

18 x 12 W^{1}; 17.7 x 10.2 P^{1}; 16 x 15 P^{1}; 16 x 14.5 P^{1}; 15 x 12 P^{1}; 15 x 11.5 W^{1}; 15 x 10 W^{1}; 14.7 x 12 P^{1}; 14 x 14 P^{2}; 14 x 13.3 P^{1}; 14 x 13 P^{1} C^{1}; 14 x 12 P^{7} W^{1} C^{1}; 14 x 11 P^{1} W^{1}; 14 x 10 P^{2} W^{1}; 14 x 9 P^{1} W^{2}; 13.5 x 12 P^{1}; 13 x 13 P^{1}; 13 x 12 P^{3} W^{2} C^{1}; 13 x 11 P^{1} W^{1}; 13 x 10 P^{1} W^{1}; 13 x 9 W^{3}; 12.7 x 12 P^{1}; 12.5 x 10 P^{1}; 12 x 12 P^{35} W^{12} C^{3}; 12 x 11 P^{2} W^{5}; 12 x 10 P^{5} W^{7} C^{1}; 12 x 9.5 C^{1}; 12 x 9 W^{1}; 12 x 8 P^{1} W^{9}; 11.5 x 11 W^{1}; 11.5 x 10.5 W^{1}; 11.5 x 10 C^{1}; 11.5 x 8 W^{1}; 11 x 11 P^{2} W^{5} C^{1}; 11 x 10 P^{2} W^{1} C^{9}; 11 x 9 W^{1} C^{1}; 11 x 8 W^{4}; 10.5 x 10 P^{1} C^{1}; 10 x 10 P^{8} W^{10} C^{25}; 10 x 9.5 C^{3}; 10 x 9 P^{1} W^{5} C^{3}; 10 x 8 W^{7}; 9.5 x 9.5 W^{1} C^{2}; 9 x 9 W^{2} C^{4}; 8 x 8 C^{1}.

On the cotton most of the spores are globose, or nearly so, nearly all have a wrinkled exospore, and the medium and smaller sizes prevail. On the cowpea the majority of the spores are globose and wrinkled, and the larger sizes prevail. On the watermelon a majority of the spores are elliptical, many are smooth and the smaller sizes are the more common, as may be seen from the preceding figures. These variations do not, however, appear to have any specific value, since the spores derived from a single ascospore sorted out and sown on culture media may vary as greatly as any here recorded. This is shown by the following set of figures derived from measurements of ascospores taken from numerous perithecia grown on potato. The pure culture which was used for this purpose was derived from a single wrinkled ascospore taken from a typical perithecium on the cowpea. It will be seen that the general tendency of these spores is to exceed the size of the original spore rather than to fall short of it. They are also larger than the average of those taken directly from the host plants.

Size of 180 ascospores from a luxuriant growth on steamed potato; original spore 12 x 12 μ, the number of each size is given at the right hand above; all with wrinkled exospore except a very few of the small ones: 22 x 12^{1}; 20 x 15^{1}; 18 x 14^{1}; 18 x 12^{3}; 18 x 11^{1}; 18 x 10.5^{1}; 18 x 10^{4}; 17 x 12^{1}; 17 x 11^{1}; 17 x 10.5^{1}; 17 x 10^{1}; 16.5 x 12^{1}; 16 x 15^{1}; 16 x 14^{1}; 16 x 13^{1}; 16 x 12^{9}; 16 x 11.5^{1}; 16 x 11^{3}; 16 x 10^{1}; 15.3 x 12^{1}; 15 x 15^{1}; 15 x 13^{1}; 15 x 12.5^{1}; 15 x 12^{2}; 15 x 11^{2}; 14.5 x 13.5^{1}; 14.5 x 12.5^{1}; 14.5 x 12^{1}; 14.5 x 10^{1}; 14.3 x 12.5^{1}; 14 x 14^{3}; 14 x 13.5^{1}; 14 x 13^{9}; 14 x 12.5^{1}; 14 x 11.5^{8} all from one ascus; 14 x 11^{3}; 13.5 x 13.5^{2}; 13.5 x 13^{6}; 13.5 x 12.5^{1}; 13 x 13^{11}; 13 x 12^{17}; 13 x 10^{1}; 12.5 x 12.5^{4}; 12.5 x 12^{6}; 12 5 x 10.5^{1}; 12 x 12^{26}; 12 x 11.5^{1}; 12 x 11^{1}; 12 x 10^{1} smooth (7 others from the same ascus were smooth); 11.7 x 11.7^{1}; 11.5 x 11.5^{1} smooth; 10 x 10^{2} smooth. Thirteen of the elongated spores were ovate; the rest were elliptical. A very few spores were flattened on the sides from the pressure of the ascus.

first snow-white, then developing a puffed-up, grayish white, tough stroma which becomes thickly studded with bright coral-red perithecia in about eight days from the sowing of the ascospores. Steamed sterile potato has proved a very suitable medium for the growth of this stage of the fungus, the perithecia becoming ripe and discharging their spores copiously in two to three weeks from the sowing of the ascospores. In a number of instances the cycle from ascospores round to ascospores (ripe and discharged from the perithecium) was as short a time as twelve days and twenty hours. These ascospores were all taken from perithecia found on stems of the cowpea.

Perithecia have also been grown from 150 or more microconidia (Pl. I, 7). They were isolated by the poured-plate method, the material being derived from an agar culture about two weeks old which was made from ascospores. The perithecia developed on five different media, viz, agar, banana, onion, carrot, and potato. On the first three media they appeared sparingly; on the carrot and potato they were abundant and appeared in about two weeks. The ripe ascospores were either shot out of the perithecia against the walls of the test tubes in such numbers as to make distinct brown patches or else were slowly extruded, crowning the ostiolum with irregular brown balls and clumps of spores (Pl. I, *1 a*).

So far as known to the writer, this is the second time perithecia have been derived from the conidial fructification of any Hypocreaceous fungus. Brefeld and von Tavel do not record any such case. On the contrary, only three such cases are mentioned by them for the whole group of Ascomycetous fungi.[1] Klebs has since recorded this for *Eurotium repens*, and Hugo Glück, in 1895 (Hedwigia, p. 254), reported it for *Nectria moschata*, which he obtained in about four weeks from pure cultures of the sickle-shaped conidia of *Fusarium aqueductum*, in water and plum decoction to which oak wood and bark had been added. Very likely Brefeld's numerous failures are to be attributed to the fact that he used his "Nährlösung" too exclusively, i. e., did not vary his culture media widely enough, so as to more nearly imitate natural conditions.

On the contrary, the conidial stage of the watermelon fungus (spore taken in July from the interior of a vessel) has been cultivated for five years on a great variety of media, including potato, without showing a

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[1] "As many yeast conidia remain under cultivation through endless generations always the same, so ordinarily the spores from conidiophores yield, in pure cultures, always the same conidiophore; those of pycnidia always the same pycnidia. In like manner many oidia, under certain conditions, never produce anything else than oidia. Only in rare cases has it been possible to obtain the ascus fructification from the spores of an accessory fruit form. Of this the Penicillium [crustaceum] spoken of in the second Heft of this work remains the most interesting example. Additional examples are *Endomyces Magnusii* and *Diaporthe controversa*.

"Up to the present time little is known of conditions governing the development of the ascus fructification. Observations in nature frequently show its dependence on a certain duration of development, on the time of year, and on a definite substratum."—Brefeld and von Tavel: Untersuchungen, Heft 10, p. 349.

trace of perithecia, although from time to time special efforts were made to find a substratum which would lead to the production of perithecia. This is the strain of fungus which has proved so actively parasitic in the hands of the writer.

On agar and on potato the perithecia of the cowpea fungus showed a distinct tendency to be larger than on the host plant, owing probably to extra good nutrition. The diameter of the largest on nutrient agar ranged from 320 to 376 μ. The diameter of the largest on potato ranged from 360 to 416 μ. The perithecia on the potato were exceedingly numerous, sometimes as many as 5,000 developing on an area of not more than 15 or 20 square centimeters. They were much less numerous on the slightly alkaline meat infusion peptone agar, and ripened and developed their bright red color much more slowly. On certain other media the peridium remained nearly colorless or the perithecia failed altogether to develop, although the fungus was under the same conditions except as to the substratum. Numerous cultures on a great variety of media have shown that the presence or absence of a stroma is entirely a matter of the substratum.

No attempts have been made to grow the ascospores from the similar perithecia which have been discovered on the dead stems of cotton and watermelon. No perithecia ever developed in any of the cultures made from internal or external conidia taken from the cotton or watermelon.

CONIDIAL FRUITS.

(1) *Microconidia* (Cephalosporium stage).—Colorless, oval to narrowly elliptical, straight or slightly curved, non-septate spores, 4 to 25 by 2 to 6 μ, borne singly one after another (Pl. III, *3*) on the ends of short branches of a mycelium, which fills the water ducts and interior parts of the *living stem* (melon, cowpea) with a dense growth that is pure white when seen in mass in the stem or when cultivated out on alkaline meat infusion peptone agar, or on other alkaline media, even rice; conidia frequently 1-septate (or rarely 2-septate) after abscission, in cultures often remaining in a little group around the end of the stationary conidiophore or becoming scattered when the latter elongates after having produced a group of spores, as is frequently the case (Pl. I, *7*, Pl. III, *4*), aerial or submerged (*Fusarium vasinfectum* Geo. F. Atkinson, described from cotton and okra; *Fusarium niveum* Erw. F. Smith, described from watermelon). None of the large, lunulate, 3 to 5 septate spores described below have ever been observed in the vessels of any of the host plants or submerged in fluids or solids.

(2) *Macroconidia* (Fusarium stage).—Lunulate; 3 to 5 septate spores, 30 to 50 by 4 to 6 μ (Pl. I, *9;* Pl. II, *7;* Pl. V, *3*), borne on the surface of *dead stems* in immense numbers on innumerable small, oval or hemispherical conidia beds which arise from the internal mycelium and consist of compact, irregularly branched, short conidiophores. Examined in water the single spores are nearly colorless; in mass they

are at first white, but very soon after the formation of the conidia beds they become colored, the *variable tint* ranging from pink, pale flesh color or pale salmon to deep salmon. When germinated in water or under acid or alkaline agar or in very moist air, producing conidia indistinguishable from those borne by the internal fungus (Pl. II, *10;* Pl. III, *11* in part).[1] Immature spores from the conidia beds are, of course, much shorter than the measurements given above, and for a time are non-septate or only 1-septate. When accidentally knocked off, such spores appear to be still capable of growth and septation. An effort was made to identify this external conidium with some one of the many described forms of Fusarium, but without success. The above measurements are derived from hundreds of spores and are believed to give nearly the limits of variability, but it would be quite possible to make half a dozen species of Fusaria from the material I have had in hand, if only a few measurements were made and a hasty description written out, as is frequently done. Indeed, there is no doubt that the literature of systematic mycology contains much of such rubbish. One has only to study critically a few members of this group and then turn to the descriptions in Saccardo's Sylloge Fungorum to be convinced of it. Not only is the identification of Fusaria from descriptions usually impossible, but very often with the specimens themselves the case is little better, owing to the fact that many Hypocreaceous fungi bear conidia which have been put into the form-genus Fusarium and which so closely resemble each other (see the plates in Vol. III of Tulasne's Carpologia, and in Heft 10 of Brefeld's Untersuchungen) that morphology alone is of very little assistance in their identification. In many cases, at least, the only safe way is to make cultures and inoculations if the fungus is a well-marked parasite; or to obtain the less

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[1] Old cultures of the internal watermelon fungus, when transferred from sterile horse dung to potato broth, produced, along with the small elliptical non-septate conidia, all sizes and shapes up to those which were lunulate, 3 to 4 septate, and 38 μ long, but none 50 μ long could be obtained in this medium, nor were any of them distinctly salmon colored. These cultures were all derived originally from a single non-septate microconidium separated out by the poured-plate method.

When hothouse watermelons were grown in soil infected with pure cultures of the internal melon fungus the macroconidial stage frequently appeared on the surface after the wilting and death of the plants. One of these big, lunulate, 3-septate, external conidia was separated from its fellows and cultivated for a long time, first in sterile horse dung and subsequently in potato broth, in the same manner as the preceding. The mycelium derived from this spore produced great numbers of microconidia, indistinguishable from those borne on the internal mycelium. At least three-fourths of the whole number of spores were of this type, but there were also plenty of typical macroconidia, spores 40 to 50 μ by 4 to 6 μ, lunulate, and 3 to 5 septate. Between these two extremes there were all possible gradations, showing clearly that little dependence can be placed on statements respecting shape and size of spores in the ordinary systematic descriptions of Fusaria. Color is likewise misleading, since the same conidia bed may be white, pinkish, pale salmon, deep salmon, etc., according to its age and the character of the substratum on which it has developed.

variable perithecia from pure cultures of the conidia, something we have not yet learned to do with any certainty; or, finally, to discover in nature the perfect fruit form and derive the other forms from it. So far as known to the writer, no Fusaria except those above mentioned have been described from cotton, watermelon, or cowpea; but even if they had, it would in the present stage of our knowledge be next to impossible to establish identity beyond reasonable doubt, since many species of Fusarium are believed to be purely saprophytic and are known to grow on almost any dead substance, and one such form has been discovered by the writer in Washington on a dead stem of cowpea in connection with the perithecia of a Nectria.

(3) *Chlamydospores*.—On the surface of the dead stems of the watermelon and in old cultures of the melon fungus on horse dung, globose, thin-walled, smooth, terminal or intercalary bodies appear, and in mass on the dung are brick red (Pl. III, *12*). These are part of the life cycle of the fungus and appear to be chlamydospores comparable with those of *Hypomyces solani* described by Reinke and Berthold.[1] They appear to have an outer and inner wall and germinate readily in water, but have not been studied as critically as the other spore forms. They were found in many test-tube cultures, and have been observed a number of times on the surface of the dead stems associated with the macroconidia. They are usually 10 to 12 μ in diameter, the extreme limits of those measured ranging from 7 to 15 μ.

(4) *Pycnidia* (?).—No pycnidia have been seen either on the host plants or in any of several hundred cultures made on a great variety of media. The cultures began in the summer of 1894 and are still in progress. The examinations on the host plants have included hundreds of dying and dead specimens collected in different years and in various localities from July to October. From these observations the writer believes he is warranted in concluding that there are no pycnidia in the life cycle of this fungus.

EFFECT OF MODIFICATIONS OF THE SUBSTRATUM.

The effect of modifications of the substratum on (1) the production of a stroma, (2) the color of the mycelium, (3) the color of the perithecia, and (4) the development of the perithecia, is described in the following paragraphs:

(1) *The production of a stroma*.—The insignificant subiculum on the host plants and the thick stroma on potato have already been contrasted. The limits of the stroma on potato are beautifully differentiated when thin cross sections are put into chlor-iodid of zinc. The starch-bearing cells of the substratum become blue, while the stroma becomes yellow, and the exact limits of fungus and substratum are easily distinguished. On ordinary nutrient agar the cowpea fungus produces only a feeble stroma. The addition of 1 per cent cane sugar

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[1] Die Zersetzung der Kartoffel durch Pilze.

to such agar increased the thickness of the stroma. The stroma was better developed than in the same agar with only 0.2 per cent sugar. In agar with 12 per cent cane sugar there was a great increase of this tissue, which formed a sort of monstrous stromatic mountain the whole length of the long slant. This ridge was 1 centimeter wide and fully one-half centimeter high in its highest parts. Its very irregular, tough, gray-white surface was covered with a thin layer of white aerial hyphæ, and 24 days from sowing was thickly set with colorless perithecia. The latter were, however, also visible at this time on the scanty, non-stromatic mycelium which had climbed up on the walls of the tube above the agar. The formation of perithecia in a similar way was also observed in other culture media. So far, therefore, as this fungus affords any basis for judgment, the stroma is one of the most easily variable parts of a fungus; consequently it appears hazardous to make separation of closely related forms into distinct species solely on the presence or absence of a stroma.

(2) *The color of the mycelium.*—The variability in color according to the nature of the substratum has been a subject of much interest to the writer. In the interior of the host plants the fungus is usually pure white, except in cotton, where the older mycelium is frequently brown. For a considerable time the writer supposed pure white was its only color, but trial of a variety of culture media brought to light some very unexpected and most astonishing facts.

The melon fungus is pure white on slightly alkaline nutrient agar. The fungus remained snow white for over a month on alkaline corn starch steamed in distilled water with asparagin added. In another series it was pure white for 11 days, but had become faint rose color on the fourteenth day and remained so up to the twenty-fifth day.

On boiled rice, with the addition of bicarbonate of soda, the fungus remained pure white for 40 days.

On crushed cowpeas, steamed in distilled water, the fungus made a copious growth from the start, but remained snow white as long as the cultures were under observation (10, 17, and 22 days).

The fungus was pure white in slightly alkaline, peptonized beef broth, and did not become colored on addition of cane sugar or of dextrin.

On acid, neutral, and alkaline nutrient gelatin the fungus made a pure white growth.

In acid potato broth the fungus was white for 11 days, except for certain hyphal strands which had climbed out of the fluid and were attached to the walls of the tubes. The submerged growth and the pellicle were pure white. The following acids were tried with this broth: Malic, oxalic, succinic, tartaric, and citric, 1 c. c. of the $\frac{1}{10}$ normal solution being added in each case to 10 c. c. of the broth. The behavior of the fungus was the same in each case, white on and in the fluid, with brown hyphæ on the walls above it.

On strongly alkaline litmus agar the fungus was white on the sixth day. During the first three days it had made a slow, poor growth, but it now covered the surface with a matted growth from which no hyphæ projected into the air. This medium consisted of 10 c. c. agar, 20 drops of saturated solution of sodium carbonate, and 2 c. c. of Sharp & Dohme's violet litmus solution. On the fourteenth day there was no reddening of the substratum and the surface was covered with a white mycelium, but some of the hyphæ threads which projected out into the air were bluish. At the end of 112 days the agar was nearly dry. It was still blue and was covered by a bluish-white film of fungus. On the glass above the agar many of the filaments of the fungus were now bright blue. This stain most probably came from absorbed litmus rather than from any pigment manufactured by the fungus.

In horse dung sterilized with distilled water the fungus made a white growth (some yellowish hyphæ).

On banana the fungus was white on the start, but in old cultures it was rose, salmon, or purple, and patches of it became bright orange buff.

In 42 days the fungus made a copious growth in the acid juice of Concord grapes, and its color varied from snow white or a very feeble tint (above) to purplish and rose color (below). For some days the fungus was barely able to maintain itself in this very acid medium, and was white, but at the end of 7 days the compact islands of mycelium were roseate. After 42 days the fluid was still strongly acid, and the red color persisted on litmus paper for some years. After 4 months the prevailing tints were white to reddish brown. The very numerous mycelial strands on the walls of the tubes above the medium were a fine red brown (between burnt sienna and tawny).

On Spanish onion cooked in distilled water the fungus made in 3 days a moderate growth, and its color varied from white to lilac (next substratum); in 5 days the fungus was purplish; in 8 days there was a distinct increase of purple and rose color, but there was no color in the substratum under the water. After 21 days the lower part of the onion in both tubes (that part under water) retained its natural yellow color, although a microscopic examination showed it to be grown full of the hyphæ of the fungus. At this time the aerial mycelium was white, rose, purplish, salmon, and brown (a few strands on the walls of the tube). At no time did any crimson color appear.

In 10 c. c. of Dunham's solution with 1 per cent malic acid the fungus filled the fluid and became bright rose color in 20 days, but the acquisition of the color was slow. The litmus reaction was still decidedly acid on the twentieth, thirty-fifth, and forty-fifth days. This experiment was repeated. In 13 days the mycelium was purplish. The addition of 2 per cent cane sugar to this acid Dunham favored vegetative growth, but did not increase the production of color or hasten it. On the fourteenth day in one tube and on the fifteenth in the other the fungus was still pure white. This experiment was repeated.

Sugar did not help on the formation of color, but rather seemed to retard it. The litmus reaction was decidedly acid on the twentieth and twenty-seventh days.

There was marked retardation of growth in Dunham's solution with 2 per cent cane sugar and 1 per cent sodium carbonate. After 20 days the fungus still seemed white, but the fluid was now slightly yellowish. There was less growth than in the acid Dunham. In Dunham's solution containing 2 per cent cane sugar and 0.4 per cent sodium carbonate there was a much better growth on the start than in the same medium with 0.4 per cent of malic acid substituted for the soda. At the end of 13 days the fungus filled the alkaline saccharine fluid and was yellowish brown; the fluid was also browned. The brown color in the mycelium was noticed as early as the eighth day.

The extreme upper part of the gelatin-tube cultures (the substratum) was finally stained rose brown.

In test-tube cultures 1 to 10 of November 27, 1894, on bread steamed in distilled water (5 consecutive days), the fungus grew luxuriantly. On December 18 the bread was nearly or quite covered and hidden by the fungus. In the top of the cultures where it projected into the air the fungus was snow-white. Farther down this pure white color shaded into yellows, purples, flesh tints, and reds, the predominating color being an irregularly distributed bright crimson. All of the tubes showed this crimson color, some more than others; several were very striking. There was less purple and more crimson than in the same fungus when grown on potato.

In 6 days, on pearl tapioca steamed in distilled water, the fungus was purple.

In 3 days, on crushed wheat steamed in distilled water, there was a copious growth and a bright purple seam where the fungus rested on the substratum. In 6 days from the inoculation the purple color had extended and a brilliant crimson was visible in the hyphæ bordering on that part of the substratum first attacked. The fungus resting on the wheat was purple, while the upper parts of the same mycelium were pure white.

In 3 days, on hominy steamed in distilled water, the fungus made a copious growth and developed an abundance of color. This was purple in the greater portion, but crimson in the oldest part. On the sixth day the purple color involved the upper half of the substratum in one tube and nearly the whole of it in the other tube.

The rice cultures proved particularly interesting. On the third day, in tubes of rice steamed in distilled water. there was a copious development of mycelium, which was snow-white in the air and purplish and crimson on the substratum. In 5 days the bulk of the culture was purplish to carmine. Even the aeriel mycelium was tinged. A little of the mycelium in the bottom of the tube and some on the walls of the tube above the rice was still colorless. After 20 days this crimson rice was stirred up in distilled water which became pink even when 20 to 30 c. c. was used with the contents of but one test-tube culture. This fluid was strongly acid to litmus. On filtering it through tissue paper it was colorless. On boiling it gave off a pleasant aromatic odor and litmus paper held in the steam was reddened. Most of the acidity passed away on boiling. The color of the unfiltered fluid changed from pink to purple on boiling in a sterile test tube. There was no change of color with 1 per cent chromic acid.

Six rice cultures were now instituted in test tubes as follows, each, with one exception, holding about the same quantity of the cooked rice: (1) Rice with 2 drops of saturated solution of sodium carbonate; (2) rice with 3 drops of the soda solution; (3) rice with 5 drops of one-half per cent solution of hydrochloric acid; (4) rice with 10 drops of this acid water; (5) rice made blue with 2 c. c. of violet litmus solution; (6) rice made blue by 2 c. c. of violet litmus solution and 2 drops of saturated solution of sodium carbonate. These tubes were all inoculated in the same way, from one of the crimson rice tubes just described, and were under the same cultural conditions. They will be described by number. In 2 days most of the mycelium in 1 was snow-white, but there was a slight purpling around two rice grains; in 2, which differed from the others in having only about two-thirds as much rice and was, therefore, nearly twice as alkaline as 1, the fungus was growing rather slower and was pure white throughout; in 3 there was a decided purpling of most of the fungus and of the rice grains which were touched by it; 4 was like 3; in 5, that part of the fungus projecting into the air was pure white, but the blue rice grains in the vicinity of the growing fungus had become bright purple; in 6 there was also some purpling of the rice grains attacked, but it was more restricted, and, as in 5, the bulk of the rice was bright blue. On the 6th day the condition was as follows: 1, fungus has made a good growth and some of it is pale purple to light rose, but there is not one-tenth as much color as in the tubes which received the acid; 2, the fungus has grown much within the last few days, but there has been no corresponding increase of the color, which is now a faint, scarcely noticeable rose or purple, i. e., there is not one-hundredth part as much color as in the acid tubes; 3 and 4, very brilliant and beautiful, the prevailing color, crimson, shading into rose and purple, but where the fungus projects above the culture into the air it is pure white, or shows only the faintest tinge of pale rose; 5, the upper one-half of the tube is filled with a copious growth of the fungus, and most of the blue color has disappeared, being changed below into violet and above into rose color, and brilliant purples and crimsons, but that part of the fungus which grows into the air above the culture is white to faint rose; 6, like 5, except that the lower one-half of the rice is still a pure blue. On the 9th day tubes 1 and 2 offered a striking contrast to 3 and 4. In tube 1 the fungus was becoming quite roseate over large areas, but none was crimson or purple; in tube 2 (which received twice as much alkali) the fungus had grown through all parts of the rice, and varied from snow white to a faint roseate color, which was scarcely noticeable. In 3 and 4 the starch grains were covered and hidden by the fungus, which was snowy only where it projected into the air above the culture. There were no purple hues, but the body of the culture varied from rose to crimson, the latter color predominating. There was now most crimson in the tube which received the most acid, but possibly this was accidental. In 5, all of the blue had disappeared, but the rice grains at the extreme bottom of the tube still showed a very little red purple. All the rest of the substratum was so closely invested by the fungus that the rice grains were hidden. The color of the fungus varied from rose color to the most vivid crimson, the latter color predominating, the only white part of the fungus being that which projected into the air at the top of the culture. In 6, which was more alkaline, a half cubic centimeter of rice in the bottom was still violet color, none was blue, and in other respects the culture was like 5. After 40 days 1 and 2 still showed the restraining effect of the soda. In 1, a little of the mycelium was now crimson, but most of it was only pale rose color; in 2, there was much less color than in 1, most of the color being pale rose, but with a little violet and a trace of crimson; the rice had shrunken from one side of this tube and the cavity was filled with white mycelium. In 3 and 4, crimson was still the prevailing color; both were shrunken away from the wall on one side, and in one tube white mycelium was beginning to fill the cavity. In 6, the lower one-third of the rice was now brilliant crimson, and the upper two-thirds, which had lost much water, was changed to dark purple and partly overgrown with white mycelium. The dark purple color and the crimson could be seen distinctly in the hyphal strands as well as in the rice grains themselves. In 6, at the end of 58 days, the entire mass was shades of violet, no crimson color remained, and the secondary superficial mycelium was white.

The above experiment was repeated as follows with five test tubes of rice boiled in distilled water: (1) Rice, with 3 drops of saturated solution of sodium carbonate; (2) rice, with 6 drops of the soda solution; (3) rice; (4) rice, with 5 drops of one-half per cent hydrochloric acid; (5) rice, with 10 drops of one-half per cent hydrochloric acid. All were inoculated at the same time in the same way and from the same culture. In 6 days there was a large amount of color in tubes 3, 4, and 5—rose, purple, and crimson. The color was as well developed in the pure rice as in the tubes which received the acid. Tubes 1 and 2 behaved much as in the preceding series. In 1, at the end of 14 days, the entire rice was invaded, and some of the mycelium was roseate to faint purplish, but there was not one-hundredth part as much color as in the acid tubes. In 2, the whole substratum was invaded, and the mycelium was white to faint roseate, there being about one-fourth as much color as in 1. On the twenty-fifth day, in 1, the color was much deeper than on the fourteenth, but it was still mostly white or roseate, there being very little crimson. In 2, the fungus was white to rose color, with occasional hyphal strands becoming crimson. The color had increased, but it was only about one-half as much as in 1. In 3, the body of the culture was a beautiful crimson mottled with purple. The color was lodged both in the substratum and in the hyphal strands. Where the rice had shrunken away from the wall a net work of white mycelium was growing out of the crimson mycelium and covering it. In the upper part of the tube, where the fungus projected into the air, it was also white, or rather, so nearly so that it appeared tinted only when taken out and massed on white paper. The conditions in 4 and 5 were like those in 3, except that there was no purple color. In both tubes the rice was shrunken away from the wall and white mycelium was filling the cavities. This contrasted curiously with the crimson hyphæ and rice grains from which it was growing.

A tube of litmus rice made much more strongly alkaline than the two previously mentioned was inoculated October 28, 1895. On November 14 the upper one-third of the rice (that best aerated) was thoroughly invaded by the fungus, the deeper parts being free, or nearly so. The fungus was snowy white. The rice grains invested by the fungus were changed from bright blue to a pale blue, but there was no purple or red color. This culture consisted of 15 c. c. cooked rice, 2 c. c. of violet litmus solution, and three-fourths cubic centimeter of a saturated solution of sodium carbonate. On December 5 the rice had lost all of its bright blue color, but there was no violet or crimson. The entire cylinder of rice was more or less overgrown and interwoven with the fungus, which was white; the rice grains in the upper part of the tube were greenish gray, and in the lower part a pale purplish rose.

In cutting through old dense conglomerated rice cylinders overgrown with the crimson fungus, the periphery was generally crimson, while the center of the cylinder was mottled, the exterior of the rice grains being red and their interior white. This seems to be another indication that the pigment requires an abundance of free oxygen for its development.

Three large Erlenmeyer flasks of rice were prepared as follows: (1) One-half pound of rice sterilized in several hundred cubic centimeters of distilled water; (2) one-half pound of rice boiled in several hundred cubic centimeters of distilled water, then knocked out of the flask and intimately mixed with one-fourth pound of c. p. calcium carbonate, and subsequently resterilized with more water; (3) one-half pound of rice boiled in several hundred cubic centimeters of distilled water, then 100 cc. of a saturated solution of sodium carbonate added, and the sterilization completed. These flasks were inoculated at the same time, in the same way, and from the same culture. In 48 hours the condition was as follows:

In 1, the fungus had begun to make a vigorous growth from four different centers of infection; color, purplish for the most part, but some crimson. Two rice grains which projected up above the general surface, and which were invested by the fungus, were wholly deep purple verging to crimson, while the hyphæ projecting from them were colorless (white).

In 2, nearly as much growth as in 1, but much less color, the hyphæ being white above and purplish where they rested on the colored substratum, but not crimson.

In 3, fungus pure white, but only a trace of growth; i. e., not one two-hundredth as much as in 1 or 2.

At the end of 13 days the condition was as follows: In 1 the surface was nearly covered with beautiful masses of crimson mycelium; the upper half of the rice was also invaded by the fungus and was mottled—white, purple, and crimson; 2, too much water in this flask, and fungus growth conspicuous only on the surface; no crimson stain, but some purple hyphæ; nearly all of the fungus was snow white; in 3, fungus snow white; there were now five small tufts of fungus on the surface of the rice, but the latter was too alkaline for a rapid growth. In 21 days the condition of No. 3 had much improved, the fungus being visible on a hundred or more of the surface grains of rice as a thin white hyphal layer. On the thirty-seventh day the fungus had increased noticeably in growth, and all of it was pure white, and the rice grains were also free from color. That the alkali did not simply mask the color was shown by the fact that when some of the fungus-infested rice grains from this flask were put into dilute hydrochloric acid there was no change of color. In flask 1 the fungus had not reached the bottom of the rice at the end of 21 days, but there were traces of it nearly to the bottom. The upper half of the culture (a large mass, it will be remembered) now varied from rose color to crimson, both the rice and the fungus, and was very showy. After about 40 days, during which the bright color increased in some parts and faded to purple in others, the top part of flask 1 was extracted with hot alcohol. The alcohol became brown-red and a bluish-violet residue remained. This brown-red alcohol became opalescent on the addition of water, but the precipitated color passed readily through a filter paper. The alcoholic extract faded slowly on exposure to light.

On another occasion some of the bright-red fungus was extracted with alcohol. In quantity the alcoholic extract was dragon's-blood red, and the residuum was blue-purple. The red alcoholic extract was rendered colorless by a few drops of strong caustic-potash liquor or caustic-soda liquor, but was not destroyed by liquor-ammonia fort., even when used in large quantities. The addition of a saturated solution of sodium carbonate did not destroy the color. It would seem, therefore, that two colors may be present—a blue and a red—the latter soluble in alcohol and easily destroyed by light and by caustic potassa and soda, the former insoluble in alcohol, more resistant to light and unaffected by alkalies.

The red fungus from a rice culture was tested with various reagents and the results are here given for comparison with those obtained with the red color of the perithecia, which are given below: *Strong ammonia*, exposure to the vapor, even for an instant, changes the red to purple; fragment still purple after 42 hours in the liquor; fluid itself slightly tinged. *Caustic-soda liquor*, red changed instantly to very dark purple, almost black; purple after 42 hours; fluid slightly tinged. *Caustic-potash liquor* (strong), red changed immediately to purple; after 42 hours still purple; lower one-third of the liquid reddish—i. e., much more decidedly tinged than any other alkaline fluid. *Sodium carbonate* (saturated solution), red changed at once to purple; purple after 42 hours, and the fluid no longer quite colorless. *Ammonium carbonate* (saturated solution), red changed at once to purple—it changes even in the vapor; purple after 42 hours; fluid as in the preceding—i. e., a very slight departure from colorless. *Chloral hydrat* (saturated solution), no immediate change unless to become brighter red; soon soluble; after 42 hours fluid still roseate; fungus dull red. *Sulphuric acid* (1 per cent), no change in 42 hours; fluid colorless, fungus red. The same result was obtained with 10 per cent sulphuric acid. *Nitric acid* (1 per cent), no immediate change, and none after 42 hours; fungus still red and fluid colorless. *Hydrochloric acid* (1 per cent), no change in 42 hours; fungus red, fluid colorless. *Acetic acid* (1 per cent), no change in 42 hours; fungus still red and fluid colorless. *Wood alcohol*, distinctly soluble; alcohol around the red fragments of fungus colored within a few minutes; after 42 hours fungus purple, fluid pale wine-red. *Ethyl alcohol* (common, 95 per cent), color soluble; the alcohol around the fungus became colored in a few minutes; after 42 hours fungus purple, fluid a pale wine-red. *Sulphuric ether*, no immediate action, but after an hour or two the ether was tinged; after 42 hours fungus purplish, fluid pale brownish-red. *Chloroform* (purified), no immediate change, and none after 1½ hours; after 42 hours fungus purplish, fluid pinkish-red. *Benzine* (purified), no change in 43 hours; fungus still red and fluid colorless. *Benzole*, no change in 1½ hours; after 43 hours fungus red to purple-red, and the fluid with a slight pinkish tinge. *Carbon bisulphide*, no change in 43 hours; fungus still red and fluid colorless.

One test was made to determine whether the fungus would produce its colors on uncooked rice in water. In 2 days a distinct purple color appeared on the rice grains infested by the fungus.

All of the above experiments relative to color production were made with pure cultures of the melon fungus.

Allusion has already been made in several places to the growth of white mycelium from colored, and vice versa. It happens very frequently that on mycelium of the same size and apparently of the same age one branch will be colorless (white) and another deeply stained (purple, red, blue, brown, yellow). The stained hyphæ were usually quite granular, but unstained hyphæ were also sometimes observed with granular contents. Went observed the same thing in Monascus (Ann. des Sci. nat. Bot. 1895, No. 1), and the writer has also seen it in that fungus.

The cowpea fungus also stains various starchy substrata, but the writer was never able to get as bright colors as with the melon fungus.

The red color of the perithecia is insoluble or nearly so in ether, chloroform, benzine, benzole, or carbon bisulphide. The color is very slowly soluble in ethyl and methyl alcohol, but decidedly more so in the wood alcohol than in the 95 per cent ethyl. That is, after 48 hours there was no change in the ethyl alcohol, and even after several weeks most of the perithecia were still bright red, although a few had faded; after 48 hours in the methyl alcohol the red perithecia (from a potato culture) were a little paler, and after several weeks a few only were pale red, most of them being pure white. In a saturated solution of chloral hydrat the color changed at once slightly, was dull orange-red in 15 or 20 minutes, yellowish-red in 2 hours, and dull yellow in 48 hours. In chlor-iodid of zinc the color soon changed to dark purplish red and then to brown. The mycelium and interior of the perithecia did not blue, but changed from white to yellow. In mineral acids (nitric, sulphuric, hydrochloric, chromic), strong or weak (weakest solution 1 per cent), the perithecia changed instantly from red to yellow and remained yellow. The same change took place in acetic acid, but required several minutes when a 1 per cent solution was used. In a saturated solution of ammonium carbonate the perithecia were purple at the end of 48 hours, but there was no visible change during the first 2 hours. In strong ammonia water they changed immediately to pansy-purple, and did not at once lose color, but were paler at the end of 48 hours.

A purplish stain has frequently been observed in the parenchyma of old dead stems of cotton, melon, and cowpea attacked and killed by this fungus, and this stain when subjected to certain solvents behaves in the same way as the red pigment of the perithecia.

The formation of purple or other bright colors in the substratum, and occasionally in the mycelium itself, appears to be common to many Fusaria. Schacht observed it many years ago (Prings. Jahrb., Bd. III, pp. 446–447). In potatoes attacked by wet rot he found the cavities lined by *Oidium violaceum* Harting. This lining was dark violet to blue black. This color he states to be due to the contents of the mycelium and to the effect of the latter on the substratum. On addition of sulphuric acid the mycelium and spores became rose red. This change, he thought, denoted conversion of starch into sugar, for it took place even inside of starch grains, and the color is similar to that which may be obtained with sugar, albuminoids (Eiweissstoff), and sulphuric acid. In dry starch attacked by the fungus and kept since 1855 he could, however, get no reduction of the copper on warming in Fehling's solution. *Oidium violaceum* appears to correspond to the chlamydospore stage of Neocosmospora. Schacht states that it is only one stage of *Fusisporium solani*, he having found both spore forms attached to the same mycelium.

K. Klein (Beitrag z. Kent. d. rothen Malzschimels, Mitt. d. österr. Vers. Stat. f. Brauerei u. Mälzerei, Wien, V, 1892) has also found a Fusarium causing bright color reactions on starchy media, but I have not seen his paper.

My conclusions relative to the formation of color by the melon fungus are as follows:

(*a*) On neutral or acid media in the presence of free oxygen and of starchy foods—e. g., potato, bread, rice, tapioca, wheat, hominy, cucumber agar, etc.—this fungus develops in the substratum a series of the most brilliant colors (Pl. I, *13*), which are then absorbed by the hyphæ. These hues include many shades of pink, red, purple, and violet, and in some of the substrata—e. g., bread or boiled rice—are particularly brilliant, changing gradually from shades of purple and rose color into the deepest crimson (rose carthamine). This color is much brighter and purer than any I have been able to obtain with Went's *Monascus purpureus*. During the development of this pigment the substratum becomes intensely acid (mostly CO_2, but some lactic acid according to Mr. K. P. McElroy). If, however, alkaline substances (caustic lime, carbonate of soda, etc.) be added to the substratum in advance, so as to neutralize the acid or acids as fast as formed, no color is developed, the fungus remaining snow white, as in the vessels of the melon plant. If less alkali be added, the colors appear gradually after a time, which is longer or shorter according to the amount added.

(*b*) The yellow and brown colors are formed in the presence of an alkali, but apparently not unless sugar is also present. According to the writer's view, the brown stain of the lignified walls of the vessels is due beyond question to the presence of this fungus. Since the lignified walls are much more apt to be stained than the pure cellulose walls, it would seem as though the presence in the lignified wall of coniferin or of some related substance may have something to do with the production of the brown stain. The vascular bundles in melon, cotton, and cowpea contain a distinctly alkaline fluid and the fungus is able to dissolve its way through cellulose walls. If it should also be able to split up coniferin, or some similar glucoside, held in the walls of the vessels, with the liberation of a sugar, then a brown stain might perhaps be formed just as readily inside of the plant as in the alkaline peptone water to which cane sugar was added.

(3) *The color of the perithecia.*—No white-walled or colorless perithecia have ever been observed on any of the host plants. All have been bright red. They have also been red on a variety of artificial media, particularly those on which they have grown best—e. g., steamed potato, crushed wheat, malic acid agar. Red must therefore be assumed to be their natural color.

The color of the peridium is, however, much more easily modified than that of the ascospores. The latter have always remained brown, no matter on what medium grown; the former have not always developed a red color. In a few instances the writer has succeeded in growing perithecia of the cowpea fungus to maturity, and the shedding of ascospores, without the development of any red color in the peridial wall. In a number of other cases the red color has been very slow to appear. It is thus established beyond doubt that the color of the peridium of a species may be entirely a matter of the particular substratum on which it happens to be growing. The principal differences observed in my cultures are given below:

(1) On steamed potato the fungus fruits copiously, the color of the peridium comes quickly (sixth to ninth day), and is first roseate, then bright coral red. The ascospores are mature in two to three weeks. By the sixth day the substratum has changed from white to dark lead gray. In one instance only (out of a great many) on the upper (dry) end of a potato culture 10 days old many perithecia were still nearly colorless.

(2) On pearl tapioca steamed with distilled water the fungus grows slowly[1] and fruits sparingly; the color of the peridium comes slowly, being first pale red and finally *black*. At the end of 2½ months most of them were destitute of necks, but a few of the black perithecia in one tube had distinct necks. Some of the blackest were removed and examined microscopically. They contained no ascospores or asci. The peridium was brown, but normal in structure. The interior of the perithecia was very full of oil. Some substance necessary to the formation of ascospores appeared to be wanting in this substratum.

(3) On yellow banana steamed with distilled water the fungus grew slowly and fruited only after several weeks, but then copiously. At the end of 5 days there was not one-fiftieth as much vegetative growth as in corresponding tubes of potato. The perithecia were pale yellowish red. None were bright red, and some were nearly colorless.

These remarks apply to two cultures made November 13, from the same culture, and examined December 16. In other cultures the perithecia were ochraceous buff at the end of 20 days. On January 23 the two tubes of November 13 were reexamined and found to be quite unlike. In one the perithecia were now coral-red, had decided necks, and were discharging ascospores—i. e., protruding them through the ostiolum in brown masses. In the other tube, the shape and the color of the perithecia were both aberrant. This culture was covered all over with perithecia, but these were globose and destitute of necks; a few were pale coral-red, but most were yellowish brown to dark brown. In the darker ones the structure of the peridium could not be made out without crushing the perithecium. There were no ascospores in this culture, not

[1] The amount of growth at the end of 8 days was not one one-thousandth as much as on potato.

even in the dark-brown perithecia. One of the darkest perithecia was crushed in water. It contained no asci, but every cell was filled with oily looking globules which blackened with osmic acid. Here we have the substratum causing change in color, change in form, retardation of the production of asci, and the storage of large quantities of reserve material. Most of the old banana cultures resembled this one rather than the preceding. The dark brown or black color was lodged in the walls of the peridium. The oily granules gave a milky appearance to the crushed contents. In some of these tubes certain microconidia were also observed to have changed into round spores. In all, 17 banana cultures were under observation, and for a long time. The one first mentioned seems to have possessed a trace of some substance wanting in the others, and which finally enabled the fungus to fruit normally.

(4) On Spanish onion steamed in much distilled water the fungus fruited slowly, but finally quite freely, the perithecia being pale red to bright coral-red.

(5) On commercial (alkaline) cornstarch steamed in distilled water the fungus grew sparingly and fruited sparingly. At first the perithecia were pale red to coral-red, but after a month they were dark—i. e., almost as black as on the tapioca. Even after $2\frac{1}{3}$ months there were very few perithecia. Some were pale red, but most of them were dark brown, especially the older ones. There were no asci in these dark-brown perithecia, but great quantities of oil globules. The mycelium was also modified. The latter was extremely variable in thickness (1 to 13 μ), irregular, much inclined to form swollen places and globose ends, or moniliform chains or clumps of big rounded cells. It was also densely packed with refringent globules. In two of the black perithecia which were crushed in water the peridial wall was brown under the microscope, but normal in structure.

(6) On crushed wheat steamed in distilled water the fungus fruited quickly and copiously, but the perithecia were duller red than on potato. In 8 days the surface was densely packed with dull-red perithecia. At the end of a month some of them which were discharging ascospores were nearly colorless, while others, also discharging ascospores, had a tinge of purple (not red). Other large clumps, which appeared to be full grown, were entirely without color—i. e., a dirty white. Most, however, were colored on this substratum. At the end of $2\frac{1}{3}$ months there was a copious protrusion of ascospores. Nearly all of these were globose, brown, with a thick wrinkled epispore, and were 11 to 13 μ in diameter. The interior of these spores was guttulate. A very few of the ripe spores were: (a) smooth, (b) broadly elliptical, (c) ovate. Several hundred were examined in vain for a septum. At this time the walls of many of the perithecia, protruding spores, were nearly colorless—very pale red or yellowish white.

(7) On hominy steamed in distilled water the fungus fruited slowly

and in moderate abundance. In 16 days the entire substratum was dark purplish red: the perithecia, yellowish red. At the end of a month the perithecia were of good size, but many of the ripe ones (discharging brown ascospores) were colorless or pale yellow and the rest were yellowish red. None were coral-red or bright red of any shade, and the majority were pale yellowish white—i. e., different enough to be considered another species, as species are often made. After 2⅓ months one of these cultures was still very interesting. The cylinder of hominy, which was now about 3 centimeters high, had shrunk away from the walls of the tube and its surface bore about a thousand normal-shaped perithecia. A majority of these had protruded ascospores which adhered in irregular brown masses to the top of the neck around and over the ostiolum. The striking fact was that *not one of these ripening and ripe perithecia was red; all were pale or dirty yellowish white*, including those crowned by the ascospores. Another culture of the same date and kind was exactly like this one, except that it contained about twice as many perithecia, not one of which was red; all were dirty or pale yellowish white. Many were shedding ascospores, but not so large a number as in the preceding tube. Nothing could be plainer than that the fungus was unable to extract a red color from this substratum; still it was able to ripen its ascospores normally.

(8) The color of the peridium was very slow to appear in perithecia on alkaline agars, and on the same with the addition of cane sugar. After 75 to 85 days, only a few were bright red, while many were colorless or only faint roseate or yellowish.

(9) On rice steamed with distilled water (5 drops of very dilute hydrochloric acid added to each test tube) the substratum was dark purplish red at the end of 16 days, except for a few white grains which projected above the rest. The perithecia were numerous and full size, but ranged from colorless to yellowish red. None were vermilion or coral-red. On the surface of a thick rice gruel no perithecia had formed at the end of 24 days. The body of the gruel, which was in a small Erlenmeyer flask, had become dirty white; its surface was mottled brown and pale rose color. At the end of 38 days the body of the rice was light écru drab, with possibly a trifle of rose color in it. The surface was thickly spotted with brown flecks, the largest of which bore numerous reddish-brown perithecia. In a few places white hyphæ were pushing out into the air in small numbers. At the end of 65 days the fungus in this flask had formed a nearly continuous dark-brown surface mat, which bore numerous perithecia, some of which had shed ascospores. The color of the peridium varied from pale yellowish brown to reddish brown, and even to dark brown. The body of the rice was rather feebly stained—vinaceous cinnamon mixed with a little vinaceous pink.

(4) *The development of the perithecia.*—By the use of strongly alkaline media the writer found it possible to entirely prevent the formation of

perithecia in the cowpea fungus, although the vegetative growth and the formation of the microconidia continued. This is the more remarkable because on all ordinary media the fungus showed the strongest tendency to form perithecia, even when it was unable to ripen its ascospores. The results obtained are as follows:

(1) In 92 days, on strongly alkaline beef-broth peptone agar, copiously inoculated with fresh ascospores, there was no trace of perithecia. This media consisted of two test tubes of standard nutrient agar (stock 82a). One of them, which contained 10 c. c. of agar, received 10 drops of a saturated solution of sodium carbonate (temperature 25° C.), and the other, which contained 8 c. c. of agar, received 4 drops of the same soda solution. Each was resteamed on 3 consecutive days. Boiling with this alkali caused a heavy precipitate in each tube and a dark color in the agar which received the most soda. Growth appeared first in the tube which received the least alkali. Neither showed any for the first 3 days. On the sixth day the slant surface of each was spotted all over by the fungus. Growth, however, in each was sparing, considering the number of ascospores used and the time which had elapsed. In the tube which received the least alkali the growth was whiter, and there was more fungus in the air than in the other tube, where the growth was mostly in the substratum. At the end of 10 days, in the tube which received the most alkali, the surface was gray-white, with scattered white flecks. The growth of the fungus was still mostly in the substratum and was not copious enough to hide the surface of the agar. The tube which received one-half as much alkali presented the same general appearance. At the end of 26 days both tubes were almost exactly alike; the entire surface of each was covered with a grayish stroma sparingly flecked with white. In other words, the growth of the fungus, while not so prompt as on neutral or feebly alkaline agar, was not prevented by the strong alkali. At the end of 51 days in both tubes the mycelium showed a marked tendency to break up into iso-diametric, or nearly iso-diametric cells, constricted at the septa and rounded in the middle. In both tubes microconidia were now abundant, and it was thought that possibly perithecia might develop later on, as there appeared to be tiny hyphæ-complexes in some of the mycelium, which had crept up out of the alkali bed and was now growing on the walls of the tube.

These cultures were started November 30, and up to January 24 they were exactly alike; that is, the surface was covered all over by the fungous stroma, which was grayish white and bore numerous microconidia, but no perithecia. On this date 2 c. c. of a sterile 2-per-cent solution of malic acid was pipetted into the tube which had received the least alkali. *In 10 days 1,500 unripe but well-developed and bright coral-red perithecia made their appearance.* The whole surface of the corresponding tube (alkaline agar) was covered with a grayish-white sheet of fungus, mostly in the agar (stroma), and it still bore an abundance of microconidia, *but there was not a single perithecium.* Up to the ninety-second day, when the experiment was lost, not a single perithecium had formed on this alkaline agar. No contrast could be more striking, except possibly the following:

(2) On the best medium known to the writer for the abundant and rapid production of perithecia, viz, potato steamed in distilled water, the development of perithecia was altogether prevented by the addition of carbonate of soda. A copious stroma was formed, and there was an abundant development of microconidia, *but in 76 days there was no appearance of perithecia.* These cultures were on potato cylinders steamed in test tubes with 2 c. c. of water and 1 c. c. of a saturated solution of sodium carbonate. A second set of tubes was prepared in the same way, but received less alkali (about one-half as much). For comparison, cylinders cut from the same tuber were steamed in a strong malic-acid water. The acidified cylinders were white; those steamed with the alkali were uniformly brown. The three sets were inoculated at the same time (December 16) copiously with ascospores from the same culture. On the fourth day there was a much better growth in the acid tubes; growth in the alkaline tubes was sparing and only to be detected with a hand lens.

On the tenth day the fungus in the alkaline tubes had made a pure white but very restricted growth, varying in area from one-half to 1½ qcm. In the tubes which had received the least alkali there was a stroma and an abundance of microconidia, but in none of the four was there any trace of perithecia. On the malic-acid substrata the fungus had now entirely covered and hidden from sight the whole of the large potato cylinder with a wrinkled stroma. This bore in each of the four tubes several thousand perithecia, which were already rose color or bright coral red. The acid appeared to have favored rather than hindered their formation. On the seventeenth day the entire surface in each of the acid tubes was so thickly studded with bright coral-red perithecia that there seemed to be no room for any more. These tubes were now no longer acid, although strongly so when inoculated. Each of the four cylinders was tested. There was no trace of acid reaction in two, and in the other two it was extremely faint and limited to the bottom part of the cylinders, which was the last part to be invaded by the fungus. It would therefore appear that the fungus consumed it as food. On this date, on each of the alkaline cylinders, the fungus had formed a stroma, which was gray-white, wrinkled, and mealy from the presence of great numbers of microconidia. In the tubes which received the most alkali the stroma covered about one-fourth of the surface and there were no perithecia. In those which received less alkali it covered about four-fifths of the cylinder in one tube, and only about one-twentieth in the other. In both of the latter perithecia were forming in small numbers, and were first visible on the fifteenth day. The tube containing the smaller stroma was now opened and the cylinder removed. It smelled like a soap barrel. The interior of the cylinder and of the stroma were alkaline, and also the beads of water excreted from it. There were very few perithecia. On the twenty-fifth day the remaining tube, which received the least alkali, was fruited rather sparingly, and the perithecia were red, but not ripe. In places the stroma was brown and destitute of perithecia; in other places it was grayish-white and destitute. In the tubes which received the most alkali the potato was now covered with a copious, puffed-up, tough, wrinkled, extensive stroma, which had become brown (color of of ascospores) since the last record. Some of this stroma was dug out and examined. The brown color was lodged in the walls of a closely felted mycelium. From this brown mycelium projected many short, colorless hyphæ, and these bore numerous non-septate, colorless, elliptical microconidia. Here and there were small masses of pseudoparenchyma, probably the beginnings of perithecia, but nothing large enough to be distinguished by shape, even under the compound microscope, as perithecia by anyone not conversant with the method of origin of these bodies. In other words, the alkali did not hinder a copious development of stroma and an abundant formation of microconidia, but did hinder the growth of the perithecia. At the end of 47 days, during which there had been no development of perithecia in either of the tubes which received the larger quantity of alkali, one of them was opened and 4 c. c. of sterile 2 per cent malic acid water pipetted into it. At this time the potato was covered all over and hidden by a copious wrinkled stroma, which was brown on one side and about normal in color on the other. The next day (February 1) the acid was entirely neutralized, and the fluid around the cylinder still gave a distinctly alkaline reaction, although less than before. The mouth of the tube was now flamed and the fluid poured out. On February 5, as soon as it could be prepared, 5 c. c. of sterile 1 per cent malic acid water was added to this tube, i. e., enough to cover the cylinder. On testing with litmus after adding, the fluid gave a strong acid reaction. On February 6 there was no reaction to blue litmus, but a slight alkaline one with neutral litmus. An additional 5 c. c. of the 1 per cent malic acid water was therefore added, and in a few minutes bubbles of gas again began to arise. On February 7 the fluid was again tested, found plainly acid, and poured off. The cylinder was not, however, fully neutralized, for on February 10 the small amount of fluid in the bottom of the tube was again plainly alkaline. The cylinder was therefore covered once more with 6 c. c. of sterile 2 per cent malic acid water. This was poured off after 24 hours and the tube set away. Up to February 15 there were no perithecia visible in this tube, although it had been 62 days since the tube was inoculated and 5 days since the last of the alkali was removed. Ten days later, however, the stroma (both the brown and the yellow parts) was slightly frosted over with white hyphæ, recently formed, and bore several hundred pale coral-red perithecia, while many others were developing and were still white. The companion tube was free from perithecia and remained so until the end of the experiment (76 days). At this time the fungus in the tube which had received only one-half as much alkali had developed perithecia all over the potato, but they were still immature and either colorless, yellowish, or pale brown.

(3) In 40 days on rice with bicarbonate of soda there was no production of perithecia, although the tube had been copiously inoculated with ascospores. The tube contained 10 c. c. of rather dry boiled rice, to which was added 2 c. c. of a cold saturated solution of the sodium bicarbonate in water. In 5 days there was only a very feeble white growth. At the end of 40 days the fungus had grown sparingly over most of the rice grains in the upper half of the tube, and microconidia were present, but the rice had not changed color and no perithecia could be found.

OTHER BIOLOGICAL PECULIARITIES.

In addition to what has already been said, there are a few other peculiarities which may here be mentioned.

The fungus in all its varieties is a strict aerobe. Up to this time the writer has never been able to find any substance in the presence of which it will grow in the closed end of fermentation tubes. It seems entirely unable to obtain its respiratory oxygen from food substances.

The melon fungus is able to obtain its nitrogen from asparagin. In carbohydrate foods nearly destitute of nitrogen, and in which the fungus could make but a very feeble growth, it at once made an excellent growth on adding a small fragment of asparagin.

Old rice cultures of the melon fungus gave off a peculiar, rather pleasant, aromatic odor when boiled in water.

On boiled seeds of the cowpea the melon fungus grew vigorously and developed a peculiar musky, pungent odor, which was observed as soon as the tubes were unplugged and was quite unlike that just mentioned.

The melon fungus grew vigorously on potato and nutrient agar which was sterilized with a large quantity of sulphur dust.

The melon fungus grew on nutrient agar in the presence of large quantities of caustic lime and of carbonate of lime.

The melon fungus also grew (at first very slowly and in small patches) in a flask of boiled rice in the presence of very large quantities of sodium carbonate (one-half pound of rice cooked with about 300 c. c. of distilled water and 100 c. c. of a saturated solution of sodium carbonate, saturation temperature 25° C.). The quantity of alkali was sufficient to make the rice quite yellow.

In a test-tube culture, the cowpea fungus grew on a cylinder of potato which had been boiled with 2 c. c. distilled water and 1 c. c. saturated solution of sodium carbonate (25° C.). After steaming, one-half of the fluid was poured off, so as to expose part of the potato to the air, and the surface was inoculated with ascospores.

Both the melon and the cowpea fungus grew in nutrient gelatin (+40, +20, 0, and —20 of Fuller's scale), but without liquefaction. The melon fungus grew rapidly on glycerin agar.

In Dunham's solution with 2 per cent cane sugar and 0.2 per cent sodium carbonate the melon fungus made more growth than the cowpea fungus (ascospore strain). After 13 days the former filled the tubes (10 c. c. portions), while the latter had made only a trifling growth on the bottom of the tubes. In each the fungus was browned.

Both the melon and cowpea fungus made a very insignificant growth on dried figs steamed in distilled water, the very sweet substratum appearing to be unsuitable for growth.

In acid media, such as the juice of ripe Concord grapes, the growth of the melon fungus was much retarded, but it finally overcame the inhibiting substances.

The melon fungus grew well in sterilized horse dung and feebly on rotten wood (soft maple destroyed by wood fungi).

Bordeaux mixture sprayed upon young melon vines in no way checked the spread of the disease.

Carbonate of copper mixed with carbonate of lime and put into the hills at planting time, or soon after, did not protect either cotton or melon plants.

HOST PLANTS.

Neocosmospora occurs on cotton (*Gossypium herbaceum* and *G. Barbadense*), watermelon (*Citrullus vulgaris*), and on cowpea (*Vigna sinensis*). It probably occurs also on okra (*Hibiscus esculentus*), although the identification is not complete, depending solely on the character of the symptoms, on the presence of similar macro and microconidia, and on the occurrence of the disease in the same localities, no cultures or cross inoculations of the okra fungus having been made and no perithecial fruits having been discovered.

HABITAT, TIME OF OCCURRENCE.

This fungus lives from year to year in the soil. It is peculiarly a soil organism, always attacking the plant from the earth. The internal conidia (Pl. II, *8*, *11;* Pl. V, *4*, *6*) occur in the vessels of the living plant throughout the growing season, causing the disease known as "blight" or "wilt"; the external conidia (Pl. I, *9;* Pl. II, *7;* Pl. V, *3*), whenever plants have been killed by the internal fungus; the perithecia, from August to November.

GEOGRAPHICAL DISTRIBUTION.

All stages of the fungus have been found by the writer at Monetta, S. C., on watermelons and cowpeas (1894 and 1895), at Charleston, S. C., on cotton and cowpeas (1895), and near Kingstree, S. C., on cotton (1895). The conidial stages have been found by the writer at Charleston, S. C., in okra and watermelon (1895), and at Chuckatuck, near Norfolk, Va., in watermelon (1898). Diseased watermelon plants containing the internal fungus were also received from Lykesland and Gurley, S. C. (1896), Pelham, Ga. (1895), and from Pepper Grove near Galveston, Tex. (1895). The cotton disease was also received from western Georgia in 1894. In addition, Professor Atkinson, in 1892, reported cotton disease associated with his *Fusarium vasinfectum* from seven localities in Alabama, and from Pine Bluff, Ark. The melon wilt was also reported to the writer in 1895 from Ocean Springs, Miss., by Prof. F. S. Earle, who stated that it had been in that vicinity for at least six years, and that in one instance it destroyed nearly an entire crop of melons. These melons were on land where melons formerly wilted to a slight extent and which had been in pasture for two years.

Finally, Mr. Wm. A. Orton found the cotton and cowpea disease at Dillon, S. C., in 1899. The cotton blight was pretty uniformly distributed over one 5-acre field. He also found it to a lesser degree in many other fields, and it was reported to be generally prevalent in that region.

This fungus, therefore, is widespread in the Southern States. It is to be looked for all the way from New Jersey to Texas, although it has not been definitely settled that it occurs north of southeastern Virginia or west of Arkansas. With exception of the one place in Arkansas it occurs, so far as known, only in the Atlantic Coast and Gulf States. It is specially to be searched for in New Jersey, Delaware, Maryland, and West Virginia, and in northeastern North Carolina, where a destructive watermelon disease of unknown origin was very prevalent about ten years ago. No account of this disease has come from any part of the Old World.

PARASITISM, INFECTION EXPERIMENTS, ETC.

This fungus is an active parasite and destroys a great many plants by first plugging the water ducts and afterwards invading the parenchymatic tissues. In case of the watermelon, the disease due to this fungus is so prevalent in places as to destroy large fields, and to threaten the extinction of melon growing for market purposes, notably at Monetta, S. C., Pelham, Ga., Chuckatuck, Va., and Galveston, Tex. The cotton fungus is also spreading from year to year, and has already spoiled many acres of valuable land on the fertile coast islands of South Carolina. Last year one large grower of sea-island cotton wrote that he had been compelled to stake out and abandon 15 per cent of his best cotton land, all of which is tile drained and under a high state of cultivation.

The fungus winters over in the soil and enters the plant through its underground parts. It first fills the vessels (Pl. I, *10*, Pl. IV, and Pl. V, *6*), causing, especially in melon vines, a sudden wilt of the foliage. Subsequently, as the plant dies, it invades all of the softer tissues and fruits on the surface (Pl. I, *11*, *12*, Pl. II, *6*). The internal fungus always precedes the external one, i. e., the external fungus has been found only on plants which have been killed by the internal one, and it almost always follows the latter, so regularly, indeed, as to be at once suspected of forming a part of the life cycle of the parasite. Several hundred plants each of melon, cotton, and cowpea in early stages of the disease, in different years and from different places, have been examined microscopically, and in every case the fungus was found plugging the vessels in quantity sufficient to account for the disease, and it had not yet invaded the parenchyma. In cowpeas, prior to their death, it is usual to find the fungus occupying the vessels of the xylem and browning their walls the whole length of the plant and not simply near the earth. In old, wilting melon vines (still alive and not showing any surface fungus), the internal fungus has been found in vessels of the stem 2 to 3 meters from the root, but, in the earliest stages of infection (the earliest yet observed), the fungus is found only in the vessels of the root and extreme base of the stem (hypocotyl). Many cotton, okra, melon, and cowpea plants further advanced in disease have also been examined microscopically. In the interior of these plants, both in the vessels and in parenchyma cells, there was an abundance of mycelium bearing great numbers of the small, colorless (white), elliptical microconidia, and at the same time, on the outside, on the salmon-colored conidia beds, enormous numbers of the big, lunulate, 3-to-5-septate macroconidia, the hyphæ of the fungus being readily traceable outward from the plugged or partially occupied vessels of the plant to the conidia beds on the surface. In early stages of the disease no external spores or hyphæ of this fungus are ever present, and the internal fungus is restricted to the vessels and connective tissue of the bundles, i. e., the non-lignified living parenchyma between the bundles is not yet invaded (Pl. I, *10* and Pl. IV). The arrangement of the external conidia beds in rows is due to the fact that the fungus comes to the surface of the dying plant along the lines of least resistance, that is, between the strands of thick-walled bast fibers. If the external fungus were an independent parasite or saprophyte due to aerial infections, the sporodochia would be scattered irregularly over the surface and not arranged in parallel rows, alternating with the strands of stereome, and always preceded by the internal fungus.

The same conclusion respecting the genetic relationship of the external and internal conidia has been reached as the result of plant-infection experiments, the watermelon being used for this purpose. More than one hundred and seventy-five typical cases of the melon wilt have been obtained in hothouses in Washington by simply burying a little of the melon fungus in the soil of the pots. On microscopic examination the fruiting fungus was found in the vessels of nearly every one of these plants (all examined) in such quantity as to readily explain the wilt. The soil and water were not sterilized, but under the circumstances this was not necessary. The soil was from Washington where this disease does not occur, and melon plants grown in quantity in the same hothouses, in the same soils, and watered with the same water, subject, in a word, to the same conditions except as to inoculation, did not contract the disease. These experiments were in progress parts of two seasons. In many pots of the inoculated soil every plant contracted the disease within a few weeks (Pl. IX, *1*). With two exceptions[1], not one case of the disease appeared in the uninoculated soils, although several hundred check plants were grown in the latter.

During the course of these inoculation experiments, which were performed in 1894 and 1895, it was found to be as easy to produce the melon wilt with mycelium derived from the external conidia (Pl. X) as with that derived from the internal conidia (Pl. VIII). The usual method of infection was by putting a little fragment of a pure culture of the fungus into the soil at some distance from the plant and at no great depth, so as to avoid breaking the roots. The wilt usually appeared suddenly in three to six weeks, whichever spore form was used for infection. The internal fungus in the vessels of the plant was the only one to be found at the time of the wilt, but later when the plant was dead the external conidia beds often appeared, and always if the air was not too dry. These infection experiments were repeated several times on a large scale with uniform results. Those with the two sorts of conidia were conducted in different greenhouses, with very great care, and, exclusive of the 4 cases already mentioned as occurring late in the course of two of the experiments, the numerous control plants in all cases remained healthy.

NUMBER OF SUCCESSFUL INFECTIONS.

Altogether more than 500 successful infections have been obtained with watermelon plants by simply inoculating the soil with the melon fungus, the above-mentioned 175 cases not including those obtained in 1896 and 1897 and described in the following section. All varieties of the watermelon appear to be susceptible. No attempts have been made to induce the disease by inserting the fungus directly into wounds, except a few futile ones made in the fields in South Carolina, when the disease was first discovered.

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[1](1) One case which appeared late in the course of the experiment (internal conidia, 1894) and the only plant out of many checks to contract the disease, although all were on the same bench and cockroaches ran about in the house.

(2) Three cases which appeared late in the course of the experiment (external conidia, 1895). These were in 2 pots only out of many checks which had been standing on the experimental bench for several months within 20 inches of numerous pots of inoculated soil, in each one of which several plants had wilted. Under the circumstances there can be no doubt that these were accidental infections derived from the inoculated soil or the wilted plants.

COTTON AND COWPEA INOCULATIONS, CROSS INOCULATIONS.

All of the cotton-plant inoculations have failed. These also were soil inoculations, and were performed on many small plants, using the cotton fungus, the cowpea fungus (cultures from ascospores), and the melon fungus. The experiments were repeated in different years and were continued in some cases for a long time with both sea island and upland cotton.

Melon-plant inoculations, on a large scale, also failed when the cotton fungus was used. These were soil inoculations. Pythium attacked and destroyed some of the plants and injured others, but no Fusarium disease appeared. The above statement should be qualified as follows: In the fall of 1894, 25 pots of melons were infected with the cotton fungus soon after the seeds were planted. For some weeks Pythium caused a good deal of trouble, and in one of the plants attacked by this fungus a small quantity of mycelium bearing the internal conidia of a Fusarium was found in the base of the stem. More cases, and typical ones, were anticipated, but they did not appear.

Cowpea inoculations also failed with both the melon and the cotton fungus. These were soil inoculations on plants in all stages of growth, from seedlings to plants two months old. Many plants were used, and the experiments were continued from four months to more than a year. The soil was copiously infected with the fungus, and repeatedly in some cases. Watermelons planted between the rows of cowpeas readily succumbed to the disease when the melon fungus was used. The above statement should be qualified as follows: On November 16, 1895, 182 cowpea seeds were planted in 26 pots of soil, in each one of which several melon plants had wilted the preceding June. The plants grew healthily all winter, but on February 14 the lower leaves of one plant began to wilt, and six days later the few remaining leaves fell off at a touch. The stem was green and appeared to be healthy except at the surface of the earth, where it was brown and partially rotted off, as when attacked by *Thielavia basicola*. In the upper part of the tap root, in the vicinity of this injury, the walls of some of the vessels were browned, and a few of these vessels were packed full of a fungus bearing the internal Fusarium conidia. More cases, therefore, and typical ones, were anticipated, but none appeared, although the plants were kept under observation for a long time.

Cowpea inoculations failed with the fungus derived from ascospores of the cowpea fungus. Nine large pots were used, but all of the 170 plants remained free from disease distinctly attributable to the Neocosmospora, although under observation for many months. These were soil inoculations, and an abundance of the fungus was used. A few melon plants grown in these same pots also remained free from disease.

Tomato plants in quantity were grown for a long time in soil full of the melon fungus without contracting any disease. This was done because a Fusarial disease of tomatoes occurs in Florida and also in

England.[1] Melon plants wilted readily in this soil. The tomatoes were developed in it from seedlings, and, to the number of more than 100, grew in the soil healthfully for several months (as long as the experiment continued) side by side with many watermelons, all of which contracted the disease and wilted.

Potatoes grown in soil full of the melon fungus also remained free from disease.

No inoculation experiments either on melons or cotton have been made with mycelium derived from the ascospores of the cotton or the watermelon fungus.

A detailed account of all of these experiments will not be given, but to show their extent and to re-enforce the above rather brief statement of the main results the following sample experiments are given:

(1) On September 5, 1894, 14 pots of good earth were planted with 56 cotton seeds and the soil of each one was infected with a pure culture of the melon fungus. During the fall and early winter the soil in these pots was reinfected three or four times with pure cultures of the melon fungus, but none of the cotton plants contracted the disease. On May 14, 1895, 46 cotton plants remained, and were healthy but for the attacks of red spiders. On this date watermelon seeds of three varieties were planted in each of the pots to see if the melon fungus was present in the soil. The seeds germinated well, and on May 25 each pot contained from two or three to six healthy melons. On June 7 the first case of melon wilt appeared—i. e., the cotyledons of a plant drooped in a suspicious way, and the conidia-bearing mycelium of the fungus was found in the vessels of the tap root. On June 8 the second case appeared. This plant was pulled and examined two days later, when the fungus was found plugging many of the vessels of the tap root. From this date cases became frequent. By July 9 the melon wilt had appeared in 10 of these pots. The cotton plants in these pots were still free from wilt and were making an increased growth, owing to the fact that the red spiders had been destroyed early in June by means of resin wash.

(2) On December 3, 1895, 28 pots of good earth were planted to sea-island cotton and an equal number to cowpeas. Each pot received 7 seeds. On December 5, before any of the plants were up, one-half the pots of each lot were copiously inoculated with pure cultures of the melon fungus, the whole of tubes 3, 4, 6, and 7, October 17 (rice cultures), being used for this purpose. The fungus was buried about 1 centimeter deep in the center of each pot. On December 11, as the plants were coming up, the other 14 pots of each series were also inoculated with the melon fungus. The pots of cowpeas received rice cultures 4, 5, and 8, October 8. The pots of cotton received rice culture 6, October 8, and 1, October 28. The fungus was buried in the soil the same way as before.

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[1] Massee: The "sleepy disease" of tomatoes.—The Gardeners' Chronicle, Series III, Vol. XVII, 1895, p. 707.

On January 7, 1896, 15 pots of the cowpeas, which were now 6 to 8 inches high, were re-inoculated with the melon fungus. There were 89 plants in these 15 pots. The fungus was derived from 5 pure test tube cultures on bruised, steam-sterilized seeds of the cowpea, and was put into the top layers of the soil very copiously. The cultures were young (1 and 2, December 21; 10 and 11, December 16; and 7, December 31) and growing vigorously—i. e., each tube contained 10 to 15 cubic centimeters of the moist peas entirely overgrown and interwoven with the fungus. In these 56 pots at least 175 plants of cowpea and as many more of cotton were exposed to infection under conditions which appeared to be admirable.

This experiment was continued 14 months, during which time no positive results were obtained. None of the cotton plants contracted the disease and none of the cowpeas. In one only of the cowpea plants a very little of the mycelium of a Fusarium was found in a few of the vessels near the earth, but the symptoms were not typical for the cowpea disease, and the fungus may have been that of the non-parasitic Nectria mentioned below. On February 4, 1897, both varieties of cotton were still alive. A few of the cowpeas were still alive, but the majority ripened their seeds and died in the fall of 1896. At this time the stems of some of the latter bore sparingly and in a saprophytic manner (in no case high on the stems, but always near the moist earth), the pinkish conidia beds of a Fusarium. These first began to appear in November—i. e., 11 months after the soil was inoculated. Some of these compact sporodochia may have been the conidia beds of the melon fungus, but they did not appear to be parasitic—i. e., they were not preceded by an extensive occupation of the vessels of the plant and were not arranged in rows up and down the stem,[1] but rather were clustered on the moist bases of some of the decaying stems. Moreover, on one stem they appeared in connection with the red perithecia of a Nectria. These perithecia in shape and color much resembled those described in this bulletin, but the ascospores were colorless, thin-walled, elliptical-pointed, smooth, 1-septate, and 8 to the ascus—i. e., typical Nectria sporidia.

To determine whether the melon fungus was alive in the soil, the earth was knocked out of the pots and the cotton and cowpea stems buried in it to form the substratum of a bed on one of the hot-house benches. This earth was then covered with three pailfuls of clean sand, on top of which an inch of good potting soil was spread. On February 10 this bed was planted with the seeds of two varieties of watermelons. Seeds enough for 500 plants were put into the earth, but

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[1] This fungus did not in any case fill the vessels and brown their walls the whole length of the plant, as the cowpea fungus does, nor even for a few inches. Neither did the external conidia beds appear in the proper way. In the cowpea disease these external conidia beds occur by thousands on the dry stems at all heights from the surface of the earth to the top of the plant (3 feet or more), and are arranged very regularly in parallel rows lengthwise of the stem. (Pl. I, *11, 12*.)

they came up badly. On March 1, 75 seedlings of the Rattlesnake melon were up and 42 seedlings of the Seminole. On March 5 two plants showed drooping cotyledons, and on making sections of the tap root the melon fungus was found fruiting in the vessels of each. During the next two weeks 24 melon plants wilted, and the characteristic fruiting fungus was found plugging the vessels of the taproot or hypocotyl of each one. Subsequently many additional plants were attacked and destroyed, showing clearly that the melon fungus must have been alive in the soil during the whole time that the cotton and cowpeas grew in it unmolested. The presence of the typical conidia-bearing fungus in the vessels of the wilting plants was determined, in nearly all cases, by a microscopic examination, although this became rather monotonous toward the close of the experiment. It was on this bed that the tomatoes grew unmolested from February to midsummer, and this, too, although many of the wilted melon plants were buried from time to time close to the roots of these tomatoes. Twenty cowpea plants which came up by accident (from seeds in the buried refuse) also remained healthy until they were removed in July.

(3) On April 12, 1897, another attempt (the fifth or sixth) was made to infect cotton and cowpeas with the melon fungus. For this purpose in one of the hothouses there was prepared a bed of good well-rotted potting earth. This bed was 6 feet long, 3 feet wide, and about 8 inches deep. As soon as this bed was ready, cultures of the melon fungus were buried in it, in rows, at right angles to the long axis of the bed, and 4 inches apart. Twenty-six test-tube cultures of the fungus were used for this purpose. These were vigorous growths on slant agar, potato, etc., which had been started for this purpose April 6. Grooves about an inch deep were made in the soil. The fungus was then uniformly distributed in these furrows and covered with the loose earth.

On April 13, 400 seeds of the Georgia Rattlesnake melon were planted in this bed, in 15 rows, alternating with the rows of the buried fungus, and consequently only 2 inches either way from the fungous masses. The germinating capacity of these seeds had already been tested and found to be high, but in this bed only about half of them came up.

On April 29 about 200 melon plants had come up, and none of them were unhealthy. The first case of melon wilt appeared April 30 and the second May 3.

On May 3—i. e., as soon as it had become apparent that the melon fungus was active in the soil—200 seeds of cowpea and 175 seeds of sea-island cotton were planted between the rows of melons—i. e., on top of the rows of buried fungus. To help on the disease and add interest to the experiment, the spores of *Thielavia basicola* were also planted in the bed in one or two places. This fungus makes wounds in cotton and cowpea plants at or beneath the surface of the earth from the surface inward, and it was thought that possibly such injuries might favor the entrance of the Fusarium.

On May 8 there were 6 additional cases of melon wilt with fruiting Fusarium in the vessels of each one, and one melon plant had succumbed to a combination of Thielavia and nematodes.

On May 10 the cotton and cowpeas were coming up nicely, and more of the melons had wilted. On May 21 there were 65 wilting melon vines pretty uniformly distributed over the bed. The cotton and cowpeas growing between these rows of melons showed no signs of the wilt disease. A few of them had rotted off at the base with Thielavia, but no Fusarium was associated with it. At this time the cowpeas were 6 inches high with the first trifoliate leaf coming, and the cotton plants were about 4 inches high with the first true leaf coming. By May 25 melons enough had wilted to make a total of about 100 cases. The cotton and cowpeas were free from wilt and growing very satisfactorily, considering how closely they were planted. By June 1 there had been 166 cases of melon wilt on this bed. All of these plants were examined microscopically, and in every one there was an abundance of the Fusarium in the vessels of the taproot or stem, or both. In the recently wilted plants the fungus was restricted to the vessels; in those which had been wilted some days, but were not yet dry-shriveled, it was also in the parenchyma, but had not reached the surface. Only 16 healthy melons remained, and these subsequently contracted the disease and died.

In digging and pulling out the diseased melons for examination the roots of the cotton and cowpea plants must have been considerably broken and disturbed, but neither in this way nor by the aid of the Thielavia or of another fungus destitute of fruit, but resembling a Pythium, was the melon fungus able to find its way into the cotton or cowpea stems.

Up to August 8, when the experiment was discontinued, all of the cotton and cowpea plants remained free from this disease. At this time they were large plants, and the cotton was suffering considerably from crowding.

ONE FUNGUS, OR THREE?

It is my intention to repeat and extend the ascospore inoculation experiments as soon as time permits, and also to settle more definitely by means of additional cross inoculations whether under any circumstances the fungus from any one of these plants will ever transmit disease to the others. Much time has already been devoted to this problem, which is one of great practical importance. From certain cultural peculiarities of the fungi, from the uniformly negative results of the hothouse experiments and from certain field observations, it now looks as though these were separate diseases due to closely related but not identical organisms. This is also the opinion of some very well-informed growers.

One of these field observations may here be given. In July, 1894, the writer examined a large field of upland cotton belonging to Mr. T. S.

Williams, of Monetta, S. C., without finding any cases of the cotton wilt, and Mr. Williams stated that there had never been any in it. This cotton was planted on land where watermelons had wilted badly in 1893. It was therefore on a large scale an experiment similar to those described above. In 1895 the field was again planted to cotton, alternating with cowpeas—i. e., 3 rows of cotton and 3 rows of cowpeas. In September of that year the writer again examined the field quite carefully, and with the same negative result. No cases of cotton wilt were to be found, but there were hundreds of wilting and dead cowpea vines, and the latter bore the external conidia beds of the lunulate-spored Fusarium quite regularly, and these were arranged in the manner shown in Pl. I, *11*, *12*. The melon fungus was undoubtedly present in the soil, but there were no melon vines on the field by means of which to establish this fact conclusively. At my request Mr. Orton reexamined this district in the summer of 1899. He found an abundance of melon and cowpea wilt, but none of the cotton disease.

Morphologically, on the contrary, so far as I have been able to determine from the careful examination of a great many specimens, this fungus is specifically identical on all of these plants, the only doubt being whether it may not have varied enough physiologically not to be transmissible from one host to the other. There are slight variations in the length of the beak and in the size and color of the perithecia on the different host plants, but these are not constant. The ascospore variations are also not constant. As already stated, the ascospores of the form on watermelon are usually smaller and more decidedly elliptical, and a larger proportion are smooth (perhaps because small). When this was discovered an earnest attempt was made to distinguish two or more species, but further studies developed the existence of all sorts of intermediate forms and sizes and left no morphological standing ground for any such conception. For example, perithecia were found on the watermelon at Monetta, S. C., in September, 1895, which contained globose wrinkled ascospores 12 μ in diameter; ascospores 12 by 13 μ and 12 by 14 μ were also observed. Other perithecia on the same root bore elliptical smooth spores. Indeed, ascospores from the same perithecium may be globose or elliptical, wrinkled or smooth. Red perithecia taken from the roots of wilted, dead cowpeas, at Monetta, September 10, 1895, were indistinguishable in color, size, and shape from those found on watermelon roots, and bore ascospores of the following sizes: 9 by 10, 9 by 14, 10 by 10, 10 by 12 (wrinkled), 10 by 13, 10 by 14 (smooth), 12 by 12 (wrinkled). Ascospores from perithecia which grew on the roots of sea-island cotton on James Island were 10 by 10 (smooth and not many so small), 10 by 12 (smooth and wrinkled), 12 by 12 (wrinkled), 13 by 14 (wrinkled). Owing to variability, it is likewise impossible to distinguish the fungus from the various hosts either by means of the mycelium or by the external or internal conidia. At most the differences can be scarcely more than varietal—i. e., such as might be induced by the long-continued use of different substrata. This is true even if the fungus can not be transmitted from one host to another, and a sufficient number of experiments have not yet been made to enable one to declare without reserve that this never takes place under any circumstances—e. g., with help of some other fungus, or under peculiar conditions of environment not yet discovered. At present, therefore, nothing remains but to consider the fungus as one species and to record the forms on the other host plants as varieties. Possibly it may finally turn out that they do not deserve even this rank, but the writer does not now feel justified in giving them any less.

VITALITY.

From its vitality under adverse conditions, its ability to live in the dung heap and in the soil, and the ease with which it may be cultivated on all sorts of artificial media in the laboratory, this fungus must be regarded as a serious enemy to agriculture. While we know it only on the plants mentioned, it is probably capable of attacking other species, and ought certainly to be expected and looked for on other hosts.[1]

The length of time the fungus will remain alive in the earth is remarkable, and adds greatly to the difficulty of combating it. Why it should ever disappear, any more than a bad weed, when once established in a cultivated soil, is not clear. It should certainly be regarded as a weed, and one the eradication of which presents unusual difficulties. In extensive field culture it has been found unsafe to plant lands which have once suffered from it until after a lapse of several years—five to seven, according to south Georgia melon growers, and certainly more than three, as shown by a 7-acre field test in South Carolina, which came under my own observation in 1895. Only 3 wagonloads of melons were obtained from the whole field.

The melon fungus has lived a year in the dried-out soil of pots used in my greenhouse experiments, and a very similar fungus parasitic on cabbage remained alive in dry soil three and one-half years.[2] The

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[1] Since this was written Mr. Orton has found the fungus on James Island, South Carolina, in a weed, the *Cassia obtusifolia* L. Not many plants were attacked, but the external symptoms were identical with those on the cotton and cowpea, while the walls of the vessels of stem and root were stained brown and the lumen was filled frequently with mycelium, abstricting the typical microconidia, and sometimes browned, as in cotton.

[2] The writer has just concluded an experiment with a similar looking and acting cabbage Fusarium. In parts of New York, Virginia, and Maryland this fungus has troubled the market gardeners, in some cases rendering impossible the profitable culture of cabbages on large and fertile fields—e. g., a field in New York which formerly yielded from 90,000 to 95,000 heads of marketable cabbage for each 100,000 plants set out, can now be depended upon for only about 30,000 heads; on a field in Maryland which formerly yielded good crops, the cabbages were so badly affected this year that the ground was replowed and planted to other crops in the middle of the season. The symptoms in the cabbage are slow growth, refusal of the heads to form, a sickly color, and the premature shedding of the lower leaves, from the axils

melon fungus lived in a dried-out condition in one of my agar tube cultures three and one-half years; in another it was alive at the end of ten months and twenty-three days; in a third trial it was found alive in 7 out of 8 test-tube cultures which had been in a warm, dry place in a dried-out condition for nearly two years. These last tubes were inoculated at various dates between July 26 and October 8, 1894, and the test was made January 19, 1897. The ascospores of the cowpea fungus remained alive in a dry condition 16 months.[1]

SYMPTOMS PRODUCED, ETC.

The gross symptoms in the watermelon are sufficiently shown on the accompanying plates (Pls. VII, VIII, X). They are those of a plant

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of which short sprouts frequently push out. This disease was first studied by the writer in 1895. It attacks the plant in the same way as the melon fungus—i. e., from the soil—and destroys it by plugging the water ducts. It first produces in the vessels of the living plant great numbers of microconidia (8 to 13 by 2 to 4 μ), and then macroconidia on the surface, in the same way as the melon fungus. In July, 1895, a quantity of soil was obtained from one of these badly infested fields (near Albany, N. Y.) and was stored away in a dry basement for three and one-half years. It was then removed from its original packings, put into a clean pine box made from freshly planed lumber, planted with three varieties of cabbage, placed in an upper window of an unoccupied laboratory room, and watered with distilled water. Some of the plants were attacked by Pythium and others by this Fusarium, which was found fruiting in the vessels. The checks did not contract the disease. The conditions under which the experiment was made point unmistakably to the soil as the source of the infection in case of these plants. This experiment, in connection with those which have been made on the watermelon, renders it probable that all parasitic soil Fusaria are alike in being very resistant to drought and other conditions unfavorable to vegetative life.

Embolisms of the vascular system due to fungi of the form-genus Fusarium are now known to the writer in plants of many different families. (See partial list on p. 43.) Most if not all of these fungi enter the plant from the earth. The fungi occurs so regularly in connection with these diseases that we are warranted in assuming them to be parasitic, although as yet in most cases no infection experiments have been instituted or brought to a successful conclusion. Judging from the results obtained with the watermelon and cabbage, it appears extremely probable that in the Cephalosporium and Fusarium stages of a variety of Nectriaceous fungi we have to deal with a large group of destructive soil parasites the very existence of which, in the earth, as active parasites, was not suspected until very recently—i. e., until the announcement of my results in 1894. (Am. Asso. Adv. Sci.)

[1] Some additional tests were begun September 28, 1899, as this bulletin was passing through the press. The watermelon fungus was found to be dead in each one of the 10 bread cultures already mentioned (p. 16) and in a few other cultures of the same age (hominy, cowpeas), but was still alive in numerous test-tube cultures of horse dung. These were made October 27, 1894 (from internal and external conidia), and have been dried out for at least four and one-half years. Twenty-two tubes were tested, and the fungus was found alive in each one.

Four test-tube cultures of the cotton fungus (from internal conidia) were also tried at the same time, and the fungus was found to be alive in each one. These 4 cultures were 5 years old. They were made on sterilized stems of the watermelon, October 3, 1894, and have been dried out and in a dry laboratory for at least four and one-half years.

The cowpea fungus (ascospore strain) was dead in each one of the 12 banana cultures made December 6, 1895.

transpiring freely and insufficiently supplied with water, although at the same time there is an abundance of moisture in the soil.

The uniformity with which this fungus first seeks out the vessels of the plant is very striking (Pl. I, *10*, Pl. IV, and Pl. V, *6*). This explains the sudden wilt of the foliage. The water ducts are clogged to such an extent that they can not function. That this wilt is attributable to lack of transpiration water, brought about by partial or complete clogging of the vessels, is shown by the fact that large plants which have begun to wilt frequently recover for a day or two if a rain sets in and the air continues moist. During such weather the progress of the disease in old vines is almost at a standstill, but it recommences when the sun shines out and the moisture of the air is dissipated. The mechanical nature of this obstruction is also shown by the fact that collapsed leaves frequently recover their turgor on cutting stems above the fungous plugs and plunging them into water, e. g., on cutting across the second internode when the plugs are confined to the hypocotyl and taproot. It is also shown by the fact that the terminal portion of shoots which have collapsed and the basal vessels of which are plugged by the fungus (as shown by the death of all the lower leaves and of all the other branches) may survive for several days, if the weather is not too hot and dry, provided they are attached to a large melon from which they can draw a certain amount of water (Pl. VII, *2*, right-hand branch). Finally, it is much easier for the fungus to plug all of the vessels of a small plant than of a large one, since in the taproot it has to make but a little growth through tender tissues to accomplish this. This explains why *young vines* frequently wilt even during rains or when the soil and air are very moist. The leaves of the cowpea usually unjoint and fall off, leaving the green stems bare. Often some of them become yellow and fall without first showing signs of wilt, as Professor Atkinson has recorded in case of the cotton disease. The watermelon leaves do not become yellow or detach, but wilt suddenly in large numbers and shrivel, so that a large, healthy-looking vine may lose all of its foliage in twenty-four to forty-eight hours (contrast Pl. VI and Pl. VII). The cotton plant is less susceptible, contains, as a rule, less of the fungus, and often recovers partially, so as to produce some fruit. In such instances the fruit-bearing stalks push out of the base of the stem and finally hide more or less completely the main shoot which has been killed by the wilt.

The xylem of the diseased plants always becomes brown (Pl. I, *10 a*, *b*), and in case of the translucent stem of the cowpea this stain shows through the green bark, giving an unusually dark appearance to the still living stem. This browning of the xylem appears to be common to all plants attacked by parasitic soil Fusaria, e. g., cotton, okra, cowpea, beans, watermelon, squash, potato, tomato, eggplant, red pepper, sweet potato, cabbage, carnation, asparagus, pineapple, and others. This browning begins in the walls of the larger vessels, and often it is confined quite exclusively to the xylem for a long time, the pith, bark, and phloëm remaining free from stain. In the cotton fungus the older mycelium itself, inside the vessels, is frequently stained yellow or brown. Browning of the mycelium of the melon fungus inside the vessels of the plant has not been observed, but it occurs in pure cultures on boiled melon stems, etc. Once started, in cotton at least, this browning may extend long distances through the woody parts of the stem with very little fungus to help it on.

OTHER WILT DISEASES.

This disease should not be confused with the cotton-root rot of Texas, from which it appears to be distinct,[1] nor with another wilt of cotton, cowpeas, etc., common in parts of Florida and first described by Prof. P. H. Rolfs. This is associated with a fungus which attacks many kinds of plants, wild and cultivated, enveloping the base of the stem externally with a copious, white, rather straight mycelium, bearing on its surface large numbers of small sclerotia which are first white, then fulvous, and finally dark brown and smooth. When grown on nutrient media (agar), the fungus reproduces itself by another crop of sclerotia, and so on indefinitely (a year in my laboratory). These sclerotia are mostly 0.8 to 0.9 by 1.2 to 1.3 mm.

RELATIONSHIPS.

The perithecium of Neocosmospora much resembles a medium-sized bright red Nectria, and if gathered in an immature condition would naturally be placed under Nectriella, as the spores are smooth and colorless and there is no indication of any septum, even in the most elongated or in very old spores. When ripe, however, the ascospores are distinctly brown, and the fungus clearly belongs to a new genus. It possesses some of the characters of both Nectriella and Melanospora, but is distinct from either. On the whole it seems to be nearer to Nectriella than to Melanospora, although the spores are brown. It is not very closely related to Melanospora as originally established by Corda and defined in Saccardo's Sylloge Fungorum. It is widely different from *Melanospora chionea*, *M. leucotricha*, *M. zamiæ*, *M. vitria*, *M. zobelii*, *M. coprina*, *M. lagenaria*, *M. parasitica*, and all other Melanosporas and Sphærodermas which the writer has been able to examine or to find figured. The ascospores of this fungus are particularly unlike those of Melanospora. In the latter they are smooth, often lemon-shaped, or even apiculate, and frequently oblique or flat on one or both sides. The general appearance of Melanospora indicates that it might perhaps be properly excluded altogether from the Nectriaceous fungi, its affinities

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[1] Four hundred cotton plants killed by this disease were received from two different localities in Texas in 1895. Pammel's Ozonium was present, but not a trace of any stage of this fungus could be found. These plants came from regions much subject to root rot.

being with the Sordariaceæ, as Schrœter pointed out in his Kryptogamen-Flora von Schlesiens. The development in the cowpea fungus of perithecia with and without beaks on mycelium derived from a single ascospore makes it probable that the same thing occurs in other genera and tends to confirm Winter's view of the untenability of the genus Sphærodcrma, which was erected to include those forms of Melanospora destitute of a beak. The development of the perithecia of this fungus, either in the soil near the host or on the surface of the latter (the more common way), or under the substratum in rifts or cavities of the host, shows that this character has no particular value and leads one to suspect that the genus Hyponectria may also have no sound physiological or morphological basis.

This fungus is most nearly related to the Cosmospora of Rabenhorst, which is a good genus and should be reestablished. It differs from Cosmospora chiefly in having non-septate ascospores and a wrinkled exospore, the former having 1-septate ascospores with a papillate or verrucose exospore. My cultures have shown beyond doubt that the ascospore is less readily modified by the substratum than any other part of the fungus, and therefore the most important for purposes of classification.[2]

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[2] These two genera may be defined briefly as follows:

Cosmospora Rabh. (emend.).

Peritheeia as in Nectria (red in the known species). Asci numerous. Ascospores 8 in one row, brown, oblong elliptical, 1-septate, usually more or less constricted at the septum, with a distinct papillate or verrucose epispore. Paraphyses present, inconspicuous, broad, loosely jointed, unbranched. Conidial stages unknown.

1. C. coccinea Rabh.
2. C. Cameroensis (Rehm).
   Syn. Sphærodcrma Cameroensis Rehm.

Neocosmospora.

Perithecia as in Nectria (bright red in the known species). Asci numerous. Ascospores 8 in one row, brown, globose or short elliptical, continuous, with a distinct wrinkled epispore (the latter sometimes wanting in the smaller spores). Paraphyses present, inconspicuous, broad, loosely jointed, unbranched, consisting of about 5 cells. Three conidial stages, viz, Cephalosporium, Fusarium, and Oidium.

1. N. vasinfecta (Atk.). On cotton (parasitic).
   Perithecia as below. Spores usually globose, wrinkled, generally about 10 by 10 μ.

α. Var. tracheiphila (Smith). On cowpea (parasitic).
   Perithecia quite variable, but mostly 250 to 350 μ tall by 200 to 300 μ broad, with or without a short neck; on the dead roots or in the soil over them Spores usually globose, wrinkled, mostly 12 by 12 μ.

β. Var. nivea (Smith). On watermelon. Very actively parasitic. Enters the plant from the earth and plugs the vascular system, causing a sudden extensive wilt of the foliage.
   Perithecia as above. Spores globose or elliptical, wrinkled or smooth, generally smaller than in the preceding and more often elliptical, but variable.

SCIENTIFIC NAME.

For the present, at least, this fungus may be designated as follows:

NEOCOSMOSPORA VASINFECTA (Atk.)

Syn. *Fusarium vasinfectum* Atk.

On cotton. Probably also on okra. Parasitism not proved. Genetic connection of various spore forms not proved. Chlamydospores not observed.

α. Var. tracheiphila.

Syn. *Nectriella tracheiphila,* Erw. Sm.

On cowpea. Parasitism not proved. Genetic relationship of ascospores, macroconidia and microconidia established. Chlamydospores not observed.

β. Var. nivea.

Syn. *Fusarium niveum,* Erw. Sm.

On watermelon. Not known to occur on other Cucurbitaceæ.[1] Parasitism fully established. One of the most destructive soil parasites known. Genetic connection of conidial stages fully established. Perithecia identical with the preceding have been found on stems killed by the internal fungus, but the genetic relationship has not been proved by exact culture experiments.

By "not proved" the writer does not mean that he has himself any doubt whatever as to the parasitic nature of the cotton or cowpea fungus or as to the genetic relationship of the various spore forms on cotton and of the perithecia to the conidial stages on the watermelon, but that these points have not been *definitely settled* by satisfactory infection experiments and by deriving one spore form from the other in pure cultures. Without such experiments the proof remains incomplete. The field evidence, however, of the parasitic nature of the cotton and cowpea fungus is of the most convincing sort, i. e., the fungus is always present in the vessels of the diseased plants, nothing else is always present, and the disease occurs year after year on the same soils. This constant association of the fungus with the cotton and cowpea disease makes it reasonably certain (in the light of what has been accomplished with the watermelon fungus) that abundant infections will be secured at no very distant day. The failures thus far have probably resulted from a greater resistance on the part of cotton and cowpea, or from the fact that the natural method of infection has not been discovered. Possibly the cotton and cowpea may be subject to infection only during germination or early stages of growth, or only

[1] A destructive disease of cucumbers and muskmelons associated with a Fusarium in the stem bundles has been reported from Ohio by Prof. A. D. Selby. The occurrence of a similar disease in muskmelons has just been reported from Connecticut by Prof. William C. Sturgis. A Fusarial disease of squashes is known to the writer. Possibly these diseases are due to the watermelon fungus, but the writer has not observed diseases of other Cucurbitaceous plants in regions subject to the watermelon wilt, and until cross-inoculation experiments have shown their identity it is proper to consider these diseases as distinct.

when injured in some particular way. If these plants are infected chiefly during the seedling stage, then the growth of young plants in uninfected seed beds and their transplantation to infected soils only when they have passed out of the receptive stage would afford relief. This is offered, however, only as a working hypothesis. All we yet know is that frequently many plants of cotton and cowpea on infected land come to a healthy maturity, i. e., there is not such a sweeping general infection as in case of the watermelon. Possibly, however, this is a statement depending on an insufficient number of observations. It is true so far as my observations have extended.[1]

Melon plants grown for several weeks in good earth, i. e., plants with one true leaf and the second one beginning to develop, are still freely subject to soil infection. The shortest period of incubation observed by the writer has been about 6 days, i. e., the cotyledons wilted, as shown in Pl. VIII, the first or second day after the plants emerged from the ground. The longest period of incubation, or rather lapse of time between infection of the soil and appearance of the disease, was 81 days. In this case the seed was planted and the soil of the pot infected April 25 and the vine showed no symptoms of disease until July 15, when it suddenly wilted. Thirty-one other vines of the same series contracted the disease between June 1 and July 11. The soil of these pots was reinfected May 20, no cases having appeared. In both instances the fungus used was derived from a big, arcuate, several-septate, external conidium. Vine 32, which wilted at the end of 81 days, was 4 feet long. There was an abundance of fungus in the vessels and it bore only the small, colorless, elliptical microconidia; these were non-septate, straight or slightly curved, and measured 6.5 to 24 by 2 to 4 μ. In field culture a period of 80 days frequently intervenes between planting and the first appearance of disease in a given vine.

The question of parasitism of the cotton fungus was left an open one by Professor Atkinson, as shown by the following citations:

"The Fusarium was considered not to be a sufficiently aggressive parasite to be able to make its way into the ducts of the circulatory system unaided." It is suggested that a damping-off fungus may first open the way. The only two infections obtained by him with the cotton Fusarium were on plants with open wounds made by the "sore-shin" fungus. "The discoloration and disease of the ducts is started

[1] Mr. Orton observed in 1899 in various parts of South Carolina what had previously escaped my attention, viz, that every cotton plant in the vicinity of dead and dying plants is dwarfed and does not bear as much fruit as it should, even when it shows no symptoms of the disease. This dwarfing is most conspicuous toward the end of the growing season and is associated with the presence of the fungus in the vascular system of the side roots of the plant, the vessels of the tap-root and of the stem being free or very nearly free from the fungus. This may help to explain the statement often made by cotton growers that one stalk in a hill will blight and another will not. In reality, it may be only a question of degree, all being more or less affected.

by the injury from the 'damping-off' fungus." "While I do not wish to be understood as making any positive assertion in favor of the Fusarium being the cause instead of bacteria [which were sometimes found associated with it], I do think the evidence thus far in hand gives greater support to the former view. The Fusarium is invariably found both in cotton and in okra afflicted with the disease. Bacteria are not always found in the diseased tissues, etc." Some experiments by Professor Atkinson also led him to believe the external Fusarium on cotton distinct from the internal one.

RESTRICTION OF THE MELON WILT.

While no cure is known for this disease, our knowledge of its cause and manner of spread is now sufficiently exact and complete so that certain rules of practice may be given. By carefully following these the farmer will frequently avoid very serious losses.

(1) Fields already infested with this fungus must not be planted to melons for a long series of years.

So far as yet known, canteloupes, cotton, peanuts, cowpeas, soy beans, or velvet beans (Mucuna sp.) may be planted on such fields without danger.

(2) Fields free from this disease may become infected by the wash from lands already infested, and probably, also, by means of the dirt adhering to agricultural implements and to the feet of horses and cattle. For this reason, if cattle are pastured on such fields, they should not be allowed to roam freely over uninfected parts of the farm, and tools used on such lands should at least be scoured bright before using on other fields. Where uplands are infected the wash from sudden heavy rain storms should be turned aside, as far as possible, from uninfected lowlands.

(3) Inasmuch as the vitality of the fungus is great and the wilting melon vines are full of it, the danger for a half year or more from such vines is very great. All such plants are magazines of infection. They should be pulled while green, stacked with brush, and burned. Large growers of melons could well afford to keep one man in the field all the time for this purpose. The plants should be removed as soon as they show distinct symptoms of the wilt, because at this time the fungus is still confined to the interior of the stems and not likely to be scattered about by the removal, as would be the case a few weeks later when the vines are dry and the fungus has fruited abundantly on their surface. This precaution should not be neglected simply because fields show only here and there a wilted vine, since in course of a few years such fields have been known to become so thoroughly occupied by the fungus as to altogether prevent melon growing.

(4) Occasionally the fungus is introduced into the barnyard, so that the dung pile becomes a source of general infection to fields previously free from the disease. This is apt to be the case where "melon hay" is

fed or used for bedding.[1] The writer discovered one striking outbreak of this disease in South Carolina in 1894 which could be accounted for in no other way, the disease making almost a clean sweep on the five acres which received most of the manure. If there is the least reason to suspect the manure pile, commercial fertilizers should be used instead.

(5) Farmers whose lands have become generally infected are advised to grow other crops on their own fields, and to rent uninfected land from their neighbors for the purpose of melon growing.[2]

UNFINISHED WORK.

It is a source of regret that this bulletin could not be made more complete, but during the period covered by this investigation many other important lines of work have also demanded attention. In the scant time at the writer's disposal for this special work he has therefore done as much and as well as he could, and must so leave it.

So far as relates to the life history of the fungus, the most important things remaining to be done are as follows:

(1) Determine time and manner of infection of cotton and cowpea plants.

(2) On cotton establish the genetic relationship of the various spore forms, perithecia and external and internal conidia.

(3) On watermelon obtain experimental proof that the perithecia on the dead stems bear the same relation to the internal and external conidia as they do in case of the cowpea fungus.

(4) Obtain infections with ascospores on cotton, melon, and cowpea.

(5) Connect the okra fungus with the cotton fungus by experimental studies.

(6) Determine why it is impossible to grow perithecia from some conidia and easy to grow them from others. Does remoteness of origin from the ascospore interfere?

(7) Determine by additional cross-inoculations and field observations whether under any circumstances the fungus from one host plant can transmit the disease to another host plant.

(8) Determine how and where the melon fungus gains an entrance into the plant.

(9) The ease with which the perithecia may be grown would seem to offer a good opportunity for studying the question of the sexual or non-sexual origin of the ascospore fructification in this group.

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[1] Melon hay consists of hay made on melon fields late in the season, after the melon crop has been harvested. It is composed of wild grasses interspersed with dead melon stems. If the latter are infested with this fungus, then the dung heap becomes inoculated, and subsequently any land on which this manure is used.

[2] This advice was given by the writer to Mr. T. S. Williams, of Monetta, S. C., in 1894, with the happiest results, as indicated by the following excerpt from an unsolicited letter written by him in 1897: "Financially your researches here have been worth thousands of dollars to myself and others. By the information you gave us we were able in a great measure to avoid land likely to die."

Many practical questions are left for further investigation, especially all that relates to cotton.

EXSICCATI.

Specimens of this fungus will be distributed in Ellis and Everhart's Fungi Columbiana (Century 15). These sets include only the fungus as it occurs on cowpea and on culture media derived from this source. These specimens will consist of the following material: (*a*) Perithecia on stems and roots of the cowpea (*Vigna sinensis*); (*b*) pure cultures of immature perithecia grown in the laboratory from ascospores sown on steamed sterile potato; (*c*) ripe perithecia from pure cultures on steamed potato; (*d*) stems of cowpea with the vascular system plugged by the white fungus, which bears microconidia (these stems were green when gathered and bore no external conidia beds, but in many instances, to my chagrin, the fungus pushed through and fruited on the surface while the stems were drying); (*e*) external salmon-colored conidia beds (macroconidia) on stems previously killed by the internal fungus and which were dry when gathered. Type specimens have been deposited in the cryptogamic herbarium of the Division of Vegetable Physiology and Pathology, United States Department of Agriculture, and these specimens, which have been selected with equal care and are of equal value, may be regarded as co-types.

PREVIOUS LITERATURE.

(1) Atkinson. *Fusarium vasinfectum.* Some Diseases of Cotton. Bull. No. 41, Dec., 1892, Agricultural Experiment Station, Auburn, Alabama, pp. 19 to 29, with 3 figures: a diseased leaf, internal mycelium in vessels of cotton plant, mycelium and conidia from cultures.

(2) Atkinson. Diseases of Cotton in "The Cotton Plant," a Bulletin (No. 33) issued by the Office of Experiment Stations, Dep. of Agric., Washington, D. C., 1896, pp. 287–292. Nothing new added.

(3) Smith. *Fusarium niveum.* The Watermelon Disease of the South. Proc. Am. Asso. Adv. Science, 1894, p. 289.

(4) Smith. *Nectriella tracheiphila.* The Watermelon Wilt and other Wilt Diseases due to Fusarium. Proc. Am. Asso. Adv. Science, 1895, p. 190.

(5) Smith. The path of the water current in cucumber plants: (5) The result of parasitic plugging of the vessels. American Naturalist, 1896, p. 561.

(6) Smith. The Spread of Plant Diseases: A consideration of some of the ways in which parasitic organisms are disseminated. Tr. Mass. Hort. Soc., 1897.

APPENDIX.

A fungus or supposed fungus, described very imperfectly by L. v. Schweinitz in his Synopsis fungorum Carolinae superioris, and by Fries in his Systema Mycologicum, as *Sphæria gossypii*, has caused the writer some trouble and should be mentioned here. It was found on unripe cotton bolls and Fries stated that he had seen dried specimens. From the description in his Systema, making allowance for inexact observations and unwarranted inferences, it seemed at first not unlikely that the perithecia found by me on the cotton plant might be the old *Sphæria gossypii* of de Schweinitz. This view I have now abandoned as untenable.

The origin and history of this name, which must be regarded as a *nomen excludendum*, are as follows:

(1) De Schweinitz. Synopsis Fungorum Carolinae superioris, p. 46.

207. [Sphæria] Gossypii Sz.

S. simplex sparsa immersa globosa purpureo-incarnata submollis, ostiolo ad superficiem elongato gelatinam fundente.

Vix capsula Gossypii invenitur sine hac Sphæria. Minuta. Nascitur in capsulis Gossypii immaturis, primum profunde immersa, sed ostiolo etiam tum ad superficiem elongato, concolori, unde spargitur gelatina indurescens, quæ capsulis purpureo-rubro inquinat. Sphærulæ non observantur nisi capsula percissa; demum assurgunt et superficiem tum exsiccatam granulosam reddunt.

This species de Schweinitz placed in his Family VIII, Simplices, Sec. C, Brachystomæ, along with *S. putaminum* on peach pits and some others.

(2) Von Schweinitz. Syn. N. Am. Fungi, p. 217. Mere mention as follows:

*1652. 507. *S. gossypii*, L. v. S., Syn. Car. 207, F. 212, non in Pennsylv.

(3) Fries. Systema Mycologicum, Vol. II, 1823, p. 488.

412. *S. Gossypii*. Sparsa, submollis, peritheciis immersis globosis, purpureo-incarnatis, ostiolo ad superficiem elongato gelatinam fundente.

Schwein. (!) l. c. n. 207.

Minuta, dubiæ affinitatis. Nascitur in capsulis Gossypii immaturis, primum profunde immersa, sed ostiolo etiam tum ad superficiem elongato concolori, unde spargitur gelatina indurescens, quæ capsulas purpureo-inquinat. Perithecia non observantur nisi capsula perscissa, demum assurgunt et superficiem tum exsiccatam granulosam reddunt. In capsulis Gossypii copiose. (v. s.)

(4) Saccardo. Sylloge Fungorum, Vol. II, p. 457. Saccardo not knowing what to do with this species refers it doubtfully to Hyponec-

tria as *H. gossypii*, quoting with a slight rearrangement of words the description of Fries.

(5) ELLIS. North American Pyrenomycetes, p. 71. Ellis uses Saccardo's name, gives an incomplete translation of the Latin description, and adds:

We have seen no specimens of this species, but have received from Prof. F. L. Scribner a *Fusarium* on capsules of cotton from South Carolina, which may be the conidial stage.

(6) ELLIS. Notes on Some Specimens of Pyrenomycetes in the Schweinitz Herbarium of the Academy. Reprint from Proceedings of the Academy of Natural Sciences of Philadelphia, February 21, 1895, p. 11.

Sphæria Gossypii, Schw. Syn. Car. 207.
This is an obscure thing. The inner membrane of the cotton boll is wrinkled or roughened in drying so as to give the appearance of minute perithecia, but there is no fruit nor even any real perithecia.

(7) CURTIS. In Dr. Farlow's herbarium, at Cambridge, Mass., is a fragment of cotton capsule labeled "Sphæria gossypii Schw." This came from the herbarium of M. A. Curtis, who received it from de Schweinitz. On the pocket in the handwriting of Mr. Curtis is a penciled memorandum to the effect that this is not a fungus. Neither the writer nor Dr. Farlow, who examined the specimen with him, could find any Sphæriaceous or Nectriaceous fungus or any Fusarium spores on this specimen.

(8) Dr. KARL STARBÅCK, who kindly examined for me the Schweinitzian material of this species sent to Dr. Fries, and now preserved in the Fries collection at Upsala, writes that no fungus whatever is present and adds: "Species Schweinitzii Sph. gossypii est typicus observationis et auctoris et Friesii."

(9) My own examination in July, 1899, of material preserved in the de Schweinitz herbarium in Academy of Natural Sciences of Philadelphia, led to no different result. The specimens were examined both by reflected and transmitted light, with a hand lens and with the compound microscope.

The specimen in the collection proper (books of Sphærias) is labeled "Sphæria gossypii L. v. S. and Fr. Salem." This pocket contained nothing but some dust particles, insect detritus, and fragments, the largest of which was less than 1 mm. in area. These dust particles and fragments showed no perithecia or Fusarium spores. No fungus with necks either long or short was to be seen. Traces of an unknown, colorless, very delicate mycelium were observed, and one Macrosporium spore. This pocket also contained the skin of a museum pest.

In a separate package labeled "Fungi | Cryptograms | fr. Dr. Schweinitz | to Collins," I found, however, an uninjured, well-preserved specimen labeled in the handwriting of de Schweinitz "Sphæria Gossypii L. v. S. and Fr. Salem." This pocket contains two fragments of cotton capsule pericarp, each measuring about 1 by 1½ centimeters. The inner membrane is white, longitudinally wrinkled, and sound, or at least bears no Sphæriaceous bodies, Fusarium spores, or fungous threads. In places it bears tiny rusty specks, which are dead cells of the membrane containing some amorphous brown substance. The dark brown outer membrane is raised into numerous small papillæ, quite regularly arranged. These papillæ are barely visible to the naked eye and under a lens magnifying only two to three times might readily be mistaken for buried perithecia. These are undoubtedly what de Schweinitz saw and named *Sphæria gossypii*, but they do not contain any perithecia. Under a lens magnifying ten diameters they look more doubtful and when examined under the compound microscope (dry and crushed in water) they are observed clearly to be not of fungous origin, at least there are no Nectriaceous or Sphæriaceous bodies either on the surface or in the depths, and no Fusarium spores or hyphæ. Such papillæ are very common on the surface of cotton bolls when shriveling, as every one knows who has seen much of the plant, and very often at at least, they are not of fungous origin.

The presence of long necks which come to the surface and pour out gelatin and the statement by de Schweinitz that "scarcely a capsule of cotton is to be seen without this Sphæria" make it reasonably certain that de Schweinitz did not found his description on the infrequent little red perithecia which I have discovered. Finally, an examination of some of the scanty material of *Sphæria gossypii* which has been preserved in herbaria seems to indicate that the species was founded on the papillate appearance of the dry cotton capsule and on the fact that the surface of cotton capsules frequently exhibits a purple stain and a shining appearance. All the rest of the description (much more of it than I at first supposed) is pure inference—i. e., an easy method of accounting for the papillæ and the purplish glaze.

DESCRIPTION OF PLATE I.

1. Mature perithecia resting on fragment of hypocotyl of an old watermelon plant killed by the internal fungus. Monetta, S. C., September 9, 1895. This figure will answer equally well as an illustration of the perithecia occurring on cotton or cowpea.

2. Immature ascus, with two paraphyses and a few cells of the hypothecium, crushed out of a perithecium on watermelon. The smooth and still uncolored spores are surrounded by granular periplasm. Monetta, S. C., September 9, 1895.

3. Mature ascus taken from a perithecium which grew on mycelium derived from the ascospore shown in *6*. The periplasm has disappeared and the spores are now brown and have a thick wrinkled epispore.

4. A group of immature asci crushed out of a perithecium on cowpea.

5. Ripe ascospores of the watermelon fungus highly magnified.

6. Germinating ascospore, cowpea fungus. Agar-plate culture. James Island, S. C., August 22, 1895.

7. Conidia-bearing mycelium developed from the ascospore shown in *6*.

8. Three of the same conidia more highly magnified, one germinating. These conidia are identical in appearance with those produced inside of the vascular system of the still living stems. (See Plate II, *11*.)

9. Surface or dry-air conidia of the cowpea fungus. These were taken from the conidia beds shown in *11* and *12*.

10. Fragment from a cross section of the living cowpea stem, about 2 feet from the ground, showing a group of vessels infested by the fungus (*c*, cambium; *x*, xylem; *p*, pith), imbedded in paraffin, cut on the microtome, and stained for many hours in acid hæmatoxylin. This picture represents about one-thirtieth of the vascular ring, nearly all of which was occupied in the same manner. The cortical parenchyma and the bulky pith were still free from the fungus, as is always the case in this stage of the disease. Later the fungus pushes through to the surface, as shown in *11* and *12*. James Island, S. C., August, 1895.

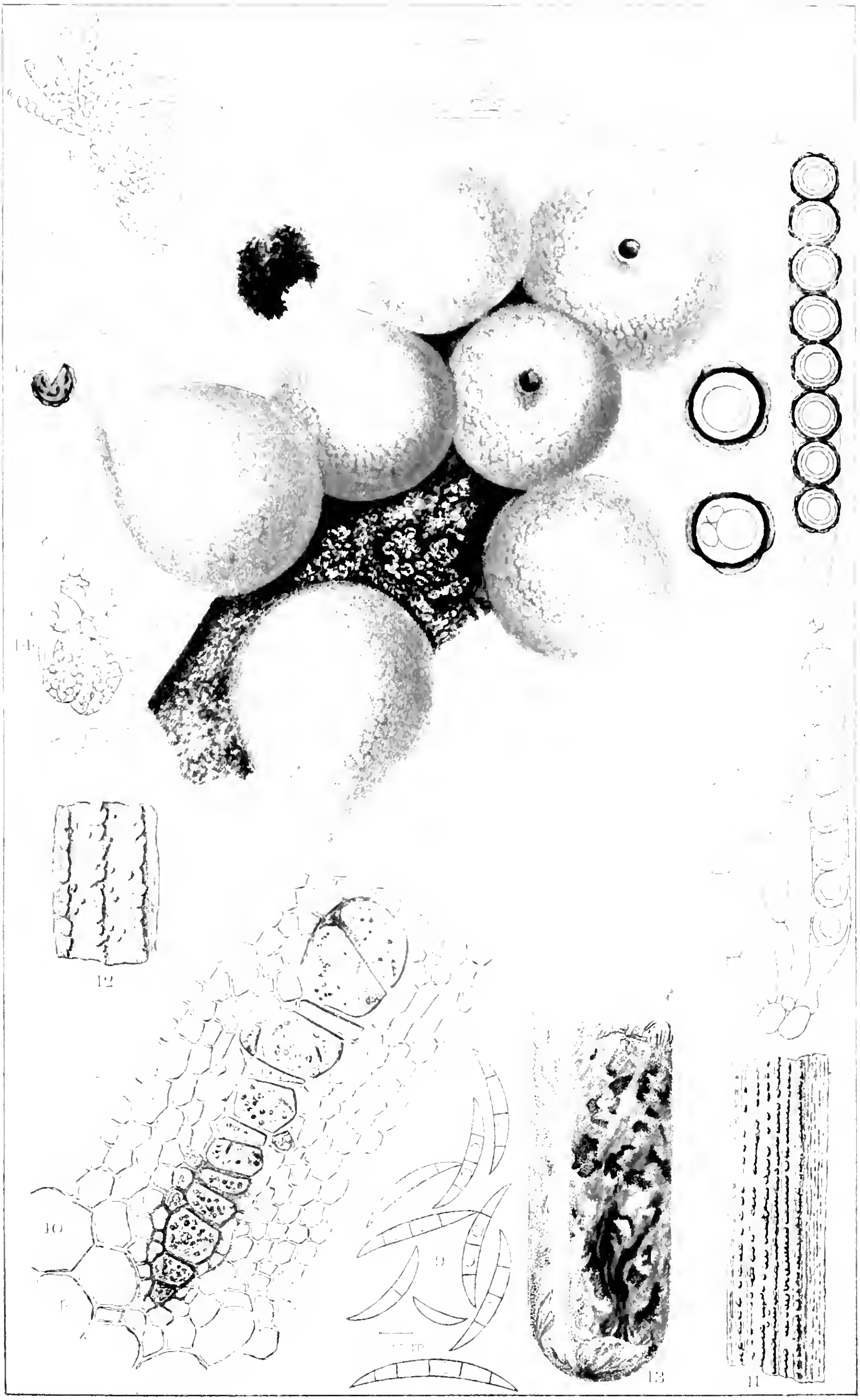
11. Surface of dead stem of cowpea, showing rows of conidia beds. The vessels of such plants are always previously occupied by the internal fungus, as shown in *10*. The row-like arrangement of the conidia beds is due to the fact that the fungus comes to the surface along lines of least resistance—i. e., through parallel rows of parenchyma cells separating the strands of tough bast fibers (stereome). ×2. James Island, S. C., August, 1895.

12. A similar fragment of dead stem of the cowpea more highly magnified. ×10.

13. A tube of boiled rice overgrown by the mycelium of the watermelon fungus (*Fusarium niveum*). Culture No. 4, October 8, 1895. Painted October 28, 1895. This culture was bright blue on the start, 2 c. c. of violet litmus water and a few drops of a saturated solution of sodium carbonate (t. 25° C.) having been added to it. The same brilliant colors may be obtained, however, as already stated in the text, without use of litmus—i. e., by simply cultivating the fungus for a few weeks on rice boiled in distilled water—and this figure will answer equally well for such cultures. High up on the walls of the tube (above the rice) the fungus is white.

14. An incipient perithecium developing on mycelium produced by the ascospore shown in *6*.

With exception of *10*, *11*, and *12*, which were painted under my supervision by Mr. John L. Ridgway directly from the specimens, and *13*, which was painted in the same way by Miss D. G. Passmore, the figures are from my camera drawings. *1* was transferred to the plate and painted by Miss Passmore. The rest of the work was done by Mr. Ridgway. Where no measurements are given they are included in the plates or may be learned from the text or from other figures of the same sort in which they are given.



Erwin F. Smith, D. G. Passmore and John L. Ridgway

A. Hoen & Co. Lith. Baltimore

NEOCOSMOSPORA NOV. GEN.

ERWIN F. SMITH

DESCRIPTION OF PLATE II.

1. Closed stoma. Perithecium of the cowpea fungus. Diameter of stoma proper, 15 μ. James Island, S. C., August 29, 1895.

2. Open stoma of the cowpea fungus, showing periphyses lining the inner wall of the throat. Diameter of the stoma, 30 μ. James Island, S. C., August 29, 1895.

3. Another view of the periphyses, a portion of the inner wall of the neck of the perithecium of the cowpea fungus crushed out and examined in water. James Island, S. C., August 29, 1895.

4. Optical section through perithecium from a dead watermelon stem, showing cavity full of loose ascospores. Some of the asci remained, but the walls of most had dissolved. This figure will answer equally well for the cotton or cowpea fungus in each of which the same phenomenon was observed. Size, 320 by 280 μ. Slightly diagrammatic. Monetta, S. C., September 9, 1895.

5. Peridial cells in the middle or ventral portion of a perithecium of the cowpea fungus. The same are shown less distinctly and somewhat diagrammatically in Plate I, *1,* and Plate V, *1.* James Island, S. C., August 27, 1895.

6. Conidial tufts on the surface of a watermelon stem killed by the internal fungus. Monetta, S. C., July 16, 1894.

7. Top of a similar tuft (melon fungus), showing attached and loose spores in various stages of growth and septation. From a plant destroyed by soil infection. Washington, D. C., September 27, 1894.

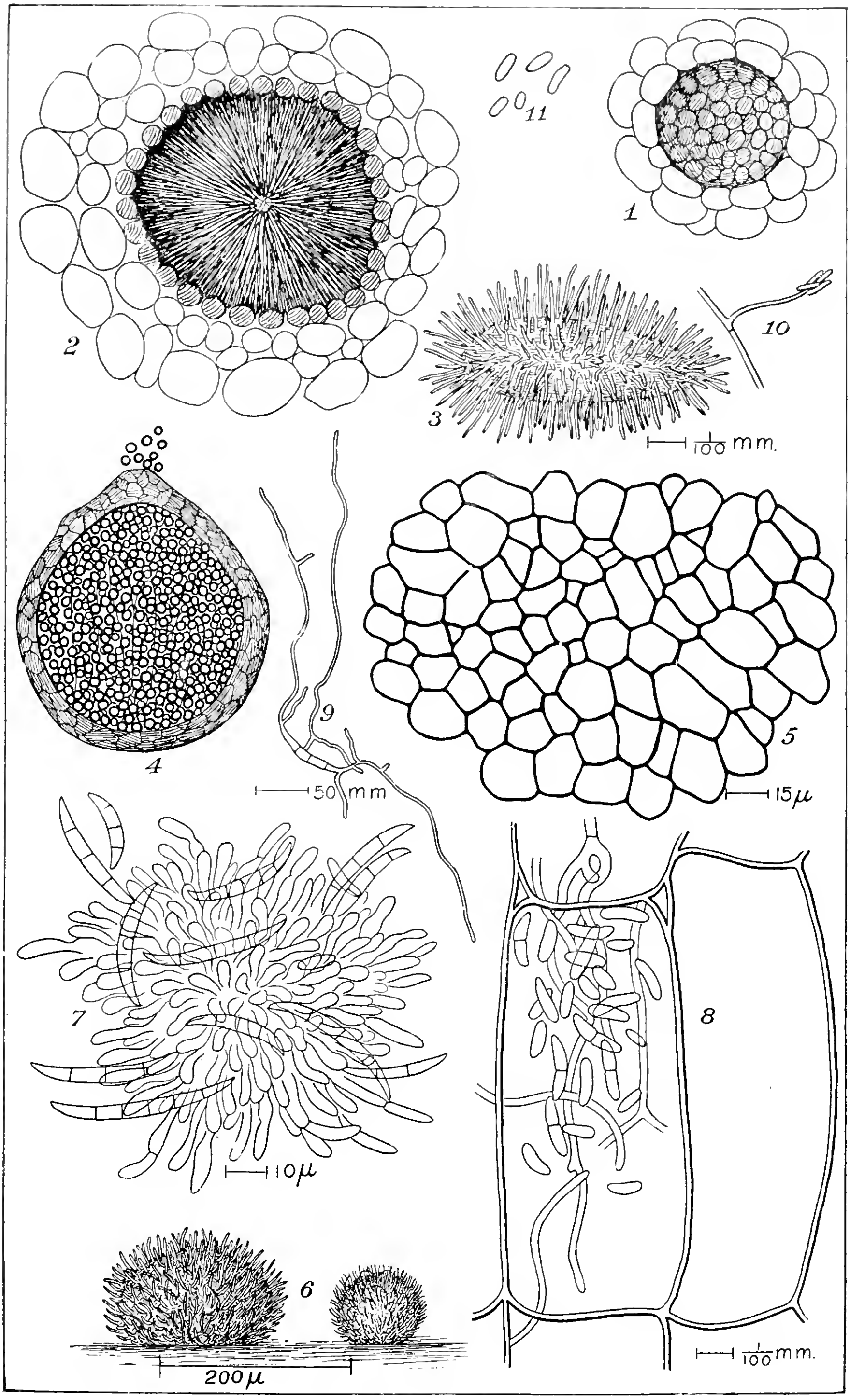
8. Parenchyma cells from the living hypocotyl of a young watermelon, third day of the wilt. Parenchyma partially occupied by conidia-bearing mycelium. No fungus on the surface. In this cell there were 26 conidia. The section was jarred repeatedly and somewhat roughly, and finally turned over without disturbing the fungus. Undisturbed nonparasitized parenchyma cells were above and below it, and the conidia were plainly inside of the cell here figured, which was from tissue near a fungus-infested bundle. Hothouse experiment, Washington, D. C., April 10, 1895.

9. An external, lunulate, 3-septate conidium of the watermelon fungus after seventeen hours in acid cucumber agar. Twenty-four hours later numerous elliptical conidia, like those shown in Plate I, *7*, were abstricted.

10. Hypha end, showing abstriction of the internal conidia from mycelium of *9,* forty eight hours after the latter was drawn.

11. Internal conidia of cowpea fungus. These spores were taken from the vessels of cowpea stems on James Island, S. C., August 7, 1895. Twenty-nine internal conidia were measured that day, the size varying as follows: Length, 4.5 to 18 μ; breadth 2.3 to 4 μ.

Figures transferred to the plate by Mr. Williams Welch, from camera drawings by the author.



FUNGUS OF THE MELON AND COWPEA WILT.

DESCRIPTION OF PLATE III.

1. Microconidium from the interior of a melon stem, germinating after 7 hours in agar.

2. The same conidium, after 24 hours in agar, showing numerous branches and the abstriction of new conidia. Under favorable conditions conidia are formed very rapidly. Three hours after this drawing was made this mycelium had given rise to 40 free conidia and 30 more were in various stages of growth.

3. Formation of microconidia of the watermelon fungus in an agar plate culture. This hypha end was under continuous observation for two hours and eighteen minutes, during which time two spores were developed and abstricted and another begun. Room temperature, 27° C. The formation of conidia was carefully followed in a number of other cases. Under the most favorable conditions of temperature and food supply only forty-five minutes intervened between the pushing off of one conidium and the formation and abscission of another. Usually, however, fifty-five to sixty minutes was required.

4. Mycelium and conidia of the melon fungus from a young agar culture. This was one piece of mycelium, broken in the drawing at the place marked x for convenience of representation on the plate. Mycelium and conidia vacuolate, all formed in the agar, only sterile hyphæ ends projecting into the air in this early stage of growth. Two spores germinating. This figure well illustrates the way the hypha end throws off a few conidia, passes into a vegetative condition, and elongates for a time, with formation of septa, and then once more ceases to elongate and becomes sporiferous. Monetta, S. C., July 4, 1894.

5. Microconidia of the melon fungus from an agar plate, showing the variability in size. Two spores germinating.

6. Conidia and torulose mycelium from a culture of the internal watermelon fungus (*Fusarium niveum*) 27 days old.

7. Fragment of mycelium from the same culture as *6*.

8. Fragment of mycelium from a culture of the internal cotton fungus (*Fusarium vasinfectum*) 25 days old. For comparison with *7*.

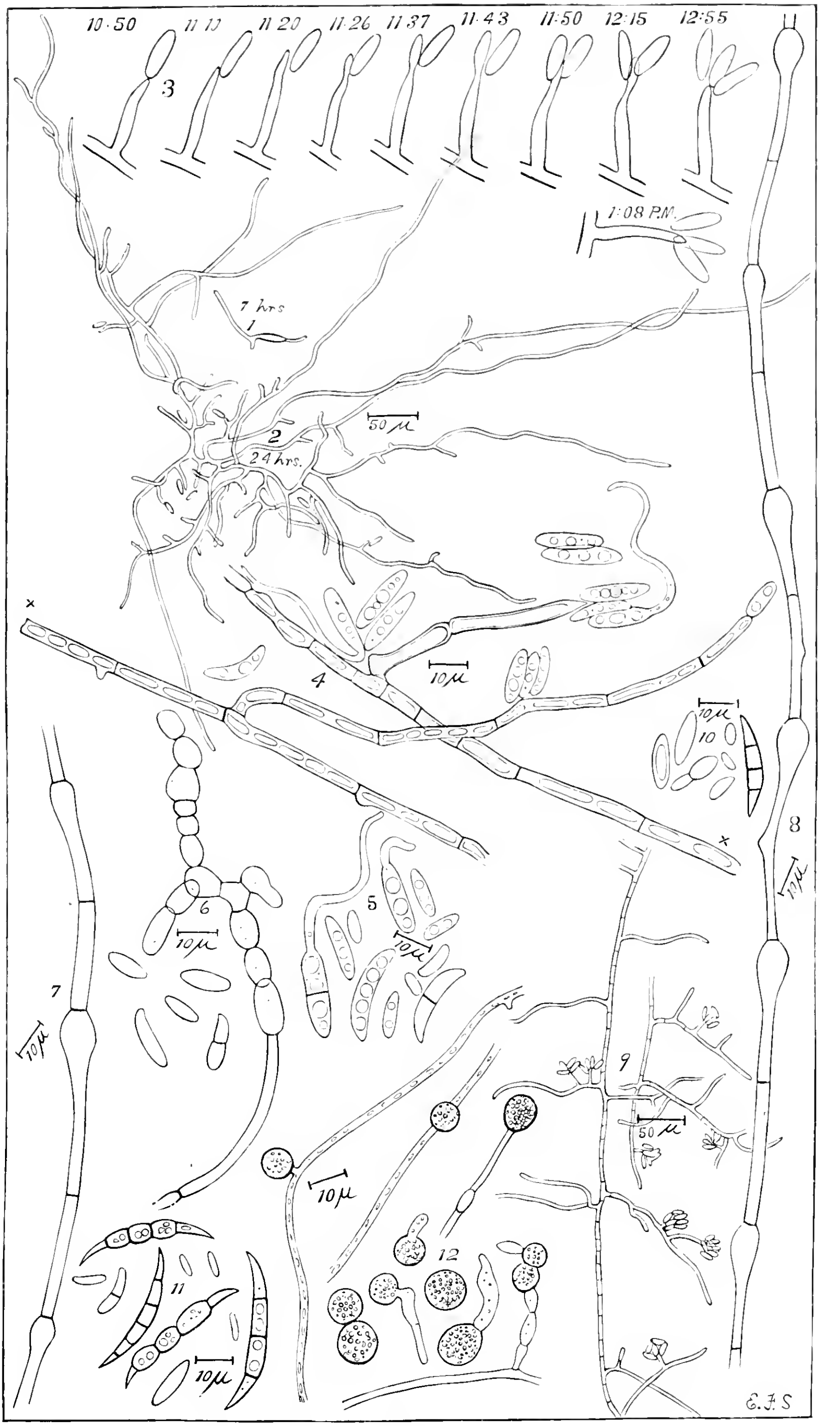
9. Mycelium and microconidia of the cotton fungus (*Fusarium vasinfectum*), cultivated from the interior of a diseased cotton stem received from western Georgia. From a pure white culture 25 days old. For comparison with *2* and *4*.

10. Conidia of the cotton fungus from a culture 25 days old, derived from the internal or microconidia. For comparison with *11*.

11. Macroconidia and microconidia of the watermelon fungus from a pure culture 5½ months old, on sterilized horse dung. The mycelium which bore these spores was derived from a spore of the size and shape of the largest here shown.

12. Chlamydospores of the melon fungus. Several germinating. From a pure culture 5½ months old, on horse dung. This culture was derived from a lunulate, several-septate, external conidium. In mass these chlamydospores were brick red, and their contents was considerably denser than has been indicated by the engraver. At 11 a. m., when the examinations began (in water), there were no germinations; at 4.30 p. m. there were many. In the same tube with these chlamydospores were conidia of all the sizes shown in *11*, the small spores being much more numerous than the large ones.

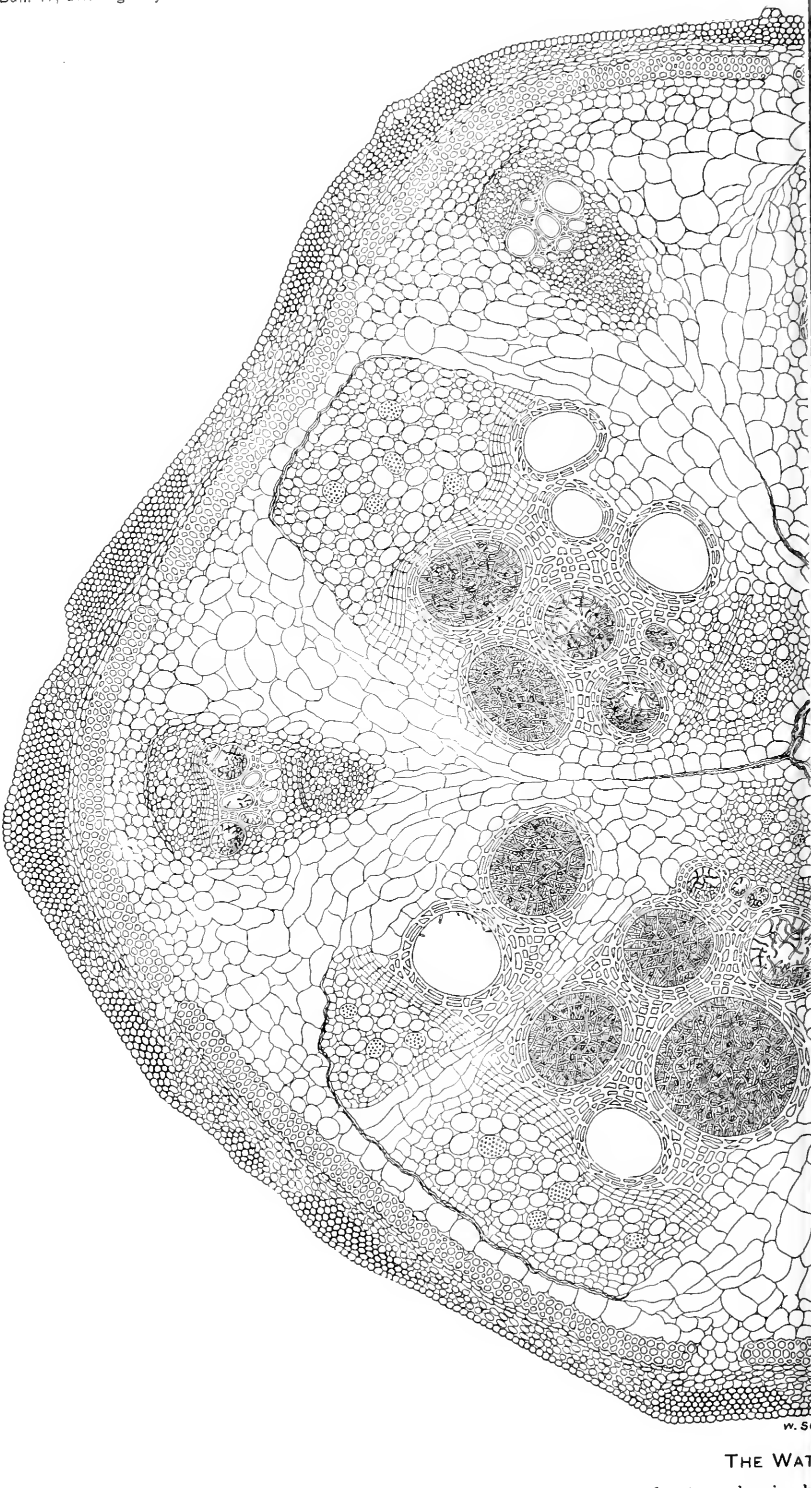
Figures drawn by the author and engraved on wood by L. S. Williams.



FUNGUS OF THE MELON AND COTTON WILT.
(From culture media.)

DESCRIPTION OF PLATE IV.

Cross section of a mature watermelon stem, showing how the vessels are plugged by the fungus. In this stage of the disease the foliage has suddenly wilted (as shown in Pl. VII, *1*), but is not yet shriveled; the stem is green and turgid and its parenchyma is not yet invaded. From the surface inward the tissues are as follows: (1) Epidermis, (2) collenchyma, (3) cortical parenchyma, (4) bast fibers (stereome), (5) medullary system, (6) ten bicollateral bundles in two rows, (7) pith. The structure of the bundles is as follows: (1) outer phloem, (2) cambium, (3) xylem, consisting of pitted and reticulated vessels held together by wood parenchyma, (4) spiral vessels lying in non-lignified living parenchyma (the primary vessel parenchyma of Strasburger), (5) pseudocambial layer, (6) inner phloem, composed like the outer phloem of sieve tubes and companion cells. On the outer side of the outer phloem may be seen the collapsed remnants of the primary sieve tubes. The middle portion of the stem is occupied by fissures. Section embedded in paraffin, cut on the microtome, and stained in hæmatoxylin. Reduced one-third from a pen drawing made directly from the section by Mr. W. Scholl. Diameter of the stem, 4 millimeters.



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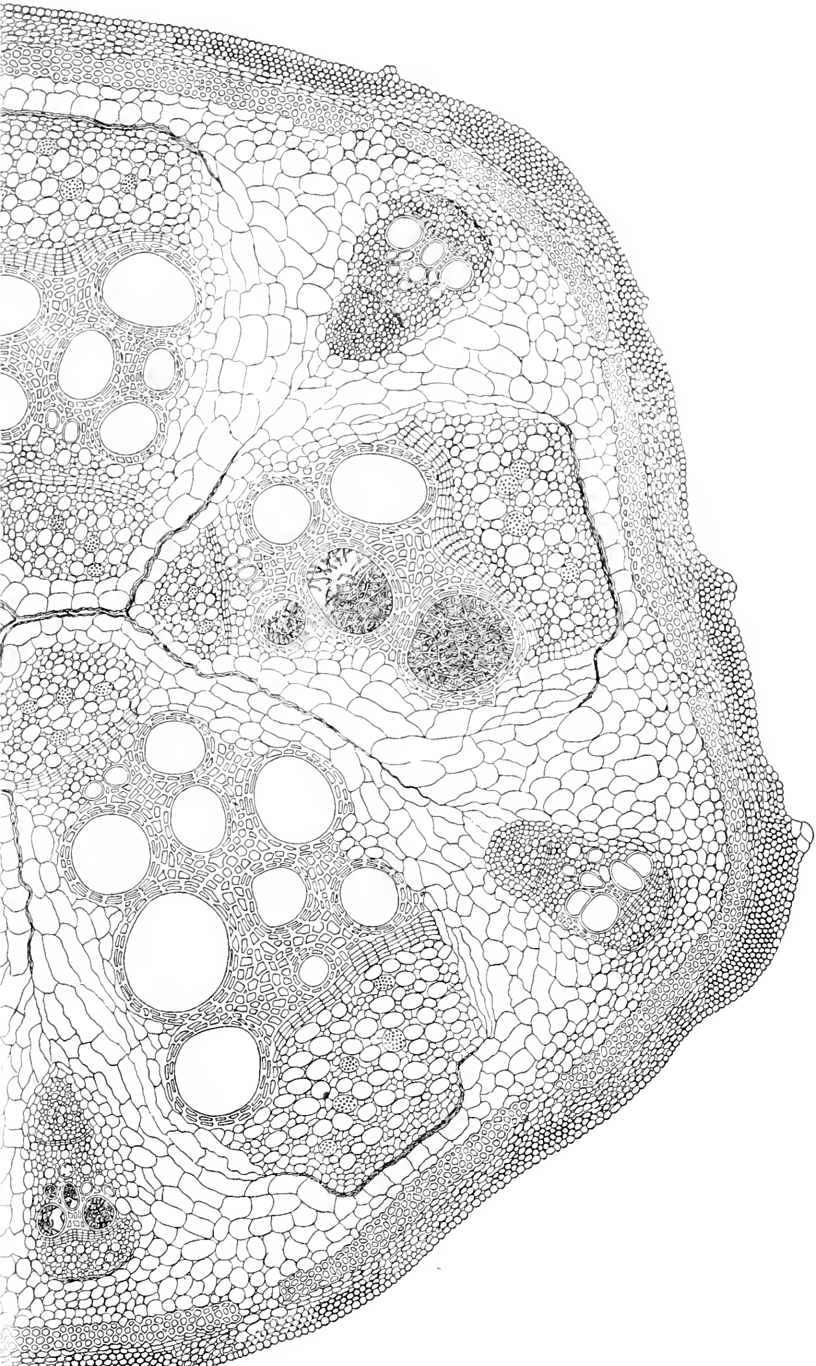
Cross section of a stem, showing b



DEL

MELON WILT.

he vessels are plugged by the fungus.

DESCRIPTION OF PLATE V.

1. Perithecium and ascospores from upland cotton. Salters Depot, Williamsburg Co., S. C., Oct. 8, 1895. Size 352 by 272 μ. For comparison with Pl. I, *1*, which, however, is less highly magnified. The ascospores of this perithecium were 10 by 10 μ with a wrinkled exospore. Others on the same specimens were 9 by 9 μ. More rarely they were 9 by 10 μ or 9 by 11 μ.

2. Ripe ascus and paraphysis from the same lot of specimens as *1*. A paraphysis from a perithecium on cowpea was 18 μ broad (cell next to the end cell).

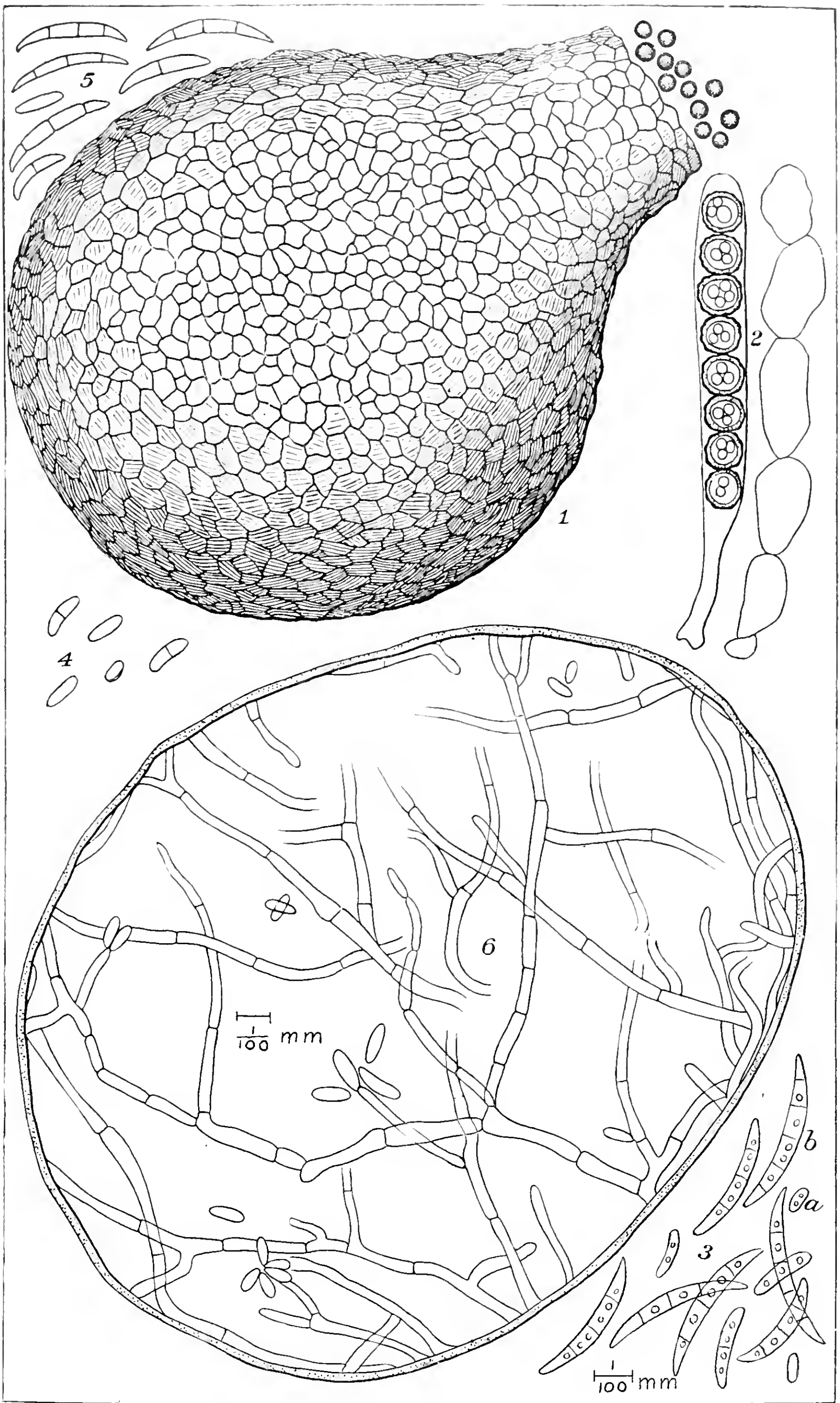
3. Macroconidia from conidia beds on the surface of killed stems of sea-island cotton. James Island, S. C., June 29, 1895. All transitions between *a* and *b* were observed.

4. Internal or microconidia from a diseased okra plant. James Island, S. C., July 25, 1895. Size 8 to 16 by 2.5 to 3.5 μ. This okra had been planted in place of cotton which wilted and died early in the growing season. Many plants were affected. The stems were 2 feet tall and about 1 inch in diameter at the base. The wood was much browned the whole length of the stem.

5. Macroconidia from external conidia beds on dead okra plants. James Island, S. C., July 25, 1895. The mature spores measured 27 to 42 by 3 to 5 μ. Occasionally one was 5-septate. The vessels and parenchyma of these plants contained a great amount of mycelium bearing such spores as are shown in *4*.

6. Highly magnified cross section of a pitted vessel which is beginning to be occupied by the melon fungus. Stem of watermelon. Monetta, S. C., June 26, 1894. Camera drawing from a fresh section examined in water. A great many of the vessels were plugged solid by the fungus, as if stuffed with cotton. For the location of these fungus-infested vessels with reference to other parts of the stem see Plate IV.

Figures transferred to the plate by Mr. Williams Welch from camera drawings by the author.



FUNGUS OF THE COTTON, OKRA, AND MELON WILT.

DESCRIPTION OF PLATE VI.

Healthy melon vines. Monetta, S. C. June 28, 1894. For comparison with the photographs shown on the following plate, which were made at the same time and from the same field. The vine in the foreground had about 200 leaves and a melon three-fourths grown.

HEALTHY WATERMELON VINES.
Monetta, S. C., June, 1894.

DESCRIPTION OF PLATE VII.

Vines attacked by the melon fungus. Monetta, S. C. Photographs a. m. of June 28, 1894.

1. On the afternoon of June 26, when last examined, this vine was to all appearances as healthy as that shown on Plate VI.

2. A vine which has been wilted for several days. Healthy vines in the background.

WILTED MELON VINES FROM THE SAME FIELD AS PLATE VI.

Vessels of the stem and root plugged as shown in Plate IV.

DESCRIPTION OF PLATE VIII.

Melon wilt. The result of soil inoculations. Hothouse experiment. Washington, D. C. Photographed April 17, 1895. Soil inoculated in 1894 with internal melon fungus brought from South Carolina.

1. Two healthy and 3 diseased plants; *2.* One healthy and 3 diseased plants.

In this stage of growth the first symptom is a drooping of the cotyledons; this is followed by flaccidity of the plumule and a bowing over of the hypocotyl. The parts above ground and the roots also are sound externally—i. e. they are not wounded, rotted, softened, shriveled, or browned in any way. In this early stage of the disease there is little or no fungus in the hypocotyl, but the vessels of the taproot are plugged.[1] After photographing, water was withheld from these plants, and as they were in a dry room they soon died, the healthy ones included. On April 24 each of the 6 plants which were wilted when photographed bore the conidia beds of the external Fusarium, and a further examination showed the bundles and parenchymatic tissues of these plants to be full of the internal mycelium and microconidia. On the contrary, the 3 plants which were healthy when photographed contained no internal fungus, and there were no Fusarium beds on the surface, although the plants were under a bell jar in moist air for a day or two prior to the examination.

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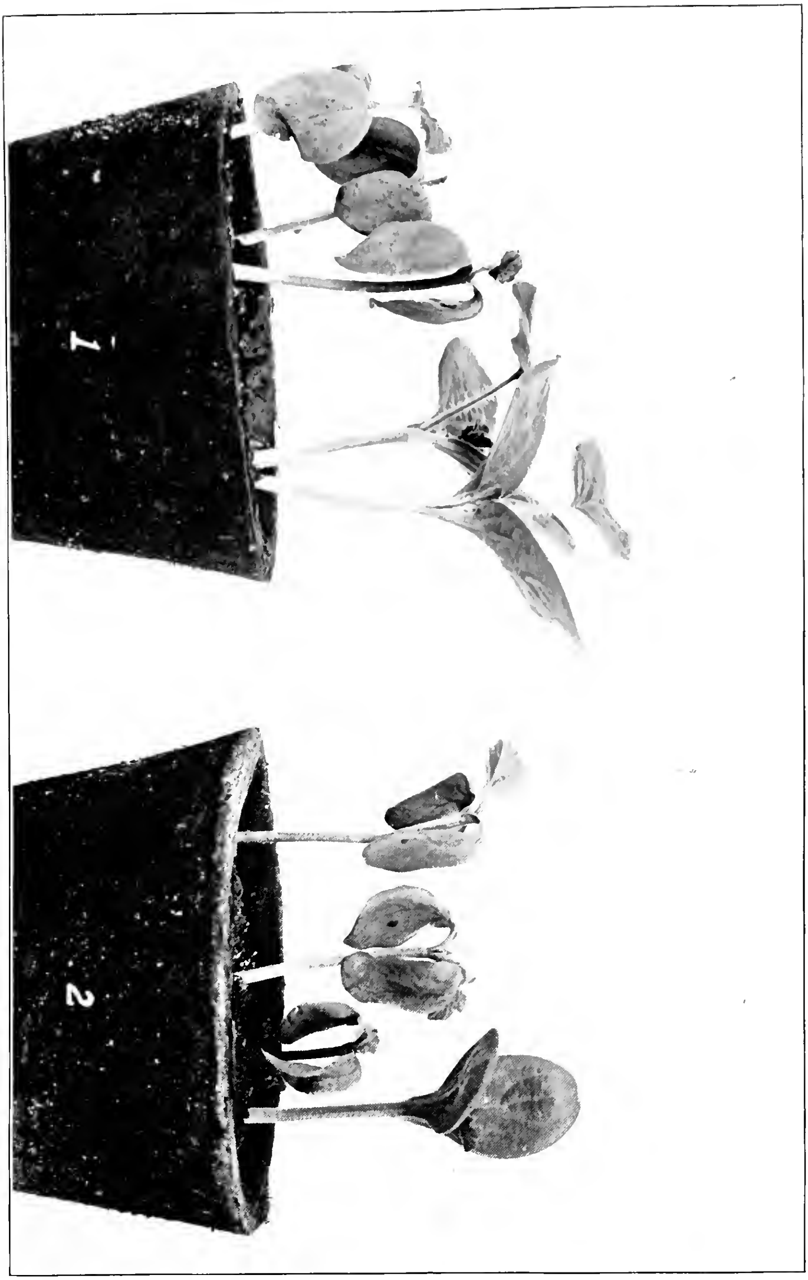
[1] June 29, 1894, about 1,500 hills of watermelons were planted by the writer on a sandy field in South Carolina, which had been infected from stable manure, and on which most of the melon vines had been destroyed by this fungus in May and June of that year. The disease began soon after the plants came up, and in 6 weeks nearly all of the young melons had wilted, altogether perhaps eight or ten thousand plants. The cotyledons first became flabby and drooped, the first true leaf then wilted, the hypocotyl lost turgor and bowed over to the ground, and the plants finally shriveled—i. e., the symptoms were precisely the same as those subsequently obtained in Washington with pure cultures of the melon fungus. A hundred or more of these wilting plants were examined microscopically, and in each one the fungus was found in the vessels of the hypocotyl or taproot or both in quantity sufficient to account for the disease and commonly nothing else was present. In many plants which were not pulled until the second or third day of the wilt, the fungus was found pushing out into the parenchyma cells and fruiting therein, as shown on Pl. II, *8*. July 14 the writer removed 14 healthy-looking young melon plants from as many different hills in this field and examined them microscopically for the presence of the fungus. Vines had recently wilted in each of these hills. The big seedlings were growing rapidly and appeared to be perfectly healthy above ground and below. In 12 of these plants no fungus could be found. In 1 there was an abundance of the fungus in the big central duct of the taproot and in some of the smaller vessels, but none could be found in the hypocotyl. In the other, there was also no fungus in the hypocotyl save doubtfully a thread or two in one vessel, but there was plenty of it in the big ducts of the taproot about 1 centimeter below the crown. No hyphæ threads were observed in the parenchyma cells of the roots, which were white and appeared to be entirely sound. These two plants would have wilted in a day or two, and the history of the experiment shows that the other 12 would subsequently have contracted the disease.



THE MELON WILT IN SEEDLINGS.

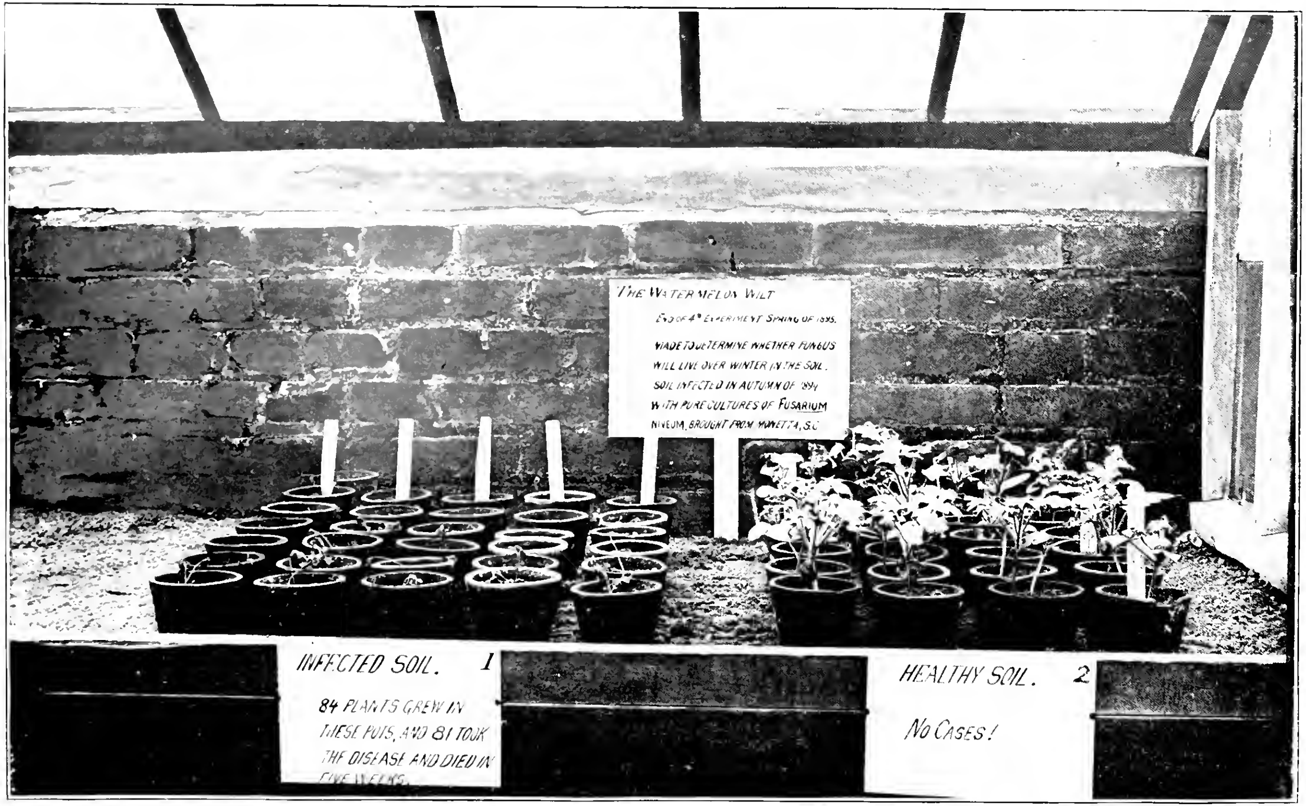
Soil inoculated with mycelium from an *internal* conidium. (Vessels of the taproot plugged.)

DESCRIPTION OF PLATE IX.

Watermelon wilt. Hothouse experiment. Washington, D. C. Spring of 1895.

1. Pots of the same series as Pl. VIII, but photographed some weeks later. All of the plants were killed by the fungus except the three mentioned above. Seeds planted March 12; photograph made some time in May.

2. Control plants growing in uninoculated (healthy) soil. None of these plants contracted the disease, but toward the close of the experiment all were dwarfed by leaf aphides.



THE MELON WILT.

Soil inoculated with mycelium from an *internal* conidium. (Fungus now fruiting on the surface of the dead stems.)

DESCRIPTION OF PLATE X.

Melon wilt. Result of soil inoculations *with the external fungus.* Hothouse experiment. Washington, D. C. Photographed June 10, 1895. The fungus used for infection was derived from a single, large, lunulate, several-septate spore, taken from the surface of a plant killed by the internal fungus. When photographed there were no conidia beds on the surface of these wilted plants, but in each case the internal fungus was found plugging the vessels of the taproot; the internal conidia were elliptical or bluntly pointed, straight or slightly curved, non-septate, and 8 to 20 by 3.5 to 4 μ. On June 8 the plant at the right was as healthy looking as its companion, but the plant in the middle pot and at the extreme left were already wilted. The three healthy vines afterwards contracted the disease.

THE MELON WILT.

Soil inoculated with mycelium from an *external* conidium. (Fungus in the vessels of the taproot.)

BULLETIN No. 18. V. P. P.—68.

U. S. DEPARTMENT OF AGRICULTURE.

DIVISION OF VEGETABLE PHYSIOLOGY AND PATHOLOGY.

B. T. GALLOWAY, CHIEF.

THE PHYSIOLOGICAL RÔLE OF MINERAL NUTRIENTS.

BY

OSCAR LOEW,

OF THE

Division of Vegetable Physiology and Pathology

WASHINGTON:

GOVERNMENT PRINTING OFFICE.

1899.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
DIVISION OF VEGETABLE PHYSIOLOGY AND PATHOLOGY,
Washington, D. C., September 28, 1899.

SIR: I respectfully transmit herewith a bulletin prepared by Dr. Oscar Loew, of this Division, on the physiological rôle of mineral nutrients. For several years Dr. Loew has been engaged in the study of the functions of mineral nutrients in plants. This work has led into new fields, and has resulted in discoveries which it is believed will be of much practical value to agriculture. The importance of mineral nutrients is so well known as to need little comment, but the part each plays in the life of an organism is still largely a matter of conjecture. It is evident that we can not hope to understand nutrition until we become better acquainted with the physiological action of the nutrients themselves. The main object of this bulletin is to show what has been accomplished in this direction, and to encourage and stimulate work along the lines laid down. The matter has been prepared primarily for teachers and experiment station workers, and is therefore treated from a technical rather than a practical standpoint. I respectfully recommend that it be published as Bulletin No. 18 of this Division.

Respectfully,

B. T. GALLOWAY,
Chief of Division.

Hon. JAMES WILSON,
Secretary of Agriculture.

CONTENTS.

THE PHYSIOLOGICAL RÔLE OF MINERAL NUTRIENTS.

By Oscar Loew.

GENERAL REMARKS ON THE MINERAL CONSTITUENTS FOUND IN ORGANISMS.

HISTORICAL NOTES.

The functions of the mineral nutrients in plants and animals constitute a highly important problem. Normal development is impeded by the decrease and entirely prevented by the absence of even a single nutrient, and gradual decline, disease, and finally death will result from the continued withholding of any such substance. Thus yellow spots will develop on the leaves of the sugar beet when the soil is deficient in lime; mold fungi will not develop spores but only mycelium when the amount of magnesia in the nourishing medium becomes too small; and even the primary segmentation will stop entirely in the fecundated eggs of lower marine animals when lime salts are withheld, while every further physiological action comes to an end as soon as sodium salts are substituted for potassium salts in the cells. Pigeons die in a few weeks when fed with materials too poor in mineral matter, and dogs can not subsist on meat which has been macerated with cold water, by which means most of the mineral matter is removed. The result of eating such food is weakness of the muscles and nervous excitability, which finally lead to death with spasms and the symptoms of suffocation.

In examining highly differentiated plants and animals there are observed not only certain differences as to the total sum of mineral matter in the different organs of the same organism, but also certain regularities as to the proportions of the mineral constituents. On the other hand, pathological conditions lead to a partial excretion of the mineral matter. Thus, in tuberculosis of man the excretion of lime and magnesia is increased, and in diabetes the increased excretion of lime is a specific symptom. These facts can be understood properly only when it is admitted that for the normal functions of normal organs a certain amount of lime and magnesia is indispensable.

Humphrey Davy[1] was the first savant to consider the mineral constituents essential for the development of plants. He says: "The chemistry of the simpler manures (the manures which act in very small quantities, such as gypsum, alkalies, and various saline substances), has hitherto been exceedingly obscure. It has been generally supposed that these materials act in the vegetable economy in the same manner as condiments or stimulants in the animal economy, and that they render the common food more nutritive. It seems, however, a much more probable idea that they are actually a part of the true food of plants, and that they supply that kind of matter to the vegetable fiber which is analogous to the bony matter in animal structures." Davy mentions among other things the beneficial action of gypsum, bone dust, and slaked lime. Indeed, the favorable effects of wood ash, bone dust, and liming upon vegetation have been known since olden times. Furthermore, mills for grinding bones existed early in this century in France and England, and enterprising men went so far as to dig up battlefields in Europe and unearth thousands of tons of bones for agricultural purposes.

Sprengel[2] was the second one to express an opinion on this subject. He says: "We can accept it as an indisputable fact that mineral matters found in plants also are real nutrients for them, and that it is not their action upon the humus which makes them important, since gypsum, potassium sulphate, and calcium phosphate do not at all act upon the humus."[3]

In quite a different sense Berzelius argued the same year that the action of lime is simply that of a stimulant for the plant and a solvent for the humus, while lime and alkali promote the rotting of organic materials, as manure.

After Sprengel followed Liebig (1840), whose theories received substantial support in the important researches of Wiegmann and Polstorf (1842). However, great as was Liebig's merit in overthrowing the dominant theory of the nourishing qualities of organic matter, called humus, in the soil, and in showing the absolute necessity of mineral salts in plants, the fact can not be denied that he made various errors, especially in his earlier years. For instance, he at one time believed that mineral bases serve merely to neutralize the organic acids in the plant and that they could replace each other, and further, that alkaloids in plants could play the part of mineral bases. He ascribed certain

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[1] Elements of Agricultural Chemistry, London, 1814.

[2] Theorie der Düngung, 1839.

[3] As a significant fact it may be mentioned that the Prussian Academy of Sciences, in the year 1800 offered a prize for an investigation to decide whether the mineral matters found in plants are taken up from the soil or whether they are produced in the plants themselves by vital power. This question was treated by Schrader, whose decision was in favor of the latter opinion. How much farther advanced was Saussure, who, in 1804, declared that the mineral matter of humus contribute in a certain degree to its fertility, since the same are found in the ashes of the plants (Récherches sur la végétation).

diseases of plants solely to the deficiency of mineral matter in the soil, but later investigations have demonstrated that fungous or animal parasites are the true causes. After about twenty years of hard fighting the importance of Liebig's mineral theory was in the main recognized and the old humus theory abandoned. However, his opinion that the mineral bases replace each other has been proved to be erroneous by the experiments of Wolff, Knop, Hellriegel, and others. The indispensability of potassa was proved, especially by Friedrich Nobbe, Schroeder, and Erdmann (1871), as was also the noxious character of lithium salts for Phanerogams. But the real significance of the bases in the plant cells has not been cleared up, and, as a botanist has expressed it, the solution of these problems must form an important final goal for every plant physiologist.

When Liebig had called attention to the necessity of certain mineral constituents in plants he set his assistants and students at work to analyze the ashes of a great number of plants. He published an account of these analyses in his works on agriculture, but a more comprehensive review on plant ashes is given in the tables of E. Wolff.[1]

These results show that the quantitative composition of the ash of one and the same plant varies according to the soil upon which it is grown, but that qualitatively there is no difference. This observation, which led Liebig to erroneous assumptions, was properly explained much later. It was found that every plant absolutely requires a certain minimum of each mineral nutrient, and that in most cases besides this minimum it takes up not only an excess of these various compounds, but also substances which are perhaps useful but not absolutely necessary for plant functions, such as sodium salts and silica. In the case of potassium or calcium salts a moderate surplus is not noxious. A large excess of lime taken up can be easily excluded from secondary influences by transformation into oxalate or carbonate—salts which are often produced by plants. Plants adapted to saline desert soils show incrustations on their leaves, which may sometimes contain, in addition to chlorid, nitrate, and sulphate of sodium, more than 50 per cent of calcium carbonate.

The surplus of mineral matter found in plants—nutrient as well as indifferent compounds—depends to a great extent upon the intensity of the current of transpiration, which explains why herbaceous plants show a higher percentage of ash for the dry matter than do the leaves of woody plants. While cabbage leaves, which have about 90 per cent water, contain 15 to 18 per cent ash for the dry matter, the leaves of potatoes, clover, and grass, having 78 to 80 per cent water, contain only 6 to 9 per cent ash for the dry matter. In trees adapted to moist soil, for instance, *Salix*, *Populus*, *Acer*, and *Tilia*, the leaves contain more water and also generally more ash for the dry matter than do the leaves of trees in which transpiration goes on more slowly, such as *Quercus*,

[1] Aschen Analysen (2 volumes), Berlin, 1871 and 1880.

Fagus, and the common kinds of *Pinus*. While leaves of *Acer* show 7 to 9 per cent of ash and those of *Salix* 4 to 6 per cent, the leaves of *Pinus montana* and *P. austriaca* show only 0.58 per cent and 0.74 per cent, respectively (Ebermayer). There is more ash in the leaves than in the roots or stems, more in the roots and stems than in the seeds, and more in the seeds than in the wood.

ECOLOGICAL AND PHYSIOLOGICAL RÔLE OF MINERAL SUBSTANCES.

A question of fundamental importance is whether a certain mineral constituent has one or several functions to perform, and in the latter case whether at least one of these several functions may not be performed by some other related constituent—in other words, whether a partial substitution in the organisms would be possible. When a mere neutralization of acids or an osmotic action is involved there can be no doubt that potassa or lime may be replaced by soda, or when incrustation of a tissue is necessary for protection the place of calcium carbonate might be taken even by silica. The solution of various mineral salts produces osmotic pressure and motion required also by animals. Thus beef tea containing 0.35 gram of salts per liter, exerts an osmotic energy of several atmospheres, of which, however, only about one-fourth can be realized in the stomach, since the blood itself also contains mineral salts. However, it suffices to produce an aqueous current from the blood to the stomach, while in the intestines the current takes the opposite direction.[1] Such functions are not specific, however. But in the purely physiological functions of a chemical nature not even a partial substitution is possible, notwithstanding that various assertions have been made to the contrary. The most novel supposition in connection with this idea of substitution, and one very amusing to chemists, is that seriously made in a recent text-book of plant physiology, that is, that on other planets there may exist living organisms in which the carbon of the organic matter is replaced by silicon.

In order to furnish a foundation upon which to base a theory of the special functions of the various mineral constituents, separate analyses for each kind of organ are indispensable. In former times entire plants or animals were subjected to incineration and the ash analyzed, but such results were of very restricted value.[2] A distinction may be drawn between ecological and physiological functions. In the former case the mineral compound serves either as a mechanical support of the organic forms, as does for example the calcium phosphate in the case of bones, and probably the silica in grasses, feathers,[3] and hair; or it furnishes a protection against noxious influences from the outside, and against the attacks of enemies,[4] as do the needle crystals of calcium

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[1] Köppe, Therap. Monatshefte, 1897.

[2] Thus one author has inferred from his analyses that there is less magnesia in cats and dogs and less potassa in dogs than in rabbits (Zeitschr. Biol., Vol. X, p. 321).

[3] The organic silica compound in feathers was recently studied by Drechsel.

[4] It has been asserted that the siliceous deposit in the bark of *Fagus* and *Acer* and in the leaves of various other plants forms a protection against parasitic fungi.

oxalate in certain leaves against snails; the incrustations of leaves and entire plants (Chara) by calcium carbonate; the lime shells of *Foraminifera*, certain worms, mollusca, and eggs of birds; the silica shells of diatoms; and the secretion of dilute sulphuric acid by certain *Gastropoda*, as *Dolium*, *Cassis*, etc. Finally, mineral matter may be an object of adaptation, as the salts in sea water is for marine animals. However, in this bulletin the physiological rôle alone is the subject of discussion.

MINERAL COMPOUNDS FOUND IN ORGANISMS.

The mineral compounds usually found in living organisms are phosphates, sulphates, carbonates, chlorids, silica, iron compounds, magnesia, lime, soda, and potassa; while in plants nitrates, manganic compounds, and minute quantities of fluorides also often occur. Small quantities of iodine compounds are found in both kingdoms. Bromine compounds occur in sea weeds. Occasionally there are present in plants small quantities of titanic and boracic acids, lithia, and alumina, and of the oxids of lead, zinc, and copper.[1] Sodium salts are not necessary for physiological uses of plants, but are for those of animals. Calcium salts are of great importance for plants and animals, only the lower fungi and lower algæ being able to do without them. Magnesium and potassium salts, however, can not be dispensed with by any living cell any more than can phosphoric acid. Manganese, which was shown by Risse to be incapable of replacing the iron in plants and was believed to be entirely useless, forms, according to recent researches of Bertrand, an essential constituent of the vegetable oxidizing enzyms, and hence may be also of physiological interest.[2] The nitrates and sulphates present in plants serve, in regard to their acids, chiefly as sources of nitrogen and sulphur for protein formation, and consequently do not require further discussion. As physiological elements these must be designated potassium, sodium, calcium, magnesium, iron, phosphorus, chlorine, iodine, carbon, hydrogen, nitrogen, oxygen, and sulphur.

GENERAL VALUE OF CERTAIN MINERAL SALTS.

Mineral salts have not only to perform ecological as well as specific chemical functions, but also seem to contribute directly to the maintenance of the continuance of the living condition of the protoplasm. A most striking instance of this is the rapid dying of infusoria in distilled water. The writer entertained for a time the supposition that this

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[1] Lippmann observed in the sugar beet not only boric acid and copper oxid, but also traces of vanadin and cæsium compounds (Bot. Jahrb., 1888). Wait found 0.31 per cent titanic acid in the ash of oak wood, 0.11 per cent in the ash of apples, and traces of it in bones and meat, and Dunnington found it in many soils.

[2] According to Lepinois, iron can replace manganese in this regard, and the formation of oxidase in plants raised in the absence of manganese was further observed by Albert F. Woods.

phenomenon might be due, as in the case of the alga *Spirogyra*, to slight traces of copper sometimes found in distilled water and derived from the copper vessels used in distilling. Experiments were therefore repeated, water distilled from glass vessels being used, but the effect was the same—the infusoria died with bloating, their protoplasm swelling and disintegrating. The only conclusion that can be drawn, therefore, is that the distilled water extracts from them traces of necessary constituents, which must be of mineral nature, since common water containing some mineral matter has no such action, but forms the very medium of existence for these organisms. A similar effect could not be observed with the same distilled water on algæ cells, which may remain alive in it for a considerable time, although the growth ceases. But here the walls of the cytoplasm are probably of greater density, which would prevent the mineral matters of the cell from passing easily to the outside.

This phenomenon observed in the case of infusoria strongly resembles that of the red blood corpuscles and leucocytes, which are adapted to the degree of concentration of the serum, and which die when transferred into distilled water, but remain alive for some time in a sodium chlorid solution of 0.6 per cent. The nature of the mineral salts loosely bound by the proteids of the living matter may vary with the character of these proteids. In the one case it may be sodium chlorid, in another the secondary potassium phosphate, and in a third a calcium salt. It should be pointed out once for all that we can hope to understand the living state of protoplasm only when the proteins of the living matter are recognized to be chemically labil bodies, which the slightest influence often suffices to transform into the more stable isomeric forms of dead matter. Relatively stable proteins are also those in milk and the reserve proteins in eggs and seeds. Spontaneous transformations of labil compounds into stable ones by atomic migration often take place very easily, for example, when certain amido aldehydes or amido ketones are liberated from their combination with acids.

Years ago M. Nencki[1] recognized the importance of the mineral matter combined with the plasma proteids. "All proteins[2] occurring in the living organisms are combined with mineral substances, whereby the proteins concerned acquire specific properties and functional signification in the organisms."

It may be proper here to call attention to another phenomenon, first recognized by Wolff. He determined the minimum of each mineral nutrient necessary for the normal development of the oat plant when the other mineral nutrients were in excess, and found that when all the mineral nutrients are offered in the determined minimum amounts at the same time it is impossible for the plants to flower and fruit

[1] Arch. des. Sci. Biologiques de St. Petersburg. 1894, Vol. III, p. 312.

[2] While "protein" is the general denomination of all kinds of albuminous substances, the word "proteid" applies especially to the complex proteins, e. g., nucleo-albumin, mucin, hæmoglobin, etc.

normally. When only the absolutely necessary minimum of one of the nutrients is offered a certain surplus of some of the others must be present.

THE LOW ATOMIC WEIGHT OF THE MINERAL NUTRIENTS.

A review of the elements necessary for organic life shows at once that they have low atomic weights, iron, with an atomic weight of 56, having the highest among them. This is due, according to Leo Errera, not only to their more frequent occurrence in the various compounds making up the earth's crust, but also to their higher specific heat. Thus water, constituting as a rule two-thirds to three-fourths and sometimes even more of the weight of a living organism, has the highest specific heat of all substances, consequently it can diminish the effects of rapidly changing temperatures upon life.

THE PHYSIOLOGICAL RÔLE OF PHOSPHORIC ACID.

RELATION OF PHOSPHORIC ACID TO PROTEIDS AND TO THE DIVISION OF CELLS.

Phosphoric acid is, above all, necessary for the formation of lecithin[1] and the nucleo proteids, e. g., chromatin[2] and plastin—the most essential constituents of the nucleus and plastids. This makes clear the statement of former writers, that phosphoric acid "follows the proteids," since every new cell requires them. Wherever phosphoric acid is transformed from the dissolved condition to an insoluble compound, as in the formation and growth of the nucleus, fresh quantities must move thither, according to the law of diffusion. The embryos can develop by cell division only when phosphates are stored up in sufficient quantities in the seeds for the formation and increase of the nuclear substance in the new cells. Phosphoric acid, further, is not only contained as calcium and magnesium phosphate in the globoids, but is also distributed in the seeds as dipotassium phosphate.

The observation that the total mass of protein in seeds is increased by an increased supply of phosphoric acid would also be easily understood on the basis of the hypothesis of Strasburger and Schmitz that the nuclei are the manufacturers of the protein matter. This hypothesis is highly probable, and in fact has been confirmed by Hofer in the case of enzyms,[3] which must be considered as a class of proteins.

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[1] Two other phosphoric acid compounds, which are, however, restricted to the higher animals, are jecorin and inosic acid, the latter probably being merely a product of metabolism. Besides phosphoric acid, the latter yields on decomposition hypoxanthin and probably trioxyvalerianic acid (Heuser). Another compound, thus far encountered in plants only, yields, besides phosphoric acid among other things, inosite (Schulze and Winterstein).

[2] The nuclein extracted from organized structures is essentially an altered chromatin.

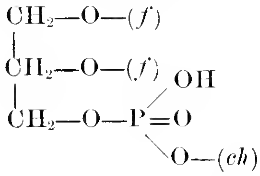
[3] Sitzungsberichte der Morph. Physiol. Ges., München, 1889.

In order to observe how a deficiency of phosphoric acid would interfere with the normal action of plant cells the writer compared at a low temperature the behavior of algæ (*Spirogyra*) in complete culture solutions[1] with that of algæ cultivated for eight weeks in solutions free from phosphoric acid, but containing all other necessary mineral nutrients. The result was that there was no growth in the absence of the phosphoric acid, but there was a yellow coloration of the chlorophyll and an accumulation of fat and albumin, while in the control algæ the number of cells had more than doubled, the coloration of the chlorophyll was normal, and the amount of fat and albumin stored up was much smaller than in the former case. When, however, at the end of eight weeks, 0.1 per mille of monopotassium phosphate was added to the culture free from phosphoric acid, a most energetic cell division began in most of the cells after a short time, thus demonstrating the great importance of phosphoric acid for this purpose.

A direct participation of inorganic phosphates in the formation of albumin, as Liebig had assumed, has not been proved, and is improbable. As the writer has observed, cells of algæ can continue to form albumin for a certain length of time, even in the absence of inorganic phosphates, although further growth and multiplication will thus be stopped.[2]

THE PHYSIOLOGICAL IMPORTANCE OF LECITHIN.

This ester of phosphoric acid contains fatty acids, glycerol, phosphoric acid, and choline, and corresponds to the following formula:[3]



It is a regular concomitant of fatty matter. It swells up in water and is even somewhat soluble in it, a property which renders it physiologically superior to the ordinary fatty matter. The chief function of lecithin is probably to serve for respiration; it represents the form into

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[1] The composition of the solution made with distilled water was as follows for the control culture:

	Per mille.
Potassium nitrate	0.2
Calcium nitrate	0.2
Sodium sulphate	0.1
Magnesium sulphate	0.1
Monopotassium phosphate	0.1
Ferrous sulphate	Trace.

The monopotassium phosphate was left out in one of the solutions.

[2] Biol. Centralbl., 1891, Vol. IX, No. 9.

[3] (*f*) Signifies the radical of a higher fatty acid; (*ch*) signifies the radical of choline.

which the fat must be changed to become combustible in the protoplasm, since the substances serving for respiration, must be present in the protoplasm in a dissolved condition.[1] Since fat is not soluble, a transformation of it into soap was formerly assumed—a view which is hardly possible in the case of plants, while upon animals soaps injected subcutaneously exert a poisonous action (Munk, 1889).

By the transformation of fatty matter into lecithin the higher fatty acids are offered to the protoplasm in a soluble form, and after being oxidized other molecules of fatty acids may enter into the place of the former and thus the same molecules of the glycerol-phosphoric acid can serve repeatedly as vehicles for oxidations of molecules of fatty acids. The fact that blood corpuscles contain lecithin but not fat seems to indicate that lecithin may be produced not only from fat, but also directly from sugar, as is fat. A great therapeutic value of lecithin has been demonstrated in cases of nervous debility and weakness of the alimentary functions. The brain and the whole nervous system in general are rich in lecithin, fully 17 per cent of it having been found in the gray substance of the brain. The nervous system requires for its perpetual great activity a substance which unites easy combustibility with a great deal of potential energy in a small volume, which conditions are admirably united in the lecithin.

Seeds rich in starch generally contain much less lecithin than those rich in protein. Thus barley grains contain less than half the amount contained in soy beans. The amount of lecithin increases to a certain point in the first stages of germination, while the amount of fat decreases.[2] Here the lecithin is evidently formed from the fat. It seems very probable that the observed increase of lecithin is less than was actually formed, since a part of it is probably consumed nearly as quickly as produced. The evergreen tea leaves lose the reserve lecithin in spring (Hanai) and green plants generally lose it when kept in the dark (Stoklasa). Heffter observed a decrease in the amount of lecithin in the liver during starvation. E. Schulze[3] found that during germination the quantity of choline increases, and that in wheat the choline is localized in the germ of the grain, but not in the endosperm. This is certainly of physiological interest, since the young developing germ must carry on an energetic respiration and therefore be capable of easily forming lecithin, in which process the presence of choline is required. It may further be mentioned in this connection that, according to Müntz, the amount of free fatty acids increases during germination, which is to be expected when lecithin is formed from fat. From

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[1] We can observe this with cholesterin, which is frequently contained in the cells and in fact is, like lecithin, a constant concomitant of fatty matter. It is not perceptibly oxidized by the protoplasm, the almost absolute insolubility in water being here the obstacle.

[2] Maxwell, Chem. Centralbl., Vol. XLI, No. 1, p. 365; Frankfurt, Landw. Vers. Stat., Vol. XLIII.

[3] Landw. Vers. Stat., Vol. XLVI.

all the observations cited it will be seen that lecithin plays an important rôle, and as its formation is made possible only when phosphoric acid is present, one of the functions of this acid at once becomes intelligible.

PHOSPHORIC ACID IN CHLOROPHYLL.

As Trécul, Gautier, and Hoppe have shown, the crystallized chlorophyllan also contains phosphoric acid (1.39 per cent)—indeed, for the formation of the chlorophyll green the presence of phosphoric acid is absolutely required (see p. 16). The opinion has been expressed that the crystallized chlorophyllan is a kind of lecithin. While it is the orthophosphoric acid that is contained in lecithin and chlorophyll, it is the metaphosphoric acid which forms a constituent of the chromatin (nuclein), as Leo Liebermann has discovered.

POTASSIUM PHOSPHATE AS A CELL CONSTITUENT.

That the secondary potassium phosphate as such also has an important physiological function becomes probable from its general occurrence in the living organisms. Relatively large proportions of it are found in yeast cells, in the forming seeds, in the liver and muscles, and in fact in all cases where special demands for great chemical achievements are made. It causes the weak alkaline reaction of protoplasm and is probably present in loose combination with certain proteins, from which even treatment with water will often easily remove most of it.

The dry substance of muscles contains about 4 per cent of mineral matter, of which again nearly two-thirds consist of dipotassium phosphate. This is also nearly the proportion found in beer yeast. Wheat grains contain from 1 to 2 per cent ash, of which nearly one-half consists of potassium phosphate and nearly one-fourth of calcium and magnesium phosphate, while another portion of phosphoric acid present in that ash corresponds to the destroyed nuclein and to the small portion of lecithin.[1]

A further special function of phosphoric acid is the use of calcium phosphate for the formation of bones. The blood ash of cattle contains 4 to 6 per cent and of man 9 to 11 per cent of phosphoric acid. The requirements for normal field crops are considerable, a wheat crop, for example, extracting from 1 hectare (about 2.5 acres) of ground about 26.5 kilos of this acid. The forest products require much less. It is in the production of seeds especially that the powerful influence of fertilization with phosphates becomes apparent.

Whether hypophosphites, phosphites, or hypophosphates can ever be of physiological value is a question which must be determined by further studies. Knop showed in an experiment with maize in 1881

[1] Several views have been expressed as to the transportation of calcium phosphate to the seeds. This salt is insoluble in water, but may be dissolved in small quantities by the weak acid juices of the plant. Vaudin (Chem. Zeit., No. 91, 1895) believes that its transportation in the vegetable organism is accomplished by sugar and potassium malate or citrate, which dissolve it in small quantities.

that phosphoric acid can not be replaced by hypophosphoric acid. The writer has observed that algæ are at least not injured by a 1 per mille solution of sodium hypophosphite, phosphite, or pyro and meta phosphate, and the two last-mentioned salts can even be well utilized by mold fungi.[1] The assertion once made that phosphoric acid in algæ may be replaced by arsenic acid is absurd and moreover Molisch had shown it to be impossible.

THE PHYSIOLOGICAL RÔLE OF IRON COMPOUNDS.

RELATION BETWEEN THE COLORING MATTER OF THE BLOOD AND OF THE LEAF.

Iron compounds are indispensable for the production of the chlorophyll[2] of the plant and the hæmoglobin of the red blood corpuscles of the higher animals. Without the former there is no assimilation of carbonic acid, hence no synthesis of organic matter in the green plant, and without the latter no respiration of the vertebrates, since it is the hæmoglobin that carries the molecular oxygen to the remotest regions of the body. Although the chlorophyll itself does not contain iron, hæmoglobin contains it as an essential constituent in the molecule.

There is evidently a close relation between the coloring matter of the leaf and that of the blood. The phylloporphyrin obtained from chlorophyll by the action of alkalies shows almost the same spectrum as the hæmatoporphyrin obtained from the hæmoglobin of the blood. Hæmatoporphyrin seems to correspond to a dioxyphylloporphyrin, and both of these compounds appear to be derivatives of pyrrol. It was especially the investigations of Nencki and of Tschirch that first directed attention to the analogies between these two physiologically important bodies.

INFLUENCE OF IRON AND OTHER MINERAL NUTRIENTS ON THE FORMATION OF CHLOROPHYLL.

Iron is not the only requisite for the production of chlorophyll. Other mineral nutrients are not less necessary, and above all only a normal plastid can produce the green color with the aid of iron salts and thus become a chloroplast; hence cases of imperfect plastids may occur, e. g., where an increased supply of lime is required to produce normally green leaves. A case where phosphoric acid was required in addition to the iron to produce the chlorophyll was observed by the writer in the case of an alga. Some threads of *Spirogyra majuscula* were placed

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[1] Bot. Centralbl., 1895.

[2] An observation on chlorophyll made by the writer may here be mentioned, as it places the great sensibility of this substance toward chemical reagents beyond a doubt. When *Spirogyra* threads are treated with moderately concentrated hydrochloric acid, they at once assume a yellowish color, but soon afterwards turn to a bluish green, which points to two successive changes and indicates that in the preparation of pure chlorophyll strong acids have to be avoided. Various discrepancies in the observations of different authors may be traced to this circumstance.

in 2 liters of distilled water, to which were added only 0.2 per mille calcium nitrate and 0.02 per mille ammonium sulphate. When they were placed in this very imperfect solution, the filaments contained in all probability some stored-up mineral matter, hence a moderate further growth of the cells was not surprising. Besides, mineral matter of some cells which died gradually may have been absorbed by the living ones. The cells did not increase by cell division, however, but merely enlarged. After standing six weeks the chlorophyll bodies had assumed a yellow color. The liquid, with the filaments, after the addition of 0.02 per mille ferrous sulphate, was now divided into two portions, and 0.5 per mille secondary sodium phosphate was added to one of them. After five days a very striking difference was noticed, the normal green reappearing only in the latter case, which proved that phosphoric acid is an essential factor for the production of chlorophyll. Stoklasa also has observed the necessity of phosphoric acid for the production of the chlorophyll green, and finally Macchiata[1] inferred from his experiments that plants may become chlorotic not only from a deficiency of iron, but also from lack of other mineral nutrients. Indeed, cases exist in which it is the deficiency of magnesia which causes this phenomenon (p. 49). Magnesia appears to form a constituent of the crystallized chlorophyllan of Hoppe, which, however, has recently been declared a mixture[2] which contains 1.72 per cent ash, of which 1.38 parts are phosphoric acid (mentioned above) and 0.34 magnesia (Hoppe).

An interesting fact observed by Zimmermann[3] is that the chloroplasts in chlorotic leaves are smaller than in normal leaves, and appear to be incapable of forming starch from sugar. Different from chlorosis is the albinism of plants. Here the leucoplasts have so far degenerated that they become incapable of producing the green color even when all the necessary mineral nutrients are present. Although incapable of forming carbohydrates from carbonic acid, however, they often form starch from sugar.[1]

FERTILIZING EFFECT OF IRON SALTS.

It is to be expected that a moderate manuring with iron salts would prove beneficial for plants grown on soil deficient in iron. Bracci[4] mixed 1 part of ferrous sulphate with 20 parts of silt and applied this mixture to soil in which oats and wheat were grown, and as a result the grain ripened several days earlier and the yields of straw and grain were increased. Spraying with ferrous sulphate is also said to produce favorable results. Ville applied a 2 per cent solution to young apple and pear fruits,[5] and thus not only hastened the ripening

[1] Bot. Jahresber., 1888, p. 20.

[2] Compare also the recent publications of Schunk and Marchlewski.

[3] Zimmermann, Beiträge zur Morph., etc., Heft II; Sapoznikoff, Bot. C., 1889, p. 321.

[4] Bot. Jahresber., 1883, p. 43.

[5] Ibid, p. 14. Other reports, however, mention an injurious action of a 1 per cent solution upon potato plants.

process, but also enlarged the size of the fruit. Cugini tries to explain this on the ground of stimulation of the protoplasm and increased production of chloroplasts in the epidermis.

ORGANIC COMPOUNDS CONTAINING IRON.

Hæmoglobin is not the only organic iron compound in organisms. Bunge isolated from the yolk of eggs a nuclein-like body, hæmatogen, which contained 5 per cent phosphorus and 0.23 per cent iron, and similar substances were observed by Zaleski in the liver of animals and by Macallum and Stoklasa in the nuclei of plant cells. Spitzer found in animals oxidizing enzyms, which were nucleo-proteids containing about 0.2 per cent of iron.

IRON IN FUNGI.

The question as to whether iron salts are necessary for fungi was formerly answered in the negative. Molisch,[1] however, observed that even very small traces of iron salts have a great effect upon the growth of fungi, and having discovered traces of it in the ash of various fungi, he considers it a necessary element for them. Indeed, slight traces of iron are frequently present in the nutrient compounds used for the cultivation of fungi. Certain writers admit that iron produces a beneficial effect, but deny that it is absolutely necessary. However, Molisch's observation that in fungi iron can not be replaced by nickel, cobalt, manganese, or zinc deserves special consideration. Traces of zinc and related salts will, according to Raulin, Ono, and Richards, also increase the fungus mass in a given time. Richards has shown that the nutrients are more economically disposed of under this influence. It may also be mentioned here that Gautier and Drouin observed that ferric oxid promotes the fixation of atmospheric nitrogen by soil bacteria.[2]

MANGANESE IN PLANTS.

Physiologically, manganese can not replace iron in plants. Plants have also been raised to perfection in culture solutions which contained no trace of manganese. However, the ash of plants, especially of woody ones, sometimes contains even more manganese than iron. Schroeder calculated for 1 hectare of eighty year old beech trees near Tharand a content of 104.1 kilos of Mn_3O_4, but only a content of 7.92 kilos of Fe_2O_3[3]. The ash of *Pinus strobus* showed a content of 2.06 per cent Mn_3O_4, and that of *Populus tremula* 1.06 per cent Mn_3O_4 (Weber).

In the case of pines, even the pollen grains contain manganese. Ramann found in them 5.23 per cent ash, and in 100 parts of this ash 1.95 per cent ferric oxid and 1.12 per cent manganic oxid (Mn_3O_4).[4]

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[1] Sitzungsber. d. Wien Akad., 1892, Vol. CIII. Aso found nearly 5 per cent ferric oxid in the ash of the spores of *Aspergillus oryzæ*.

[2] Bot. Jahresber., 1888, p. 29.

[3] Wolff's Aschen Analysen, Vol. II.

[4] The manganese content in oxidizing enzyms has been mentioned on p. 9

THE PHYSIOLOGICAL RÔLE OF HALOGEN COMPOUNDS.

PLANTS RAISED WITHOUT CHLORIDS.

The chlorine compounds to be considered in this connection are essentially those of sodium and potassium.[1] These chlorids are not necessary in the physiological functions of lower organisms. Fungi and fresh-water algæ can be successfully cultivated without a trace of a chlorid. In the case of the higher plants, Knop and Batalin successfully cultivated even halophytes in the absence of sodium chlorid, and Knop[2] maintains that chlorids are superfluous for all plants, and hence recommends a culture fluid free from chlorids.[3] On the other hand, functions appear, in certain plants at least, which perhaps by adaptation become dependent upon the presence of chlorine, especially in the form of potassium chlorid.

VALUE OF POTASSIUM CHLORID FOR BUCKWHEAT.

Nobbe has observed that buckwheat plants thrive normally in culture solutions without chlorids until the flowering period is over, but that soon thereafter the tips of the stalks die off; the upper part of the stalk thickens and shows ring-like swellings; the epidermis bursts vertically; the dark green leaves become brittle, spotted, and puffy, and roll in; no fruit is produced;[4] and a microscopical examination shows a great accumulation of starch granules in parts of the stems. These observations have been confirmed by Leydhecker.[5]

It might be supposed that the formation of diastase is prevented by the absence of chlorids, and that the transportation of starch thus becomes impossible, but the difficulty interposed by this hypothesis is that the development of the plant proceeds normally for a considerable length of time, that is, until the flowering stage is reached. This also militates against Detmer's belief that the beneficial action of potassium chlorid on the migration of starch is due to the formation of hydrochloric acid from this chlorid,[6] which acid he claims will in very small quantities promote the saccharification of starch by diastase.

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[1] Calcium and magnesium chlorid have an injurious effect on plants, probably on account of the liberation of hydrochloric acid in cells, this not being assimilated like nitric or sulphuric acids and therefore accumulating to a noxious degree.

[2] Kreislauf des Stoffs, Vol. I, p. 616. The writer can testify that when 0.01 per cent of sodium or potassium chlorid is added to suitable complete culture solutions no essential difference in growth or the amount of starch will be noticed in the cells of *Spirogyra*, but 0.5 per cent will retard growth.

[3] In Knop's culture fluid the proportion of the mineral nutrients is as follows: 1 KNO_3, 1 KH_2PO_4, 1 $MgSO_4$, and 4 $Ca(NO_3)_2$. The iron is suspended as ferric phosphate.

[4] All these phenomena have been observed by the writer in the case of buckwheat plants which received rubidium nitrate, and to a smaller degree also when rubidium chorid was used (p. 24).

[5] Landw. Vers. Stat., 1865 and 1866, Vols. VII and VIII.

[6] Pflanzenphysiol. Unters. über Fermentbildung, Jena, 1884.

INJURIOUS EFFECTS OF CHLORIDS ON PLANTS.

However necessary may be the presence of a certain amount of a chlorid for buckwheat and probably for many other plants, very undesirable results are produced when it is increased beyond a certain point, owing to the fact that the solution of starch might be facilitated in organs the value of which depends on their starch content, as in potatoes. Should it prove to be correct that the chlorids favor the formation of cellulose from sugar, then the decrease of the sugar content in the sugar beet on account of the influence of chlorids would also be explained. On the strength of this hypothesis it might also be inferred that woody growth would be increased by supplying trees with moderate doses of chlorids.

To decide the physiological value of chlorids, plants of other families should also be cultivated in the presence of an abundance of potassium nitrate alone and in combination with potassium chlorid and sodium chlorid. Beyer's[1] experiments with peas and oats are not convincing in this regard, as anyone must infer who compares the composition of his main and control solutions.

An increase of sodium chlorid beyond a certain point has a retarding influence upon assimilation in the chloroplasts (Schimper). Coupin[2] has determined for several plants the amounts that would be injurious; e. g., a solution of 1 per cent will retard the growth of wheat and a solution of 1.8 per cent will prevent its germination. Sodium chlorid reduces the amount of chlorophyll in plants of the seacoast region, but causes the leaves to increase in thickness. The intensity of assimilation of carbonic acid is less in plants on the seacoast than in such plants growing farther inland (Griffon). Certain algæ, such as *Spirogyra crassa*, will suffer in culture solutions containing 0.5 per cent potassium or sodium chlorid, while lower kinds are not affected by 1 per cent chlorid of sodium or even more, and certain bacteria and small yeasts can even grow in the presence of from 10 to 12 per cent.

ABSORPTION OF CHLORIDS BY AQUATIC PLANTS.

The considerable absorptive power of many aquatic plants for chlorids is interesting. The ash of *Nymphæa alba*, amounting to 7 to 10 per cent of the dry matter, was found to contain 9 to 23 per cent of chlorine and that of *Spirogyra nitida* 24 per cent. The ash of such plants does not always show a sufficient potassium content to bind all the chlorine present, hence a part of the latter will in such cases be present as sodium chlorid. In order to estimate the absorptive power of *Elodea canadensis*, the writer has determined the amount of chlorine in water which ran slowly through a basin in which this plant was cultivated, and found that besides some sulphate and calcium and magnesium bicarbonate the water contained, per liter, 4.5 mgr. chlorine, 1.6 mgr.

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[1] Landw. Vers. Stat., 1869, p. 262.

[2] Revue Générale de Botanique, Vol. X, p. 177.

potassa, and 2.7 mgr. soda. On the determination of the amount of ash in the plant it was found to be 8.04 per cent, in which was 0.6 part chlorine, so that the plant therefore contained in the dry matter over one thousand times as much chlorine as an equal weight of the water in which it was grown.

SODIUM CHLORID IN ANIMALS.

Chlorine, in the form of sodium chlorid, plays an important rôle in animals, the formation of normal gastric juice being impossible in its absence. An idea of its great importance for the blood may be inferred from the fact that on an average about one-half of the blood ash consists of chlorid of sodium. Nearly one-third of the ash of the white of hens' eggs is made up of it. This salt can not be replaced by potassium chlorid, as the latter in the same quantity would exert a noxious influence on the animal. Generally, sodium salts exert an injurious effect on animals only when present in about five times larger quantities than potassium salts.

PHYSIOLOGICAL OCCURRENCE OF CALCIUM FLUORID.

The general occurrence of calcium fluorid in the teeth of animals renders very probable the supposition that it is present in many plants also, and indeed traces have been discovered in several cases. Fluorids, however, are not necessary for plants, the latter having been raised in culture solutions containing no trace of such compounds. It may be said that soluble fluorids in moderate amounts exert a poisonous action upon plants, as well as upon animals, and that they are more injurious to bacteria than to yeast—a fact of which practical use has been made in the manufacture of alcohol.

BEHAVIOR OF PLANTS TO POTASSIUM BROMID.

Bromine compounds occur normally in seaweeds, but as yet it is not known whether they are present in them only as organic or also as inorganic combinations. The physiological substitution of potassium bromid for potassium chlorid in the higher plants is impossible. In the case of buckwheat plants cultivated with potassium bromid, the writer observed that only one of six lived to bear a single seed, the others dying at or near the flowering stage; hence the recent assertion that bromids are not noxious for Phanerogams can be admitted only in the case of certain plants or a limited period of development.

RELATIONS OF ORGANISMS TO IODINE COMPOUNDS.

Since the discovery that an iodine compound occurs in the thyroid and the thymus glands of animals, it must inevitably be assumed that traces of iodine compounds must exist in soils and plants also. Gautier[1] has demonstrated that there are traces of iodine in the air of Paris.

[1] According to Gautier (1899), marine algæ contain in 100 grams dry matter 60 mgr. iodine, while fresh-water algæ contain only 0.25 to 2.40 mgr.

He determined also the amount of iodine in sea water to be 2.32 mgr. per liter.[1] Various marine organisms contain moderately large quantities of iodine. For instance, Harnack isolated iodospongin, containing on an average 8.2 per cent iodine, from marine sponges.

Drechsel[2] found in a protein, viz, the axial horny skeleton of the coral *Gorgonia carolinii*, 7.7 per cent iodine. On decomposition with baryta this protein yields a compound of the composition of mono-iod-amido-butyric acid. Potassium or sodium iodid, even in small doses, exerts a poisonous influence on animals as well as on plants. Germinating buckwheat seeds placed in a full mineral solution in which the potassium was offered as iodid, died before the first leaf was developed, as the writer observed many years ago. The poisonous action of the iodid of potassium is no doubt due to the liberation of iodine by oxidation favored by the acid cell sap. Lower organisms without acid juices are rather indifferent in this respect. The writer found certain algæ and infusoria alive in culture water five weeks after 0.5 per cent of iodid of potassium had been added to it. On the other hand, 0.2 per cent potassium iodid killed larger kinds of *Spirogyra* within a few days when the culture solution contained traces of the acid monopotassium phosphate. Lower fungi and bacteria are not injured in neutral culture solutions to which even 1 per cent of this iodid is added. Potassium iodid has been found by bacteriologists to possess a germicidal action only when present in large doses.

THE PHYSIOLOGICAL RÔLE OF ALKALI SALTS.

IMPORTANCE OF POTASSIUM FOR THE FORMATION OF STARCH AND PROTEIN.

The paramount importance of potassium salts for every living cell is firmly established. In green plants they are concerned not only in the synthesis of carbohydrates, but also in that of the protein bodies, since not only is there an increase of potassium salts in such parts of green plants as are developing rapidly and consequently forming large amounts of protein, but most fungi, even in the presence of such a favorable nutrient as sugar, are found to require potassium salts for the production of protein. These salts can never be replaced by lithium[3] or sodium salts, but in certain fungi they may be replaced to a limited extent by rubidium or cæsium salts (p. 25).

It is a well-known fact that plants cultivated in the presence of more sodium than potassium salts will nevertheless absorb a greater quantity of the latter than of the former, and some plants grown on soil

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[1] A part of this iodine is present in organisms and organic compounds.

[2] Zeitsch. f. Biologie, 1895, Vol. XV. Drechsel calls this protein "gorgonin." On decomposition it yielded not only iodine, but also 2 per cent chlorine (or bromine?).

[3] Although lithium salts exert a noxious action on Phanerogams they do not readily affect algæ. Spirogyra still appeared normal after four weeks in a complete culture solution to which 0.3 per mille lithium chlorid was added. At a higher concentration, however, the result may differ.

very rich in potassium salts will absorb almost no soda. The amount of potassa annually required per hectare of pine forest is about 7.5 kilos, of wheat field 37.5 kilos, of clover field 102 kilos, and of potato field 125 kilos. Other things being equal, an increase of potassa will increase to a certain degree the percentage of carbohydrates, and further, potassa is reported to be present in larger proportions in those parts in which the carbohydrates are transported, as in the parenchyma of the bark and pith.

Secondary potassium phosphate possibly forms loose combinations with proteins more easily than does sodium phosphate, since an increase of potassium phosphate is generally accompanied by an increase of proteins, as in the seeds. Pollen grains also seem to be rich in this salt; at least Ramann found that of the ash in the pine pollen 50.74 per cent was potassa and 30.08 per cent phosphoric acid. Seeds always contain much more potassium phosphate than sodium phosphate, while on the other hand the proportion of soda to potassa in form of other salts than phosphates is often found to be larger in the leaves and roots.[1]

The following table shows the composition of seeds of Gramineæ and Leguminosæ, the latter containing, as is known, relatively more protein than the former:

*Analysis of the seeds of Gramineæ and Leguminosæ.**

Product analyzed.	Number of analyses.	Total ash. Average.	Average in 100 parts of ash.		Protein.
			Soda.	Potassa.	
Gramineæ:		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Wheat	98	1.97	2.25	31.16	11.0
Rye	20	2.09	1.70	31.47	10.3
Barley	50	2.60	2.53	20.15	10.1
Maize	9	1.51	1.83	27.93	10.0
Oats	23	3.14	2.34	16.32	9.8
Millet	3	3.43	1.30	11.39	....
Average	....	2.457	1.99	23.07	10.2
Leguminosæ:					
Vetch	3	3.10	7.86	30.14	27.9
Pea	29	2.73	0.96	41.79	22.7
Lupin	3	3.95	0.37	29.84	35.3
Soy bean	1	2.83	1.08	47.00	33.2
Field bean (*Vicia*)	15	3.57	1.34	42.49	24.8
Garden bean (*Phaseolus*)	13	3.22	1.49	44.01	24.3
Average	....	3.23	2.17	39.21	29.0

* These figures were taken from E. Wolff's Aschen Analysen, Vol. I.

Calculating from the above data the amount of soda and potassa for 1,000 parts of dry organic matter, the seeds of Gramineæ contain 0.48 part soda and 5.67 parts potassa, while those of Leguminosæ contain 0.70 part soda and 12.66 parts potassa. It is seen, therefore, that there

[1] In some cases the amount of soda found in the leaves exceeds even that of potassa. Wolff's tables give for the leaf of *Daucus carota* a total ash content of 13.53 per cent for the dry matter, and for 100 parts of this ash 19.83 parts soda, but only 11.26 parts of potassa. The occasionally rather large soda content in the leaves is due to the current of transpiration, containing sodium salts among other things.

is more potassa in seeds which are richer in protein, but the proportions do not show any very close relation. For the Gramineæ the proportion of potassa to protein would be as 1 to 17, and for the Leguminosæ as 1 to 23. Hornberger's investigations[1] on the growth of maize showed the relation between potassa and protein nitrogen in the different periods of plant development to be for the leaves 1–1.1 to 1–1.8, or calculating from the protein itself, 1–6.8 to 1–12.2.

Although potassa is indispensable in the formation of carbohydrates, the quantitative proportions in the seeds show a closer relation to the protein than to the starch content of the seeds.[2]

BENEFICIAL ACTION OF SODIUM SALTS.

The fact that many kinds of plants have been raised to perfection in the absence of sodium salts proves that the latter have no indispensable function to perform in plant life. Stahl-Schroeder[3] recently inferred from his experiments what others also had already observed, that is, that sodium can not perform the special part of the functions of potassium which relates to the preparation of organic substances in plants. Nevertheless, sodium salts may sometimes exert a beneficial action, and several observers ascribe to them a promoting action in the ripening process of the Gramineæ. Wagner and Wolff have each reported favorably on the application of sodium salts, pointing out that as regards osmotic and neutralizing functions a replacement of potassium by sodium compounds is quite possible, which is of practical value, since the sodium salts are much cheaper than the potassium salts. In a recent article Dassonville[4] pointed out the beneficial action of sodium salts upon wheat. However, further control experiments along this line will be necessary.

CAN POTASSIUM SALTS BE REPLACED BY RUBIDIUM SALTS IN GREEN PLANTS AND IN ANIMALS?

Various authors have shown that potassium can not be replaced in plants by sodium or by lithium, starvation phenomena occurring with the former and toxical phenomena developing with the latter (Nobbe). As regards their atomic weight, sodium and lithium stand below while rubidium and cæsium stand above potassium, as follows:

Li =	7	} diff.: 16
Na =	23	
K =	39	diff.: 16
Rb =	85.4	diff.: 16 × 3 − 1.6
Ci =	133	diff.: 16 × 3 − 0.4

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[1] Landw. Jahrb., Vol. XI, p. 461.

[2] Fertilizing with potassium salts does not always increase the yield of grain. Frequently it is only the yield of straw that is increased. The form in which the potassium salts are given exerts much influence.

[3] Jour. f. Landw., Vol. XLVII, p. 78.

[4] Revue Générale de Botanique, 1898, Vol. X. He states also that "potassium silicate produces a dark green color."

Since the properties of elements are to a certain extent functions of their atomic weight, it might be supposed that the physiological capabilities of the alkali metals would increase with their atomic weight, but the facts observed are not in accord with this view. Birner and Lukanus[1] demonstrated that plants soon perish when the culture solutions contain rubidium or cæsium nitrate in place of potassium nitrate. In experiments with buckwheat plants the writer afterwards confirmed this conclusion as regards rubidium nitrate,[2] not taking cæsium salts into consideration; but he observed in addition that the action of rubidium chlorid differed to some extent from that caused by rubidium nitrate. Where the chlorid was offered the plants attained a greater height than with the nitrate. Those with rubidium nitrate died before the flowers were formed, while those with rubidium chlorid died after that period. Torsion and thickening of the stalk and curling and rolling up of the leaves were the most striking results with rubidium nitrate. In both cases, however, a diagnosis of the pathologic characters revealed essentially a disturbance in the functions of the chlorophyll bodies and in the transportation of starch, the effect on the latter being more marked with the nitrate than with the chlorid. A chemical comparison of buckwheat plants grown with potassium chlorid and of those grown with rubidium chlorid showed (1) that the ethereal extract of the "potassium plants" was of a normal pure green, while that of the "rubidium plants" was of a yellowish green; (2) that the rubidium plants contained 7.8 per cent of glucose in the dry matter, while the potassium plants contained none; (3) that there was more starch in the potassium plants than in the rubidium plants.

The writer has observed further that the replacement of even one-half of the potassium chlorid in a culture solution by rubidium chlorid will impede the development, the plants reaching after six weeks only half the size of the control plants. Moreover, the leaves were partially rolled in, the flowers were scanty, and the plants died before the seeds ripened.

These experiments proved that it is impossible to raise normal seed-bearing buckwheat plants when the chlorid of potassium in the culture solution is replaced by chlorid of rubidium, but on the other hand they left hardly any doubt that rubidium chlorid can serve for certain physiological functions of which sodium chlorid is utterly incapable. With rubidium chlorid, buckwheat plants may reach a dry weight of even thirty-three times that of the seeds,[3] but with sodium chlorid they seldom reach over five times. In a normally raised plant, however, the dry matter may be over six hundred times the weight of the seed. In the experiment with rubidium chlorid starch was formed by assimilation, but in those with sodium chlorid none was formed. The flowering stage was

[1] Landw. Vers. Stat., Vol. VII, p. 363.

[2] Ibid., Vol. XXI, p. 389.

[3] A certain writer's recent statement that rubidium salts have a poisonous effect on plants has to be somewhat modified.

reached[1] in the former case but not in the latter. With rubidium chlorid pathologic phenomena made their appearance chiefly after the flowering stage, but with sodium chlorid starvation phenomena were observed very much earlier.

Molisch had demonstrated that algæ can not develop if the potassium salts of the culture solution are replaced by rubidium salts.[2] In animals, also, neither cæsium nor rubidium salts can take the place of potassium salts, although a moderate amount of the rubidium salts is not noxious, and in large quantities they are even less injurious than the potassium salts.[3]

NECESSITY OF SODIUM SALTS FOR ANIMALS.

The great amount of sodium chlorid in the blood has already been mentioned, but the blood contains still other sodium salts of importance, such as sodium bicarbonate (in the ash of ox blood was found 14 to 18 per cent sodium carbonate) and the secondary sodium phosphate. Both these salts have an important bearing on the respiration process, as they carry in solution to the lungs for exhalation the carbonic acid produced by even the most remote cells of the body.

BEHAVIOR OF FUNGI TOWARD RUBIDIUM SALTS.

It has long been observed that mold fungi thrive in the presence of even very small quantities of potassium salts, traces of which are sometimes contained as impurities in certain organic compounds. These traces have to be considered in preparing culture solutions for special purposes. Yeast requires a larger amount of potassium, especially in the form of the primary and secondary phosphate, than do mold fungi. Certain kinds of microbes, such as *Anthrax* bacilli, do not develop well when the amount of potassium salts is very small. Sodium salts can not replace potassium salts even for these simple organisms, but rubidium salts can do so in certain cases, as in *Bacillus coli*, less successfully in *B. pyocyaneus*,[4] and still less in *Cladothrix*.[5] The writer has also established the fact that a mold fungus (*Penicillium*) and yeast can utilize rubidium and cæsium salts when the composition of the nourishing solution is otherwise very favorable and contains sugar and peptone. Günther's observation that the behavior of different mold fungi to rubidium salts varies, is interesting, these salts being utilized by *Botrytis cinerea*, but not by *Rhizopus nigricans*.[6] The less favorable

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[1] It would be of considerable interest to investigate whether the buckwheat egg cell is properly fecundated when rubidium chlorid in place of potassium chlorid is offered.

[2] On the other hand no injurious influence upon algæ is noticed when to the complete culture solutions 0.3 per mille of the chlorids of rubidium or cæsium is added.

[3] According to Richet, the lethal minimum dose of rubidium in form of rubidium chlorid is 1 gram for 1 kilo body weight when applied subcutaneously. This is about twice as much as the lethal dose of potassium chlorid.

[4] Bot. Centralbl., 1898, No. 26.

[5] Winogradzki has shown that *Mycoderma vini* also can utilize rubidium salts to advantage, but not cæsium salts.

[6] Dissertation, Erlangen, 1897.

the organic nutrient is, however, the more will potassium show its superiority over rubidium. An observation which appears to throw some light on one physiological difference between potassium and rubidium salts may be mentioned here: The cultures of *Cladothrix* and of *Penicillium* formed floating masses in the solution containing potassium salts,[1] while they gradually sank to the bottom in those containing rubidium salts. As the swimming is probably caused by the presence of fatty matter, it seems that potassium salts are more favorable for producing fat than are rubidium salts. Further, spore formation is almost entirely prevented in *Penicillium* when rubidium is offered in place of potassium. Only after an increase of the magnesium sulphate was a scanty formation of spores noticed.

The secondary and primary phosphates are the most favorable forms in which to offer potassium salts to fungi. In case phosphoric acid is applied in combination with ammonia, potassium may be added as lactate or tartrate or as other assimilable organic salts.

Finally it may be mentioned that of all the alkali salts potassium salts exert the most powerful positive chemotaxis upon bacteria, and that next to them come rubidium salts (Pfeffer).

PHYSIOLOGICAL SUPERIORITY OF POTASSIUM SALTS.

The question as to what peculiar property of potassium its physiological capacity must be ascribed, implies also the questions: Why can the physiological functions of potassium salts not be performed by the related sodium salts? In reviewing all the properties of the two metals and of their compounds can not such chemical differences be discovered as would also explain the great physiological difference? Can there not be found in potassium chemical properties that give it a certain superiority over sodium? Long ago the writer searched for striking and characteristic differences and believes he is justified in calling attention to the following facts, which prove that potassium and its oxid can bring on in certain cases a so-called chemical condensation which sodium and its oxid can not. For instance, carbonic oxid can be condensed by potassium to triquinoyl, a benzene derivative, but not by sodium (Lerch, Nietzki). Phenol added to fusing potassium hydroxid, will, under condensation, yield diphenol among other things, but with sodium hydroxid, oxidation, but little condensation, is observed, resorcin and phloroglucin resulting (Barth).

Among other noticeable differences may be mentioned, (1) that certain potassium salts condense ethyl aldehyde to aldol, while sodium salts change it to croton aldehyde (Kopp and Michael); (2) that potas-

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[1] The writer prepared the culture solutions with the purest materials, consisting in this case of—

	Per cent.
Sodium acetate	0.5
Glucose	1.0
Di-ammonium phosphate	.1
Magnesium sulphate	.02
Potassium tartrate	.10

sium acts on boiling triphenyl methane resulting in the development of hydrogen, but that sodium does not; (3) that potassium salicylate is converted at 210° C. into the isomeric paraoxybenzoate,[1] while in the sodium paraoxybenzoate just the reverse transformation is produced at 300° C. (Kolbe); (4) that potassium hydroxid decomposes peroxid of hydrogen more quickly than does sodium hydroxid (Schöne).

It seems very probable to the writer that from the physiological point of view the condensing properties of potassium are of prime importance. Substantial reasons exist for assuming chemical condensation processes, not only in the formation of carbohydrates and fat, but also in that of the proteins, i. e., in the three principal compounds of the plant cell. The writer called attention to this probable rôle of potassium salts in plants as early as 1880,[2] and still holds this explanation to be the correct one.

It is very probable that for the condensing operations the organoids of plant cells use a potassium protein compound. It is well known, of course, that chloroplasts require potassium salts for the assimilatory function and further that they have an alkaline reaction.[3] Finally, there can be no longer any doubt that sugars are produced by condensation.

As regards the formation of protein, the writer has on various occasions pointed out that certain facts, especially the great rapidity of protein formation in many instances and the absence of by-products and between-products, inevitably lead to the assumption that in this process also condensation plays an important part. But potassium salts are absolutely indispensable in animal life also, although the synthetical work performed is not so far-reaching as in plants. However, the formation of fat from sugar in the animal body requires condensation as well as reduction, while the formation of glycogen[4] from glucose and that of proteids from proteoses consists in dehydration and polymerization. In such cases potassium salts may play a rôle, and perhaps also in the processes of organization, as, for example, in the leucocytes and gland cells, which latter are in certain cases frequently renewed, or in the contractile substance of the muscles when work or starvation have destroyed a part of it.[5]

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[1]The corresponding rubidium salt in this case behaves similarly and therefore bears more resemblance to the potassium than to the sodium salt.

[2]Pflüger's Arch., Vol. XXII, p. 510.

[3]Molisch (Bot. Zeit., 1898, No. 2) observed that as soon as the cells are killed and the chloroplasts come in direct contact with the acid cell sap, the cells of *Coleus* or *Perilla*, rich in chloroplasts and containing anthocyan in an acid cell sap, underwent the characteristic change from red to blue and green produced by alkaline liquids. Cells of the same plants which are poor in chloroplasts or free from them do not show this change.

[4]The liver, which is the principal organ in glycogen formation, contains, according to Oidtmann, three times more potassium than sodium, while in the spleen the proportion is, according to the same author, just the reverse.

[5]Organization, as it takes place in a developing organ, is one of the least-known vital processes. One thing, however, is sure, that is, that a connection of numerous protein molecules in groups of a higher order takes place. This connecting process was supposed by Pflüger to consist in polymerization or etherification.

Nägeli ascribed the differences in the physiological capacities of potassium and sodium salts to their different affinities for water. Sodium salts bind the water of crystallization, but corresponding potassium salts do not, and thus being free from such a dense sphere of water the latter are better qualified for katalytic work. The dense layer of water around the molecules of sodium salts would not only prevent the salt itself from coming into immediate contact with other molecules, but it also would impede an effectual transmission of vibrations. On this basis also Nägeli tries to explain the fact that the soil absorbs potassium salts better than it does sodium salts, claiming that the latter are prevented by their water mantle from following the attracting forces.[1] However, objections can be easily raised against this view, the most serious one being that by no means has every sodium salt the water of crystallization.

THE PHYSIOLOGICAL RÔLE OF CALCIUM AND MAGNESIUM SALTS.

DISTRIBUTION OF LIME AND MAGNESIA IN PLANTS.

It has long been known that calcium and magnesium salts can not physiologically replace each other, and the question as to the functions of these salts has until recently been a matter of conjecture. The striking regularity with which the leaves of plants show a relative increase in lime, while the seeds show an increase in magnesia, has furnished a clue to the mystery of the action of these salts. A number of cases will serve to illustrate that different parts of the same plant contain quite different proportions of lime and magnesia. Let us first consider the leaves of the Gramineæ, since in them the absence of calcium oxalate excludes a misleading factor. The following data are taken from tables in Liebig's work:[2]

Per cents of lime and magnesia in the ash of the grain and the straw of Gramineæ.

	Magnesia.	Lime.
Grains of—		
Barley	8.29	2.48
Oats	7.70	3.70
Wheat	11.75	3.30
Maize	13.60	0.57
Rye (bran)	15.82	3.47
Straw of—		
Barley	2.97	7.28
Oats	4.58	7.29
Wheat	1.69	6.93
Maize	1.84	5.33
Rye	2.41	9.06

A better basis for a comparative estimate will be obtained if the average of these figures is taken and compared with the relative number of molecules instead of the absolute weight. The seeds of Gramineæ will

[1] Sitzungsber. d. Bayr. Akad. Wiss, 1879, p. 348.

[2] Die Chemie in ihrer Anwendung auf Agrikultur und Physiologie, 7 ed., Part I. The analyses were made by Way and Ogsten, Weber, and others.

then be found to contain for every 17 molecules of lime 100 molecules of magnesia, while in the straw there will be found fully 224 molecules of lime for every 100 molecules of magnesia. The leaves of *Phaseolus vulgaris* contain in comparison to the magnesia content four times as much lime as the seeds, and those of *Brassica napus* seven times as much. The proportion of magnesia to lime in tobacco leaves was found to be, on an average, as 1 to 5. The proportion of these constituents in the flowers is also different from that in the leaves. For example, in the case of *Humulus lupulus* there was found in the—

Flowers..1 part magnesia to 2 parts lime.
Leaves..1 part magnesia to 6 parts lime.

On comparing the underground parts of the plants with the leaves, it was also found that the latter contain more lime. For example, it was observed in—

Daucus carota, roots ....1 part magnesia to 2.5 parts lime.
leaves..........................1 part magnesia to 14.0 parts lime.
Solanum tuberosum, tubers......................1 part magnesia to .6 part lime.
leaves ....1 part magnesia to 6.1 parts lime.

Very great differences are revealed also in the comparison of the wood with the seeds in this regard, the lime content being relatively increased in the wood:

Abies pectinata, seeds..........................1 part magnesia to 0.09 part lime.
wood ....1 part magnesia to 4.62 parts lime.
Pinus sylvestris, seeds..........................1 part magnesia to .12 part lime.
wood ....1 part magnesia to 1.60 parts lime.

For the fruiting year of a beech tree 150 years old, R. Weber[1] several years ago made some interesting observations on the migration of magnesia. He found that magnesia as well as nitrogen migrates from the trunk to the points of seed formation, and in a smaller measure also sulphuric and phosphoric acids do the same. The decrease of the magnesia in the wood extended to ninety annual rings. The wood of the tree was analyzed in zones of thirty rings each. The percentage of lime and magnesia in the ash are given as follows, as is also for comparison the composition of a beech tree of the same age which had grown near by, but which bore no fruits that year:

Lime and magnesia in a fruiting beech and in a control beech.

Part of tree.	Beech tree in fruit. In the ash—		Beech tree not in fruit. In the ash—	
	Lime.	Magnesia.	Lime.	Magnesia.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Bark	85.05	2.60	82.10	3.65
Zone 1	33.92	12.65	27.69	29.25
Zone 2	34.13	11.95	31.52	26.72
Zone 3	35.98	12.15	33.55	20.39
Zone 4	33.36	13.36	27.59	19.02
Zone 5 (heartwood)	....	....	31.21	11.00

[1] Forstl. Naturw. Zeitschr., 1892.

As shown by the table, there was relatively a most striking decrease of magnesia to lime in zones 1, 2, and 3 of the trunk of the seed beech as compared with the corresponding zones from the control beech.

The leaves of aquatic plants are also rich in lime. The proportions of magnesia and lime were found to be, in *Nymphæa lutea*, 1:8.5; in *Lemna*, 1:3.3 to 1:7.6; and in *Elodea canadensis*, 1:8.4. Also algæ show similar proportions, as seen from the ash analyses of *Spirogyra nitida* by Pennington (1896) and of fucoids by Gödschens (1854). Algæ incrustated with calcium carbonate must, of course, be here excluded.

From what has been said under this head it will be seen that the analytical investigations of the ash of plants show (1) that lime and magnesia are present in every part of the plant, and (2) that the leaves contain relatively more lime and the seeds relatively more magnesia than the other parts of the plants. These characteristics can not be accidental, but must be the result of certain functions.

THE PHYSIOLOGICAL IMPORTANCE OF LIME SALTS IN PLANTS.

The more leaf surface is developed in a given time, the more lime is necessary. A normal crop of wheat requires per hectare (nearly 2.5 acres) about 11.6 kilos; sugar beets, 30.2 kilos; grass, 49.4 kilos; clover, 111.8 kilos; and tobacco, 153.7 kilos, while a normal growth of wood needs annually about 20 kilos of lime, besides 7 to 16 kilos of magnesia, 2 to 10 kilos of potash, and 0.8 to 4 kilos of phosphoric acid. When the large demand for lime salts by plants is taken into consideration, it is easily understood that an absence or deficiency of lime becomes apparent very early.

Stohmann[1] kept maize shoots alive for some time in a culture solution free from lime, but all development gradually ceased with the consumption of the stored-up lime. However, when at the end of several weeks some calcium nitrate was added, a very striking effect was noticed, hardly five hours elapsing before new buds pushed out from the sickly looking tips.

Heiden[2] observed that maize and peas in culture solutions without lime lived only four weeks, and reached respectively only 18.9 and 27 cm. in height. In culture solutions without magnesia, however, maize lived ten to twelve weeks and peas lived eight weeks and attained a height of 44 and 30 cm. respectively. In solutions without potassa or phosphoric acid, but otherwise complete, such plants lived from eight to twelve weeks. The absence of lime, therefore, was felt first, owing

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[1]Ann. Chem. Pharm., Vol. CXXI.

[2]Centralbl. f. Agr. Chem., Vol. XVII, p. 622. Prianishnikow observed that shoots develop quicker in a solution of gypsum than in distilled water, which fully accords with the writer's observations. Seedlings of *Phaseolus*, *Pisum*, and *Cucurbita* kept in distilled water die before all the reserve material is consumed. An addition of a calcium salt to the distilled water leads, however, to the perfect exhaustion of the reserve stores (Boehm, Liebenberg).

probably to the relatively small amount of lime in the reserve store of the seeds.

Palladin[1] placed etiolated leaves of *Vicia faba* on the surface of distilled water, on a 10 per cent cane-sugar solution, and on solutions of 0.3 per cent calcium nitrate with and without the addition of cane sugar, but a noticeable growth was observed only where both sugar and calcium nitrate were present. The same author[2] has found that etiolated leaves of *Vicia faba* contain less lime than do green leaves. His analysis showed that there were contained in 1,000 parts of green leaves 13.3 parts of lime, but in 1,000 parts of etiolated leaves only 2.6 parts of lime. The former yielded 10.3 per cent of ash, the latter 7.54 per cent. Stoklasa found in diseased leaves of the sugar beet less than half the amount of lime present in healthy leaves of this plant.

Church's investigations[3] with albino leaves demonstrated that the composition of their ash is very different from the ash of healthy leaves, as the potassa is considerably increased in the white leaves, while on the contrary the lime is more abundant in the green leaves. It is to be regretted, however, that the author did not determine separately the amount of lime present as oxalate and as carbonate and that portion of the lime belonging to the organized matter itself, calculating the results for equal surfaces in both cases. It is also very characteristic that the lime content of the phanerogamic parasite Cuscuta, which forms no chloroplasts in the full-grown state, amounts to only 2 per cent in the ash, while the clover, its host, is very rich in lime.

Another interesting case, showing a decrease in lime content in diseased leaves, was observed by Dr. Erwin F. Smith in his studies of the peach yellows. He gives the percentage of lime in the ash of the healthy leaves, according to analyses made by Mr. N. E. Knorr, as 40.58, and in the diseased leaves as only 23.88.[4] According to a later analysis, made by Dr. Eastwood at Dr. Smith's request,the ash content of healthy twigs of one season's growth is given as 2.10 to 2.58 per cent and that of diseased twigs as only 1.6 per cent, and of healthy twigs from another orchard as 1.4 per cent and of diseased twigs as only 1 per cent.[5] In these cases the amount of lime was also less in the diseased

[1] Ber. d. Deut. Bot. Ges., 1891, p. 230.

[2] Ibid, Vol. X, p. 179.

[3] Jour. Chem. Soc., 1878 and 1886. The investigations were made with *Quercus rubra* bearing some albino branches, and also with albino leaves of *Plectogyne variegata* and of *Hedera helix*.

[4] Smith, Erwin F., Bull. No. 4, Division of Botany, U. S. Dept. of Agr.

[5] Smith, Erwin F., Bull. No. 4, Division of Vegetable Physiology and Pathology, U. S. Dept. of Agr.

leaves, while potassa, magnesia, and in most cases phosphoric acid also were relatively increased, as will be seen from the following table:

Analytical data from diseased and healthy trees from four orchards.

[Per cents in the ash.]

	Orchard A, at Magnolia, Del.		Orchard B, at Dover, Del.		Orchard C, at Magnolia, Del.		Orchard D, at Still Pond, Md.	
	Healthy.	Diseased.	Healthy.	Diseased.	Healthy.	Diseased.	Healthy.	Diseased.
Calcium oxid	40.58	23.88	61.21	47.61	48.85	43.68	40.54	34.75
Magnesium oxid	4.81	5.97	5.62	7.65	3.21	4.31	2.85	10.23
Potassium oxid	15.52	31.86	15.02	20.19	28.26	32.51	30.18	30.76
Phosphoric acid	7.55	13.79	10.63	12.63	10.45	9.29	12.00	16.86

The observations which Honda and the writer[1] made with young pine trees cultivated in pure quartz sand moistened with culture solutions free from lime have shown that the leaves reached only half their normal size, and that the young trees gradually perished.

Bokorny[2] has cultivated algæ (*Spirogyra*, *Zygnema*, and *Mesocarpus*) in culture solutions, in one of which there was no lime, in another no magnesia, and in a third neither lime nor magnesia. These culture solutions were kept in aluminium vessels to avoid any trace of substances derived from glass. In the complete solution a normal formation in every respect was noticed. In the solution in which lime was absent the first phenomenon to occur was a decrease of chlorophyll, the chlorophyll band of *Spirogyra* diminishing not only in breadth and thickness, but also in length, and the original spiral finally becoming a straight line parallel to the longer axis. Some starch, however, was still produced, which proves that it is not the lack of organic matter and of potassa which here brings on this shrinkage, and that the result can be attributed only to the absence of lime. In the solutions in which magnesia and lime magnesia alone were absent, the volume of the nucleus decreased considerably, as well as that of the chlorophyll bodies. The writer has repeatedly observed that *Spirogyra majuscula* collected from swamps containing only traces of lime had very slender chlorophyll bands and scarcely any starch, but that they contained much stored-up albumin. When placed in culture solutions containing a moderate amount of lime salts the bands soon became broader.

Rudolph Weber[3] instituted a series of experiments with cultures of peas under glass of different colors, and compared these plants with

[1] Coll. of Agr., Bull., Vol. II, No. 6, Tokyo, Japan.

[2] Bot. Centralbl., 1895, No. 14. The complete solution contained—

	Per cent.
Potassium nitrate	0.04
Potassium sulphate	.03
Monopotassium phosphate	.03
Calcium nitrate	.03
Magnesium sulphate	.03

[3] Landw. Vers. Stat., 1875, Vol. XVIII, p. 19.

plants grown in very faint light and with normal control plants. The plants were grown in purified quartz sand and watered with culture solutions in equal quantities. The culture was terminated after forty-four days, because the plants under violet and green glass began at that time to show signs of approaching death. The analyses of the ash gave some interesting results, especially as regards the lime content, and are as follows:

Comparative amounts of magnesia, lime, and potassa per thousand parts of dry matter of normal and etiolated plants and plants grown under different colored glass.

Condition of plant.	Magnesia.	Lime.	Potassa.
	Per cent.	*Per cent.*	*Per cent.*
Normal	10.2	32.1	48.5
Etiolated	6.7	12.4	44.9
Under green glass	8.3	18.2	56.5
Under violet glass	8.5	20.2	45.6
Under red glass	9.5	24.3	56.5
Under blue glass	8.8	30.2	61.1
Under yellow glass	9.5	30.3	53.2

The amount of phosphoric acid varied only from 16.7 to 20.5 per cent. The etiolated plants and those under green glass contained the smallest amount of lime, and a certain relation of the lime content to assimilation or rather to the plastids is evident.

VIEWS ON THE FUNCTIONS OF LIME SALTS.

Boehm[1] observed irregularities in the transportation of starch when lime salts were absent in the culture solutions. The plants (*Phaseolus multiflorus*) recovered[2] on the addition of calcium salts, while on the other hand the addition of magnesium salts hastened their death. The irregularity of behavior in the absence of lime consisted in the accumulation of starch in the pith and bark of the lower part of the stem. The death of the affected plants commenced generally in the upper parts of the stems and gradually spread to the lower parts. Boehm further attributed to the lime a function in the formation of the cell wall. He says: "In order to form the cell wall from starch and sugar, lime is just as important as for the formation of the bone. The lime forms the skeleton of the cell wall." One author,[3] however, claims that Boehm's inferences are not justified, as he had studied only one case. Some authors have even gone so far as to assert that lime salts are by no means required for every part of a plant, and one author concluded that leaves of *Tradescantia* may be raised without lime, another that the young wood is free of lime, and a third that *Fucus* may be found with-

[1] Ber. Akad. d. Wissensch., Wien, 1875.

[2] The addition of calcium chlorid, however, did not prevent death, probably owing to the liberation of hydrochloric acid when the attempt is made by the plant to assimilate the lime from this salt.

[3] Liebenberg, Ber. Akad. d. Wiss., Wien, 1881.

out a trace of lime.[1] These statements, however, were based principally on microscopical tests and could not be upheld. Some new leaves of *Tradescantia* may indeed develop completely when the branches are kept in distilled water, since, as the writer has observed, the nodes contain a considerable amount of stored-up lime. As to the assertion in regard to young wood, Weber's analyses[2] have revealed a considerable amount of lime in its ash. For example, 1 cubic meter (Festmeter) of the wood of *Larix* was found to contain 700 grams of lime, of which 112.4 grams belonged to the young wood. The young wood of *Fagus* contained about 29 per cent of lime in the ash. As regards the *Fucus* referred to above, it was only its cell sap that proved to be free from lime, while an examination of the organized parts revealed lime in them.

Thus far the only plants which have been proved positively to develop without lime salts are lower forms of algæ and fungi (p. 44).

Like Boehm, Schimper observed an abnormal accumulation of starch where there was a deficiency of lime, but he declares this to be a mere secondary pathological phenomenon, and pointed out that even leaves which are packed with starch may die. This, however, can not be regarded as a refutation of Boehm's views. In order to render starch available for respiration it must be saccharified. In Schimper's case a failure to produce diastase might adequately account for the result. Other discrepancies between the observations of several authors may have their origin in the different lime content of the seeds used for the experiment.

Raumer[3] agrees with Boehm in ascribing to the lime the function of aiding in the growth and solidification of the cell walls, but he does not agree with his other views. However, his reason for believing that lime has nothing to do with the transportation of starch is not convincing Certainly, the mere chemical process of forming starch from sugar does not require lime, but the production of the plastids—the indispensable apparatus for starch formation—may require it.

Holzner's view[4] that lime salts aid in the assimilation of sulphuric and phosphoric acids is very improbable, since his hypothesis would require the formation of oxalic acid in every protein-producing cell—a condition which is not realized; and, moreover, the assimilation of these acids also takes place in fungi in the absence of every trace of lime salts. Finally, Hornberger[5] and others have objected to this view as not agreeing with their observations.

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[1] Boehm's hypothesis was entirely misconstrued by one author, who believed he had refuted it by showing that the migrating sugar is not bound to lime—a fact that might have been foreseen, as such a compound would be decomposed quickly by carbonic acid.

[2] Forstlich. Naturw. Zeitschr., 1892, p. 6, and 1893, p. 215.

[3] Landwirtsch. Vers. Stat., 1883, Vol. XXIX, p. 271.

[4] Flora, 1867, p. 497.

[5] Landw. Jahrb., 1882, Vol. XI, p. 455.

The functions of lime salts are believed by Schimper and others to consist in merely effecting certain processes of metabolism. Schimper[1] found that in the absence of lime the acid potassium oxalate accumulates in the leaves and buds and acts as a poison, hence calcium salts are useful, inasmuch as they precipitate the oxalic acid and thus prevent its noxious action. P. Groom[2] suggested that the injurious action of the acid potassium oxalate consists in retarding the action of diastase on starch, and thus its presence in the assimilating tissue brings about an accumulation of starch, due to the arrest of its transformation into sugar; then, as the soluble oxalate accumulates, there is also a retardation in the formation of starch, and this finally leads to the death of the protoplasm. Groom's theory, however, does not explain why calcium is required by plants also that do not form oxalic acid, hence the bad effects caused by a deficiency of lime must be explained in some other way. Although *Equisetaceæ* and most ferns and grasses, and even some species of the *Solanaceæ* and *Liliaceæ* are free from calcium oxalate, they all nevertheless require lime.

Neither Schimper nor Groom have raised the question as to why oxalates, even if neutral, exert a poisonous action on chlorophyll-bearing plants, while to the writer this question appeared to be the most important in this connection.

The greater lime content of the green parts first led the writer to suppose that the chlorophyll bodies might contain calcium compounds, and on the basis of this hypothesis he inaugurated a series of investigations. Among other things, these showed that the neutral oxalates are not poisonous to the lower fungi and that the development of these is not at all retarded by adding considerable quantities of neutral potassium oxalate to the culture solutions. Beer yeast is not injured by adding even as much as 4 per cent of this salt to a fermenting mixture. As in such cases the lime would become insoluble and its assimilation would thus be frustrated, the writer has come to the conclusion that these organisms do not require lime.[3] This is different in the case of the higher algæ, however. As the chlorophyll bodies of *Spirogyra* possess a highly differentiated structure, and even slight evil effects readily manifest themselves in certain changes along their margin, in the retraction of the lobes, etc., vacuolation of the chloroplasts, this alga was selected for the test. When *Spirogyra majuscula* was put into a 2 per cent solution of neutral potassium oxalate, a very striking fact was brought out, many of the chlorophyll bands being injured in even as short a time as thirty to forty minutes, while in even less time the nucleus showed a remarkable contraction, dwindling to a mere thread and thus causing a constriction of the cytoplasm where the plasma

[1] Flora, 1890, p. 209.

[2] Bot. Centralbl., 1896, No. 33.

[3] Erroneous representations in regard to this point have been refuted by the writer in Bot. Centralbl., 1898, Vol. LXXIV.

strings were attached. Moreover, filaments of *Spirogyra* which had been exposed for only ten minutes to the action of this oxalate solution and had still preserved their full turgor, were incapable of repairing the injury done after returning them to well water rich in lime, and they died after twenty-four hours. Even five minutes' action ultimately caused death. In a weaker solution (0.5 per cent) of oxalate the nucleus does not shrink to a thread, but slowly swells up and finally becomes an irregular, scalloped figure. In a still higher dilution (0.1 per cent) the poisonous action proceeds so slowly that it requires a number of days to completely kill all the cells.

In other species of algæ, such as *Vaucheria*, *Mougeotia*, *Zygnema*, *Cosmarium*, *Œdogonium*, *Chladophora*, *Sphæroplea*, etc., death, accompanied by swelling of the chlorophyll bodies, occurred after twenty-four hours' action of a solution of 0.5 per cent. Diatoms died in this solution in fifteen hours, but in a solution of 0.05 per cent some diatoms were still alive after three days. In higher dilutions the poisonous properties decrease rapidly.[1] Phanerogams also are easily attacked by oxalates. When placed in a 2 per cent solution of neutral potassium oxalate, the nucleus of an onion shows a contraction of about one-fifth of its normal diameter within ten to fifteen minutes. Leaves of *Elodea canadensis* and *Vallisneria spiralis* were killed completely in thirty-six hours[2] in a 1 per cent solution. The control experiments with potassium tartrate or sulphate, failed in all cases to show similar action. The claim, therefore, that lime salts are necessary to precipitate tartaric acid in plants that contain tartrates instead of oxalates has no support, since neutral tartrates are not poisonous, as are neutral oxalates.

The cytoplasm succumbs last, and its death is probably a secondary effect, due to the death of the nucleus and the chlorophyll body. Indeed it can be easily seen that the cytoplasm dies sooner when the number of chlorophyll bodies contained in it is increased. It is on this account that the circulation of the cytoplasm lasts much longer in the root hairs of *Chara* when under the influence of a dilute solution (0.5 per cent) of potassium oxalate than it does in the cells of the internodes filled with chlorophyll bodies. An equally dilute solution of neutral potassium tartrate shows no injurious action in the same length of time. The writer's explanation of the poisonous action is as follows: Judging from the most characteristic properties of soluble oxalates, that of precipitating lime from even highly diluted solutions of lime salts and that of depriving lime compounds generally of their lime and of converting it into the insoluble oxalate, he inferred from the peculiar poisonous action t h e e x i s t e n c e o f c a l c i u m p r o t e i n c o m p o u n d s i n t h e o r g a n i z e d p a r t i c l e s f r o m w h i c h t h e n u c l e u s a n d

[1] This, however, is not the case with free oxalic acid (p. 38).

[2] There are some remarkable cases in which monopotassium oxalate exists in the cell sap and still produces no injury, as, for instance, in *Rumex* and *Oxalis*. In these cases it is necessary to assume an unusual density of the tonoplasts—that is, a density sufficient to protect the nucleus and protoplasm.

the chlorophyll bodies are built up. Such organized calcium compounds would have a well-defined capacity for imbibition, which would change with the replacement of the calcium by another metallic element, and this altered water content must lead to a disturbance in the structure, which must prove fatal if not remedied in its initial stages. A peculiarity of protoplasm is that alteration of the structure is soon followed by the chemical change from the active to the passive modification of its proteids. Now, when potassium oxalate acts on the inferred calcium protein compounds they yield in addition to calcium oxalate the corresponding potassium protein compounds, which, on account of the different capacity for imbibition, can not physiologically replace the calcium compound. Moreover, neither tartr te nor sulphate (which act much less energetically than the oxalate on calcium compounds[1]) attack the nucleus or the chlorophyll bodies. This also shows plainly that it is impossible to accept the view that potassium oxalate becomes dissociated in the cells and that it is the free oxalic acid which, on account of its acidity, kills the nucleus, since potassium nitrate would be expected to act in just the same way.[2]

It will of course be difficult to prove microchemically the formation of calcium oxalate in the chlorophyll body or nucleus when potassium oxalate is left to act upon them, since the amount of calcium in them is naturally very small, judging from the great molecular weight of the organized proteids with which it would be combined. Moreover the formation of distinct crystals of calcium oxalate would be impeded by the peculiar consistency of the living structures. It was claimed that in view of the highly complicated conditions in the cells the assumption of a direct connection between a working cause and an observed pathological result could not be admitted, as the latter might be simply the effect of primarily produced "disturbances of nutrition." However, this claim can not be sustained in the case of the action of neutral oxalates upon the nuclei, for in the first place this proceeds very rapidly in concentrations of over 1 per cent, and in the second place the processes of metabolism in objects like *Spirogyra* proceed very slowly.

Further observations by Migula[3] deserve to be mentioned here, as they demonstrate that free oxalic acid is among the most poisonous of organic acids. For example, in a solution of 0.004 per cent of free

[1] Calcium tartraté dissolves in abont 2,000 parts of water.

[2] When acting on *Spirogyra* the potassium oxalate seems to pass direct to the nucleus through the plasma strings and not through the tonoplast, but on the other hand when potassium oxalate is contained in the cell sap of certain plants it seems to be confined there by the density of the tonoplast, which also prevents its direct contact with the nucleus in this case. In this connection Migula observed some interesting facts with *Spirogyra* kept in well water to which very small quantities of organic acids had been added. These were gradually oxidized in the cells into oxalic acid of which some was retained as neutral oxalate in the cell sap, and yielded a precipitate of calcinm oxalate when placed in a diluted solution of lime salts.

[3] The Influence of Dilute Acids on Algæ (Breslau, 1888).

oxalic acid the nucleus of *Spirogyra orbicularis* was observed to swell up, frequently to six times its normal volume, and become turbid and opaque, while the cytoplasm still remained alive for some time. In concentrated solutions the cells die too quickly to show such characteristic symptoms, their death being due chiefly in this case to mere acidity.

When some filaments of *Spirogyra majuscula* were placed in 500 cc. of a solution of free oxalic acid[1] in even as high dilution as 0.0001 per cent, the writer observed great injury to some of the threads after five days. In most of the cells the plasma strings were retracted, the nucleus was contracted and rolled to the cell wall, and the sinuate margins of the chlorophyll bands were swollen up and numerous little drops became visible in them.[2] A very striking feature was the long-continued persistence of the turgor under these conditions, this being due to the cytoplasm remaining alive for a considerable time. In equally diluted solutions of tartaric acid most of the cells were perfectly normal after nine days, which shows that the character of acidity at this high dilution exerted merely a secondary influence, and that this alone can not account for the action of the highly diluted oxalic acid.

FORMATION OF LIME INCRUSTATIONS.

It may not be out of place here to say a few words about the formation of incrustations of calcium carbonate on certain aquatic plants, especially *Chara*—a phenomenon which Pringsheim[3] tries to explain on the hypothesis that by assimilation of the dissolved carbonic acid the neutral calcium carbonate is produced from the bicarbonate. However, the fact that not every plant growing in the same water and near *Chara* shows the incrustation must lead to the assumption that either the assimilation is of much greater energy in *Chara* than in many other plants, or that the surface of this plant is especially adapted for the absorption of the neutral calcium carbonate.

Hassack[4] advanced another hypothesis, that is, that the plants secrete an alkaline carbonate, which decomposes the calcium bicarbonate. However, the writer has proved this view to be entirely erroneous.[5] The reaction with phenol phthalein, which Hassack used is not due to an alkaline carbonate, but to neutral calcium carbonate in a colloidal condition. Even the warming of ordinary water rich in calcium carbonate will produce ephemerally a red color with phenolphthalein.

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[1] Purest water distilled from glass vessels was used for all experiments with *Spirogyra*.

[2] Considerable swelling of the nucleus took place in a solution of 0.01 per cent oxalic acid.

[3] Jahrb. f. Wiss. Bot., Vol. XIX, p. 138.

[4] Unters. aus d. Bot. Instit. Tübingen, Vol. II, pp. 469–475.

[5] Flora, 1893, No. 4.

CAN CALCIUM IN PLANT CELLS BE REPLACED BY STRONTIUM?

It has long been recognized that calcium salts can not be replaced by potassium salts or sodium salts. Were it a well-founded hypothesis that calcium salts serve only for certain phases of metabolism and are not connected with more important properties of the protoplasm itself, then there might be taken a plain chemical view of the matter, that is, that the action of the bivalent elements is often different from that of the monovalent elements. Thus, for example, dextrose yields saccharin[1] when treated with lime, but not when treated with potassa (Kiliani); calcium carbamate yields calcium cyanamide upon heating, while potassium carbamate yields potassium cyanate (Drechsel); barium dibromsuccinate yields monobrommaleic acid on boiling of the aqueous solution, while the sodium salt yields monobrommalic acid.

It is certainly not the bivalent character of calcium, however, that determines its physiological value, for in that case barium or strontium might fulfill the same office, which is impossible. The inability of barium to do this might be explained by the most characteristic property of soluble barium salts, which is to precipitate sulphuric acid from even high dilution of sulphates, hence in plants the assimilation of sulphur from sulphates would become an impossibility. However, it would still be difficult to explain why barium salts are poisonous for animals, and also why strontium salts can not replace calcium salts in either plants or animals.[2]

The more intimate the connection between the functions of the lime and the vital properties of the cells, the more difficulty will naturally be encountered in an endeavor to substitute strontium for calcium, and experiments made in this connection argue against the possibility of the substitution. The writer made some experiments with an alga (*Spirogyra*) in 1892 which demonstrated that although this alga can remain healthy for several weeks at the ordinary temperature in a culture solution containing strontium nitrate in place of calcium nitrate, its further growth is nevertheless impeded, and moreover, that there is soon a noxious influence at a higher temperature (28° C.). Thus, for example, many cells died when kept at 28° C. in a solution of 0.3 per cent strontium nitrate, but this was not the case in a 0.3 per cent solution of calcium nitrate. This conclusion has been essentially confirmed by Molisch, who observed the interesting fact that the cell plate in the process of cell division is not properly formed when strontium salts are present in place of calcium salts. This occurs even when a small amount of a calcium salt is present, in which case the injurious effects of the strontium salt are not entirely prevented. The cell plate is the result of the work of the nuclear spindle, and the supposition that the cause of this defective work is attributable to a diseased condition of the nucleus seems justifiable. If the lime were not concerned in the

[1] This product is not the sweet saccharin of commerce.

[2] Only certain enzym actions form exceptions, as Bertrand has shown for pectase.

most intimate working of the nucleus the phenomenon in question would hardly be intelligible.

Similar experiments with beans and maize were inaugurated later on by Haselhoff,[1] but he offered calcium and strontium salts together in the beginning and gradually diminished the lime in the culture solution. The plants, however, very probably made use of the occasion to store up a certain amount of lime, which they may have used in the later period, and hence his conclusion that a substitution of calcium for strontium salts is possible can not be admitted.

The writer made an experiment with a phanerogamous plant also. Branches of *Tradescantia*, from 12.5 to 12.8 cm. long, were placed in solutions of—

	Per cent.
(1) Calcium nitrate	0.2
(2) Strontium nitrate	.2
(3) Calcium and strontium nitrate, each	.1

At a temperature of 10–15° C. a decided difference was noticed after twelve days. In the calcium nitrate solution young rootlets 0.5 cm. in length had appeared, but in the strontium nitrate solution only minute knobs were visible. Gradually a difference was also evident between the calcium nitrate and the calcium and strontium nitrate solutions, the root hairs in the former being long and numerous, while in the latter they were short and few. However, when the strontium nitrate gradually attained an excess over the calcium salts stored up in the branches, the noxious effect became evident, they having attained a length after forty-two days of only 13 and 13.3 cm., with only two or three leaves on each branch, while those in the solution of calcium nitrate attained a length of 16, 17.2, and 18 cm., with six to seven leaves on each branch. The leaves of the former branches were partially dying, but those of the latter were still healthy. A control case with distilled water demonstrated beyond a doubt that in the case of the strontium nitrate solution the phenomena mentioned were not merely due to the absence of the lime, but to a direct noxious action of the strontium salts. The numerous root hairs which developed in the distilled water further justified the conclusion that lime salts were stored up in the stems. Indeed the writer has demonstrated that besides sulphates, the nodes of the *Tradescantia* stems have stored up in them nitrates, potassium, and magnesium and calcium salts. An undeniable analogy appears to exist, therefore, between the noxious effect of the strontium salts and that of magnesium salts (p. 42), both beginning to be noxious when the amount of lime falls below a certain limit.

A series of very instructive experiments were recently carried out by U. Susuki[2] with five phanerogamous plants—*Hordeum*, *Fagopyrum esculentum*, *Phlox paniculata*, *Rubus idæus*, and *Coreopsis tinctoria*. Some of the plants were watered with a normal solution containing

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[1] Landw. Jahrb., Vol. XXII, p. 853. [2] Bull. Coll. of Agr., Tokyo, 1899.

calcium in the form of calcium nitrate and others with solutions in which the calcium nitrate was replaced by equivalent quantities of strontium nitrate and of barium nitrate. Only the plants in the normal solutions showed a strong and vigorous development, while those in the barium and strontium solutions exhibited gradually an injurious action, and when at the time of their early death the experiment was terminated, the following data were obtained:

Action of calcium, strontium, and barium salts.

BUCKWHEAT SHOOTS.

	Nitrate of calcium.	Nitrate of strontium.	Nitrate of barium.
Average weight of one stem	0.352	0.260	0.187
Average weight of one leaf	.198	.080	.050

BARLEY SHOOTS.

Average weight of one plant	1.50	0.67	0.51
Ratio of dry weight	100.00	44.06	34.00

It will be noticed that the action of the barium solution was more injurious than that of the strontium solution. Branches of the other three Phanerogams mentioned were used, here those in the barium and strontium solution died after eight days, while those in the normal solution containing calcium nitrate remained healthy and developed new leaves. Control cases in distilled water showed here also that the injury in the case of the barium solution is due not merely to the absence of lime, but directly to a poisonous influence of the barium and strontium salts. Further tests showed that these poisonous actions are retarded by the addition of lime salts.

Now, if calcium salts act only in processes of metabolism it might be inferred that such processes could be performed as well by strontium salts, the main properties of the salts of both elements being to a certain degree alike. Thus, strontium oxalate dissolves with difficulty in water (1:12,000), as does also the sulphate. The latter, however, being less soluble (1:6,895) than calcium sulphate (1:488), it might be supposed that the assimilation of sulphur is seriously lessened. However, considering the diluted state in which the phosphates enter and still how well they are assimilated, it is clear that the lesser degree of solubility of strontium sulphate would not be a serious obstacle to the assimilation of sulphur. It may then well be asked what kinds of processes of metabolism in plants have to be assumed for calcium salts which it would be impossible for strontium salts to perform.[1] Thus

[1] Whether a gradual adaptation to strontium salts could ever take place, or, in other words, whether in the course of many generations strontium-protein compounds could gradually be utilized like the corresponding calcium compounds, is an entirely different question. However, in this connection only the simpler kinds of organisms might yield satisfactory results. It may be mentioned that 0.1 per cent strontium nitrate added to the culture water does not, even after months, injure Diatoms, Flagellata, or Infusoria in presence of sufficient lime.

far the defenders of the metabolic theory have given no satisfactory explanation. The writer's above-mentioned theory on the function of lime salts, on the other hand, makes it perfectly clear why strontium salts in certain doses become hurtful and even poisonous for all organisms except the lowest forms of algæ and fungi.

POISONOUS ACTION OF MAGNESIUM SALTS.

If the writer's view that a calcium protein compound participates in the organized parts of the nucleus and chlorophyll body is correct, it might be expected that magnesium salts of the stronger acids would exert a noxious action. The lime as the stronger base would in such a case combine with the acid of the magnesium salt, while magnesia would enter into the place which the lime had occupied in the organized structures, the capacity for imbibition would thereby be altered, and a disturbance of the structure would result which would prove fatal. On the other hand, judging from the laws of the action of masses, it would naturally be inferred that an excess of lime salts would remedy the evil effects by making the reverse process possible. As a matter of fact, a detrimental action is observed when plants are treated with sulphate or nitrate of magnesium in the absence of calcium salts—an effect which is not observed when the same plants are exposed to the exclusive action of calcium, sodium, or potassium sulphate or nitrate. These phenomena were foreseen by the writer, and may be readily explained by his theory, while the holders of other views have not come forward with an explanation.

The writer observed that *Spirogyra* died within four to five days in a 1 per mille solution of magnesium sulphate, but remained alive for a long time in corresponding solutions of sodium, potassium, or calcium. In a 1 per cent solution of magnesium nitrate smaller kinds of *Spirogyra* will die in from six to twelve hours, but will live a long time in corresponding solutions of sodium, potassium, and calcium nitrate. *Spirogyra* which had been kept for several weeks in a healthy condition in a solution of 0.1 per mille of monopotassium phosphate in absolutely pure distilled water, died within three to four days when 2 per mille magnesium sulphate was added to this solution, but when dipotassium phosphate instead of the monophosphate was used death set in much later, that is, after fifteen to eighteen days.

Some threads of *Spirogyra majuscula* placed in a solution (1 liter) containing 0.02 per mille each of magnesium nitrate and ammonium sulphate, died in from ten to twelve days, while in the control solution, containing calcium nitrate in place of magnesium nitrate, they were still alive after six weeks, although cell division had stopped completely, and the cells exhibited an emaciated appearance owing to the absence of other mineral nutrients. In still another case threads of the same alga were placed in a solution of 1 per mille of magnesium nitrate, while in the control case 3 per mille of calcium nitrate was added.[1] In the former case death resulted in five days,[2] while in the latter the cells were still alive after a number of weeks. Lime salts, therefore, are the antidote for magnesium salts.[3] Nothing can replace them successfully in this case, not even nourishment with organic matter.[4] Microscopical examinations of *Spirogyra* cells exposed to the exclusive action of magnesium salts show that the nucleus is attacked first and then the chlorophyll body is injured, the phenomena closely resembling those produced by potassium oxalate, but while in a 1 per cent solution of magnesium sulphate the nucleus will swell up after twelve hours, in a 0.5 per cent solution of potassium oxalate it will do so in a much shorter time.

The noxious action of magnesium salts also soon becomes evident in the roots of seedlings. Thus *Vicia* and *Pisum* do not start lateral roots when kept in a solution of 0.5 per cent magnesium sulphate or nitrate, and the root cap and epidermal cells die after a few days. In a solution of calcium nitrate of equal strength, however, development continues. Seedlings of *Phaseolus* placed in a solution of 0.1 per cent magnesium sulphate, with 0.1 per cent monopotassium phosphate, showed injury to the roots after five days, and the entire plant succumbed soon afterwards. Similar observations had been made by Wolf, by Raumer and Kellerman, and by others, but all failed to recognize the true cause and to ascertain that lime salts alone act as the specific remedy.

Raumer[5] observed that in *Phaseolus multiflorus* kept in various culture solutions there was a detrimental effect much sooner when lime alone was absent than when both lime and magnesia were absent. The difference was most striking in the main roots and also in the number and vigor of the lateral roots. Here, then, the noxious effect of magnesia in the absence of lime is again manifested.

The writer has made a special study of the development of roots in culture solutions free from lime and from magnesia, using branches of *Tradescantia* for this purpose. These have calcium as well as magnesium salts stored up in their nodes, and hence some development of roots is possible even in distilled water. Nevertheless, a most striking difference was noticed, the roots in the culture solutions containing lime but not magnesia producing a "dense forest" of root hairs that reached a length of one-fourth centimeter, while the roots in solutions

[1] These observations the writer described in Flora, 1892, and also in Landw. Vers. Stat. of the same year.

[2] The time is probably prolonged when lime salts are stored up.

[3] An addition of strontium salts may delay death for a short period, but it can not prevent it, as do calcium salts.

[4] It may be mentioned that *Spirogyra* remains alive for from five to six weeks if kept in distilled water. Of course any further development is stopped, but assimilation and respiration soon reach a suitable equilibrium.

[5] Landw. Vers., 1883, Vol. XXIX, pp. 254 and 268.

containing magnesia but no lime, although larger than the others,[1] produced only a few short hairs. The lack of lime in these roots was felt especially in the epidermis, the interior parts being able to draw a sufficient amount of lime from the stem. Indeed, a microchemical test showed the presence of lime in the ash of these roots, gypsum needles forming when treated with a little sulphuric acid.

The extraordinary effects of lime salts on the development of root hairs is of special interest, as it furnishes the key to the observation of Wolff that the potassium and ammonium salts of the soil are absorbed in increased quantities by plants after manuring with lime salts.

LIFE WITHOUT LIME SALTS.

While lime salts are indispensable for animals, Phanerogams, and higher algæ, they are not so in the case of bacteria, fungi, and lower algæ. Thus far no investigations relating to the higher fungi have been made in this regard. The occurrence of lime in the ash of yeast or of tubercle bacilli[2] must be regarded as merely accidental. It was first observed by Adolph Mayer that for yeast magnesia is of greater importance than is lime. Later the writer proved that yeast and bacteria can do without lime entirely,[3] and Molisch has observed that this is also true of mold fungi.[4] It has been observed, on the other hand, that in certain cases the presence of lime promotes the action of fungi, but this is very probably due only to a secondary effect. Thus, the nitrification in soils is enhanced by calcium carbonate, and, according to Thaxter and Wheeler,[5] the scab of potatoes and of sugar beets is increased by liming the soil. Recently Laurent[6] reported that certain bacteria, *Bacillus coli communis* and *B. fluorescens putidus*, can attack potatoes in soils which have been strongly limed. He believes that by this means the power of resistance of these plants is diminished so much that the microbes named can commence their parasitic life, and

[1] These roots were 4.1 cm. long, while those in culture solutions without magnesia were only 3.2 cm. long. The composition of the complete culture solution in the above case was as follows:

	Per mille.
Monopotassium phosphate	0.1
Potassium nitrate	.5
Sodium sulphate	.2
Calcium nitrate	.5
Magnesium sulphate	.2
Ferrous sulphate	Trace.

[2] According to de Schweinitz and Dorsett (Centralbl. f. Bakt., No. 23, 1898), the phosphates of sodium, calcium, and magnesium predominate in this ash over that of potassium, while the reverse is true in the ash of yeast.

[3] Flora, 1892, pp. 374 and 390.

[4] Ber. Wien Akad., 1894, Vol. CIII.

[5] Storer, Relation of Agriculture, Vol. II, p. 546.

[6] Ann. de l'Institut Pasteur, 1899, Vol. XIII, p. 1.

he further asserts that only such plants can resist as have at the same time a great amount of potash and phosphoric acid.[1]

Both Molisch[2] and the writer[3] have observed that lime is not required by the lowe rforms of algæ. Molisch proved this in the case of *Ulothrix*, *Microthamnion*, *Stichococcus*, and *Protococcus*,[4] and the writer proved it in the case of a kind of *Palmella*.

Bipartition, zoospores, isogamy, and oogamy represent a scale of progress which probably requires an increasing differentiation of the nuclei. Isogamy in its simpler forms must be distinguished from its more perfected form, as it is found for instance in copulation of *Spirogyra*, where the uniting plasma bodies remain protected by the cellulose wall during the entire process. Some forms of the order *Protococcoideæ* multiply only by bipartition, others by swarm spores, certain forms by isogamy, but only two genera (*Volvox* and *Eudorina*[5]) by oogamy. In the order of the *Conferroideæ*, *Ulothrix* multiplies only by isogamy, while *Œdogonium* multiplies by oogamy also. In other groups a still higer potentialization of the nucleus has to be inferred, as in the *Characeæ* from the highly differentiated structure. Since neutral potassium oxalate has a poisonous effect upon *Diatoms*, *Œdogonium*, *Cladophora*, and apparently also on *Draparnaldia*, the presence of important lime compounds in these organisms may be inferred. All these organisms, however, are more differentiated than *Ulothrix*, which, according to Molisch, can grow in the absence of lime salts.

A careful study and comparison of the various chloroplasts of algæ might also show certain advantages in favor of those which require lime for their development. For instance, certain low genera, such as *Nostoc* and *Oscillaria*, form no starch, while others do. In such cases starch formation is to be regarded as a step forward, one that depends upon a higher differentiation of the chloroplasts. The beautiful chloroplasts of *Spirogyra* show a high degree of differentiation, the pyrenoids, which form stations in the chloroplasts, being the manufacturers of the starch.

It is true Schmitz also observed well-defined chloroplasts multiplying

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[1]A satisfactory explanation as to the decrease of power of resistance under the influence of such an important nutrient as lime would be very desirable. Perhaps the cells beneath the lenticels are thereby stimulated to growth and open a way for the parasites to enter.

[2]Sitzungsber. d. Wiener. Akad. d. Wissenschaften, 1895, Vol. CIV. In this article Molisch has also proved that the algæ mentioned are incapable of assimilating free nitrogen. This confirms an earlier observation on *Nostoc* by the writer (Biol. Centralbl., Vol. X, p. 591) and a later observation by Kossowitsch.

[3]Botan. Centralbl., 1895, No. 52. Probably *Nostocaceæ* and *Oscillatoriaceæ* also do not require lime. The culture of *Oscillaria*, however, presents especial difficulties.

[4]It was not ascertained whether any other mode of multiplication than that by bipartition would be possible in the absence of lime in some of the forms mentioned. This question might also be raised in regard to fungi.

[5]It would be of special interest to ascertain whether *Eudorina* and *Volvox* require lime salts. They probably do.

by bipartition in such simple alga forms as *Protococcus*, *Stichococcus*, and *Palmella*, but these chloroplasts appear to be of a lower order than those of *Cladophora*, *Zygnema*, or *Spirogyra*.

The nutrition of the chloroplasts is in all probability cared for by the nucleus, hence it is reasonable to suppose that nuclei which prepare calcium-protein compounds for themselves furnish these same compounds to the chloroplasts also. This is probably the simplest explanation as to why chloroplasts become sensitive to even neutral oxalates in all plants the nuclei of which are killed by oxalates. Where the nuclei contain calcium-protein compounds the chloroplasts also contain them.

The writer has advanced the view that a higher development in form and function becomes possible only when the lower forms of life acquire the ability to assimilate lime and to utilize the resulting calcium proteid compound for organization purposes. This seems to him the simplest explanation of the fact that lime salts are required by all plants except the very lowest forms. Agreeing especially well with this view is the further observation that neither neutral oxalates, nor magnesium, nor strontium salts are injurious to these lowest forms,[1] although noxious to all other plant life.

If lime were necessary only for certain processes of metabolism in plants, as some authors claim, it would not only follow that the higher forms of algæ have quite a different mode of metabolism from the lower ones, but it would also remain entirely incomprehensible why magnesium salts act so poisonously on the nucleus and why only calcium salts can prevent this deleterious effect. It would be very interesting to know the exact line of development below which calcium salts are not required and above which they are indispensable for plant life. A division of the algæ into two such groups would certainly prove instructive.

ON POSSIBLE RELATIONS BETWEEN THE LIME AND THE TRANSPORTATION OF STARCH.

One of the first disturbances to appear when there is a deficiency of lime is the cessation of starch transportation. Starch gradually accumulates in the lower parts of the stem, and even its transportation from the storage receptacles to the axial parts may gradually stop. It has already been seen (p. 18) that a similar phenomenon was observed by Nobbe in plants showing a deficiency of chlorine compounds. Two causes, either separately or combined, may produce this phenomenon, and it follows, therefore, that the conditions bringing it on in different cases may not necessarily be wholly identical. One cause may be that cells fail to produce the diastase which is necessary for dissolving

[1] *Palmella* can develop quite well, even in 4 per cent solutions of neutral potassium oxalate or magnesium sulphate to which traces of ammonium sulphate and potassium phosphate had been added. Beer yeast may be kept for several hours at 30° C. in a 1 per cent solution of magnesium nitrate without serious injury.

the starch, and another the impossibility of forming in the growing parts new plastids and chloroplasts, which produce starch from sugar.

The writer's view, according to which lime is required in the compounds which build up nuclei and chromatophores, explains not only the failure to increase these organoids, but also that to produce diastase when line is absent. Enzyms are secreted from the nuclei, as Hofer has shown with amœbæ, and therefore if the nuclei can not be normally formed for want of lime enzym formation also may stop. However, this latter explanation does not seem to apply for the initial pathological stage, since Raumer and Kellerman observed that in *Phaseolus multiflorus* sugar also was formed from starch for a certain period when lime was deficient, hence diastase was probably present.

In this case the upper part of the stem was devoid of starch and seemed to be incapable of forming starch from the sugar present. This accumulation of sugar prevented any further solution of starch in the lower parts.

The intensity of starch transportation depends essentially on two factors, (1) the saccharifying activity, and (2) the starch-forming activity of the plastids in other parts of the plants.

Further investigations in this direction would be very desirable. They would perhaps also show differences between the action of chlorids and that of lime in regard to the transportation of starch. Finally, since a deficiency of lime, like the absence of phosphoric acid, potassa, or magnesia, stops the formation of new cells, an accumulation of proteins may result, and indeed such a case was observed by Stock, the crystalloids increasing in number when lime was deficient.[1]

THE PHYSIOLOGICAL RÔLE OF MAGNESIUM SALTS.

It has already been pointed out that magnesium salts are especially important in the formation of seeds, but they are also required by all other parts of plants, and especially in the process of development. The amount of magnesia taken up by crops varies considerably. For example, an average crop of wheat will take up 8 kilos per hectare, a crop of leguminous plants 12 kilos, and a crop of tobacco as much as 43 kilos. It has also been pointed out that magnesium salts can fulfill their nourishing functions only in the presence of calcium salts, while in the absence of calcium salts they even exert an injurious action.[2]

In studying the questions as to what the nourishing function of magnesium salts is and why they can not be replaced physiologically by calcium salts, the probable answer is found in the well-known property of the magnesium salts to easily undergo dissociation, as the writer pointed out some years ago.[3] Magnesium salts are easily hydrolyzed, as is shown in the preparation of chlorid or carbonate of magnesium in the

[1] Bot. Centralbl., Vol. LIII, p. 83.

[2] Only the lowest algæ and fungi are exceptions (p. 44).

[3] Flora, 1892, p. 286.

ordinary method of preparation, whereby a part of the acid is easily liberated. Moreover, in boiling with water the secondary magnesium phosphate is decomposed into tertiary phosphate and free phosphoric acid. The inference suggests itself that this property is of great value to the cells, since in the assimilation of nitrogen from nitrates, sulphur from sulphates, and phosphoric acid from phosphates, the dissociation of these salts would immediately precede assimilation; hence the easier these acids are separated from the base the easier their assimilation will be accomplished. However, this deduction relates more to the assimilation of phosphoric acid than to that of sulphur and nitrogen. This latter assimilation must be possible also, to a certain degree, from other sulphates and nitrates besides those of magnesia. According to this view the formation of nucleo-proteids depends upon the presence of magnesium salts. As a matter of fact, it is found that magnesia always increases where rapid development is taking place. In accordance with this view also, very small quantities of magnesium salts can be used for a great deal of work, since the same amount of base can serve over and over again as the vehicle for assimilation of phosphoric acid. This may also explain the fact, pointed out long ago by Adolph Mayer, that "magnesia is more movable in the plant than lime is," and that "magnesia, like the phosphates, follows the proteids."

The fact that comparatively little magnesia can serve for extended physiological operations may be noticed in fungi in culture solutions devoid of lime, and also when seeds are left to develop in culture solutions free from magnesia and with only a moderate amount of lime in proportion to phosphoric acid. For example, beans may reach even 1 meter in height in such solutions, the reserve magnesia sufficing for this result.

Besides the easy dissociation the solubility of the secondary magnesium phosphate in water must also be considered. This solubility is much greater than that of the secondary calcium phosphate. When 100 cc. of a 0.2 per cent solution of disodium phosphate are mixed with 2 to 3 cc. of a 10 per cent solution of magnesium nitrate no precipitate is formed, while with an equivalent amount of calcium nitrate there will be a considerable precipitate. It may be inferred, therefore, that the secondary magnesium phosphate is more capable of migrating in plants than is the calcium phosphate, at least in neutral media and in the cytoplasm and its intercellular connections.

The alga *Spirogyra* is especially well adapted to show the influence of magnesium salts upon the production of protein matter. This influence may be double, (1) in facilitating the assimilation of sulphur and nitrogen from sulphates and nitrates the albumin formation as such is enhanced; and (2) in making the assimilation of phosphoric acid possible, nucleo-proteids may be formed, so that division of the nucleus and growth can proceed. If growth is as energetic as the formation of protein no accumulation of protein will take place, all being organized for the wants of the multiplying cells. However, by reducing the amount of phosphate to a trace multiplication can be very much retarded or stopped altogether, while albumin formation may go on; hence in this case an accumulation of albumin takes place either in the cell sap or in the cytoplasm or in both.

These conclusions can be very easily verified by studies with *Spirogyra*, for which the bicarbonate, obtained by dissolving magnesium carbonate in water charged with carbonic acid, is a very favorable form of magnesium. Thus a most energetic growth was observed with the following composition:

	Per mille.
Magnesium bicarbonate	0.5
Magnesium sulphate	.1
Calcium nitrate	.5
Monopotassium phosphate	.05
Potassium nitrate	.2
Ferrous sulphate	Trace.

The supposition that the favorable action of the magnesium bicarbonate consists simply in a "neutralization of acids" formed in the process of metabolism, can not be correct, since a substitution of an equal amount of calcium bicarbonate by no means shows the same beneficial influence, and besides in this case the above culture solution would contain such an excess of lime over magnesia that the assimilation of phosphoric acid might be retarded, involving a slower development.

The foregoing makes it intelligible why in the absence of magnesium salts the multiplication of cells is stopped, the nucleus not being able to increase to that point where division sets in. In the mixture of different salts occurring in plants there is sufficient opportunity for magnesia to combine with phosphoric acid, and the secondary magnesium phosphate thus formed can, in passing into the tertiary salt, yield some free acid. The tertiary salt remaining can easily be redissolved by weak organic acids, and thus yield again the secondary phosphate, which may in turn be utilized for the assimilation of phosphoric acid. This explains why germinating seeds and rapidly growing parts generally develop an acid reaction.

The rapidly proceeding cell division requires the most favorable conditions for the assimilation of phosphoric acid. One of these consists in utilizing the same amount of magnesia over and over again. Where an abundance of magnesium salts is present, however, as in most culture solutions of bacteria, the reaction does not need to be acid to insure a rapid assimilation of phosphoric acid.

Thus far few authors have expressed any view as to the primary functions of magnesia. Raumer observed that *Phaseolus multiflorus*, grown in culture solutions without magnesia, reached 1 meter in height, after which the internodes stopped stretching, but thickened abnormally. The new leaves also remained small and ceased to produce chlorophyll[1]—an interesting case of chlorosis, which disease may be

[1] Hoppe's chlorophyllan contains 0.34 per cent magnesia, but this product is now declared to be a mixture.

produced by other causes than by the absence of iron, as has been already pointed out (p. 15). Raumer ascribed to magnesia and not to lime, as Boehm has done, the transportation of starch, basing his claim on the ground that in the beginning the leaves contain not only considerable starch, but also a relatively large proportion of magnesia, which condition is found later in the stems. Finally, magnesia is found to be increased in the seeds, in which starch also is generally deposited. This hypothesis does not, however, seem to be well founded, since the relations indicated are not direct. Many other facts make it much more probable that it is the proteids and not the starch that have a close relation to magnesia. Where development is going on, starch is required for furnishing the necessary carbon and hydrogen in the production of proteids, hence magnesia is found in cases where the starch is migrating. Here magnesia is connected with the protein production and not with the migration of starch. Furthermore, the organoids of starch formation, the plastids, also require magnesium salts for their growth and multiplication, since they contain phosphoric acid in their nucleo-proteids; hence there also exist some reasons for the belief in the remote connections between the starch content of an organ and the amount of magnesia present, but not in the direct connection supposed by Raumer.

INCREASE OF MAGNESIA IN OILY SEEDS.

If the writer's theory as regards the relation of magnesia to phosphoric acid is correct, more magnesia ought to be found where both compounds, nucleo-proteids as well as lecithin, are formed than where nucleo-proteids alone exist, since the assimilation of phosphoric acid is required not only for the formation of nucleo-proteids, such as chromatin and plastin, but also for that of lecithin. Lecithin is a constant concomitant of fat, and therefore seeds rich in fat ought to contain, *cet. par.*, more magnesia than such as are rich in starch. A review of Wolff's ash tables confirms this deduction. The following table shows that for 1,000 parts of organized substance there are of magnesia in—

Starchy seeds.		Oily seeds.	
	Per cent.		*Per cent.*
Oats	1.9	Cotton	5.6
Barley	2	Flax	4.7
Rye	2	Poppy	4.9
Maize	1.9	Rape	4.6

The average proportion of magnesia in starchy seeds to that in oily seeds, therefore, is as 2 to 5.

It may furthermore be pointed out that fungi grown in culture solutions containing only traces of magnesia form no spores. Spores, however, contain lecithin, and in all probability relatively large amounts of nucleo-protein. Here the importance of magnesia can be readily demonstrated by increasing its amount in the culture solution, after which spores are soon formed. A similar effect on oats was observed by Schneidewind.[1] Of all nitrates tested, magnesium nitrate yielded the largest grain production.

NECESSITY OF MAGNESIUM SALTS FOR FUNGI.

Magnesium salts are also indispensable for fungi, but an exceedingly small amount will suffice when the nourishing solution has an acid reaction. In fact, even traces of magnesia taken up from glass vessels, if the latter are not made of the most resistant material, will suffice for growth. Fränkel denies the necessity of magnesia for certain kinds of bacteria—[2] *Bacterium coli*, *B. pyocyaneus* Friedl., and other bacteria having been cultivated by him in solutions of aspartate or lactate of ammonia in absence of magnesium salts. However, a suspicion as to the absolute purity of his materials may be justly entertained.

How small a quantity may suffice for mold fungi is shown by the following observation: The writer prepared a nourishing solution containing 2 per cent of ammonium acetate, 0.04 per cent monopotassium phosphate, and 0.02 per cent potassium sulphate and infected the solution, which was made with absolutely pure materials, with spores of *Penicillium*, but obtained no growth, owing to the absence of magnesia. He then added 0.0003 per cent of magnesium sulphate, and soon a considerable development of mycelium took place, its weight finally becoming very nearly the same as that in the control flask containing 0.1 per cent of magnesium sulphate.[3] The only difference observed between the two cases was that in the former flask spores were entirely absent, while in the latter they were present in great numbers.

Günther[4] inferred from his experiments that the limit of sensibility of the fungus *Rhizopus* to magnesium sulphate is 0.005 milligram. From such experiments it seems very probable that in those made by Fränkel with bacteria traces of magnesia were present as impurities in some of the compounds used.

Molisch has observed, and his observations have been confirmed by the writer, that spores of *Penicillium* do not even germinate in culture solutions entirely free from magnesia and containing ammonium acetate as the only organic nutrient—a fact which appears very strange, as there is certainly stored up in the spores a sufficient amount of magnesium phosphate to make germination and even some further development possible, and indeed magnesia has been found repeatedly in the ash of various fungi. The writer has cultivated *Penicillium* in a solution containing peptone, tartaric acid, monopotassium phosphate, and 0.1 per cent magnesium sulphate, and has convinced himself of the

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[1] Journ. f. Landw., 1898, Vol. XLVI, p. 1.

[2] Centralbl. f. Bakt., Vol. XVII, p. 32.

[3] Experiments with *Penicillium* succeed best in moderately acid solutions.

[4] Loc. cit. (p. 25).

presence of magnesia in the spores.[1] However, these same spores did not germinate in the solution of ammonium acetate used by Molisch and by the writer, but they germinated in various other solutions, as, for instance, in a 0.5 per cent solution of sodium acetate or of cane sugar containing a small amount of ammonium sulphate. It appears probable, therefore, that a solution containing ammonium acetate as sole organic nutrient is unfavorable for starting in the spores certain processes which render the stored-up magnesium phosphate available for the beginning of germination. Perhaps there is formed in the spores the but little soluble magnesium ammonium phosphate when too much ammonia is present in the culture solution. In suitable culture solutions, free of magnesia, the magnesium phosphate stored up in the spores may be economically utilized, and even a considerable mass of mycelium may be produced provided an abundant sowing of spores had taken place.

CAN MAGNESIUM SALTS BE REPLACED BY BERYLLIUM SALTS?

The attempts to penetrate the mystery of the physiological functions of magnesium naturally have raised the question whether beryllium can perform the functions of magnesium in living cells, since the general behavior of the compounds of these elements bears a strong chemical resemblance to each other.

In 1890 Sestini[2] undertook to determine whether wheat could be raised in culture solutions in which magnesium sulphate was replaced by beryllium sulphate. He sowed the grains in quartz sand which had been treated with hydrochloric acid to remove all mineral impurities, and watered the plants with a culture solution containing beryllium sulphate in place of magnesium sulphate. The plants reached a height of 90 to 95 cm., but the control experiment showed the superiority of magnesium over beryllium, as will be seen by the following comparison:

Wheat grown—	Number of seeds.	Weight of seeds.	Weight of single seed.
		Grams.	*Grams.*
In the beryllium solution	283	12.31	0.435
In the magnesium solution	322	15.20	.472

[1] It has been shown by Aso that the spores of *Aspergillus* contain a moderate amount of magnesia. He has kindly furnished the writer the results of an analysis which yielded for the ash of spores of *Aspergillus oryzae* the following composition:

	Per cent.
Potassa	45.96
Soda	4.13
Lime	1.03
Magnesia	4.36
Oxid of iron	4.91
Phosphoric acid	39.64
Sulphuric acid	2.00
Silica	.40

The percentage of ash in the dry matter was 5.15. The fungus had been grown on boiled rice.

[2] Le Staz. Agr. Ital., Vol. XX; Centralbl. f. Agr. Chem., 1890, p. 464, and 1891, p. 558.

The harvested seeds were grown again in the same way.[1] Of twenty seeds of the plants grown in beryllium solution, however, only seven germinated and only three of the plants produced seeds, the resulting crop of fourteen seeds weighing only 0.37 gram and averaging only 0.026 gram. This clearly shows that beryllium can not replace magnesium in wheat, and very probably also not in any other of the Phanerogams. The fact that the first generation yielded a much better result than the second must be ascribed to the presence of a relatively large amount of magnesium phosphate in the seeds used.

In an experiment made by the writer with shoots of *Tradescantia* placed in culture solutions containing 0.1 per cent beryllium sulphate in one case and 0.1 per cent magnesium sulphate in the other, the lower leaves of the beryllium plant commenced to die after several weeks, and the newly developed upper leaves scarcely reached one-third the normal size, these shoots dying off after eight weeks, while in the control case they were still in a healthy condition.[2]

In regard to algæ, the writer has observed that a solution of beryllium sulphate in which the other mineral nutrients are wanting exercises an injurious influence sooner than does the magnesium sulphate. Some threads of *Spirogyra communis* were placed in 0.2 per cent of these salts dissolved in purest distilled water, and it was found that the number of dead and injured cells was much larger after two days in the former case than in the latter.[3]

In a subsequent experiment the amount of both these sulphates was diminished and mineral nutrients added, the composition of the main solution being—

	Per mille.
Calcium nitrate	0.10
Calcium sulphate	.01
Monopotassium phosphate	.01
Dipotassium phosphate	.01
Beryllium sulphate	.10

In this solution *Spirogyra* threads were still normal and healthy after three weeks, but had not grown to any noticeable extent.

In another experiment the following solution was prepared:

	Per mille.
Calcium nitrate	0.25
Calcium sulphate	.10
Monopotassium carbonate	1.00
Monopotassium phosphate	.05
Ferrous sulphate	Trace.

One half of this solution received 0.2 gram magnesium sulphate and the other half 0.2 gram beryllium sulphate. Very soon a slight turbidity, followed later by a flocculent precipitate, was noticed in the beryl-

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[1] The ash of the beryllium plants contained 2 per cent of BeO.

[2] Mineral nutrients are stored up in the nodes, as already mentioned.

[3] For further information relative to the noxious effect of magnesium salts in absence of calcium see p. 42.

lium solution, while the control solution remained absolutely clear. Into both flasks a trace of a *Palmella* culture, with some Diatoms, was now introduced. After four weeks it was found that the Diatoms had multiplied to a great extent in the control solution, but not one could be observed after repeated microscopical examinations in the beryllium solution. The *Palmella*, however, was well developed in both flasks. This might seem to indicate that such a simple alga form as *Palmella* could utilize beryllium salts in place of magnesium salts, at least when it is offered in a favorable culture solution, but slight traces of magnesia might have been furnished by the glass vessel.

To determine the effects of beryllium on fungi an experiment was made by Molisch, the culture solution used containing—

	Pec mille.
Ammonium acetate	20.00
Beryllium sulphate	.40
Monopótassium phosphate	.04
Ferrous sulphate	.01

There was no development whatever in this solution when spores of *Penicillium* were inoculated, but upon the addition of 0.02 per cent magnesium sulphate 78 milligrams of fungous mass was produced after nineteen days.

Notwithstanding the close chemical relations between beryllium and magnesium there must exist such chemical differences that the inability of beryllium to physiologically replace magnesium can be easily explained. As the text-books on chemistry fail to give minute comparisons of the chemical behavior of soluble beryllium and magnesium salts toward phosphates, the writer has made a few tests in this regard. When 1 per mille solutions of beryllium sulphate and dipotassium phosphate are mixed the liquid is at first clear at the ordinary temperature, but gradually becomes opalescent, and after one day the beryllium is precipitated as a flocculent phosphate, but if the mixture is heated or if some sodium acetate is added a flocculent precipitate is produced at once. Magnesium sulphate behaves very differently, giving no precipitate whatever under the same conditions.

If a 10 per cent solution of monopotassium phosphate is mixed with a 10 per cent solution of magnesium sulphate no precipitate is formed at the ordinary temperature, and the liquid remains clear even on boiling. This, however, is not the case with beryllium sulphate, which produces a copious flocculent precipitate in a few minutes, and even if more dilute solutions, as for example a 1 per cent solution of monopotassium phosphate and beryllium sulphate, are mixed the mixture becomes turbid on boiling.

Although a higher diluted solution of beryllium sulphate gives no precipitate with monopotassium phosphate, the addition of sodium acetate, even at the ordinary temperature, will cause a precipitate of beryllium phosphate. Thus even in a dilution of 0.001 per cent beryllium sulphate, turbidity will be produced and finally some flocculi will be deposited. Under the same condition solutions of magnesium sulphate, whether highly or moderately diluted, will remain perfectly clear.

It is seen, therefore, that there is a fundamental difference between beryllium and magnesium salts in their behavior to phosphoric acid—a difference which amply accounts for the fact that beryllium salts can not replace magnesium salts, as far as the process of the assimilation of phosphoric acid is concerned. In this respect magnesium is unrivaled even by the most closely related elements. With the properties of easy dissociation of the salts and its character as only a weak base, magnesia unites a moderate solubility of the secondary phosphate not found with any other related base. Although beryllium oxid is also a weak base, the fact that it is much more inclined than magnesia to yield an insoluble phosphate renders it unsuitable for the function mentioned.

As to the rarer elements it may still be questioned whether there may not exist among them some that could physiologically replace magnesium or calcium. The experiments with cerium and lanthanium showed no evidence in favor of that view, these salts killing algæ in a solution of 0.1 per cent. Thorium sulphate is not so injurious, but no further studies as to whether it can be utilized for any physiological function have been made, nor have any experiments been made with yttrium, niobium, or some other rare elements.

IMPORTANCE OF LIME SALTS FOR ANIMALS.

In animals lime salts are necessary not simply for the formation of the bones, but also for every part of the body, and they are required for the lowest forms as well as for the higher animals.

The action of the heart is above all most intimately connected with the presence of lime salts. Thus, a frog's heart will soon stop even in a physiologic salt solution (0.6 per cent sodium chloride), but will continue to beat when some ash of blood is dissolved in the same solution. Ringer has shown that a good circulating fluid for the heart may be compounded by preparing a mixture of such salts as normally occur in the blood. In such a solution the isolated frog's heart will beat almost as long as it would in defibrinated blood. Halliburton[1] says: "The necessity for lime salts is especially great. In fact, the close adhesion of proteids generally with small quantities of mineral matter is rather suggestive of combination than mere mixture. Lime salts adhere especially closely and in fact seem indispensable for many of the functions of the body, of which the beating of the heart and the contraction of skeletal muscle are good examples. Blood from which the salts have been removed keeps the heart going, but the tracing is abnormal, resembling that produced by a weak solution of a lime salt. It is in

[1] Chem. Physiol., 1891, London, p. 256.

fact found that dialysis will not remove the lime from serum albumin, though it removes the greater part of the sodium and potassium salts."

The great importance of calcium salts for the various organs of animals is also illustrated by the empirical knowledge gained by physicians. Thus a prominent medical work[1] states: "Calcium chlorid is used with benefit as an internal remedy in the various manifestations of the strumous diathesis. It often causes the resolution of glandular enlargements and the calcification of tubercular deposits, aids the cicatrization of ulcerating cavities, and has proved curative in eczema and lupus. It is highly praised in phthisis, also in chorea, and for the colliquative diarrhœa of strumous children. In solution used externally as a fomentation it is said to hasten the maturation of boils." In direct contact with the heart, however, this salt is not harmless, as shown by the experiments with a frog's heart. Probably a hydrolytic dissociation, with liberation of hydrochloric acid, however slight it might be, brings on the injurious effect.[2]

Munk[3] observed during the inanition of men and dogs a gradual increase of the lime secreted in the urine. Katsuyama[4] noticed in observations on starving rabbits in the first four days a gradual decrease and afterwards a slow increase of lime in the urine, while there was a gradual and steady decrease of magnesia. This decrease of magnesia, compared with the increase of lime, is very significant and instructive.[5]

PROPORTIONS OF LIME AND MAGNESIA IN ANIMAL ORGANISMS.

The muscle fibrillæ of the mammalia are made up principally of the contractile substance, or, as Kupffer has called it, the dynamoplast. The energide (the nucleus with its connected cytoplasm), which manufactures the fibrillæ, occupies but a small volume within the dynamoplast, hence the writer's hypothesis would suggest the inference that the lime content of muscular masses should be less than that of glandular masses, since the relative mass of the nucleus in muscles is much smaller than in glands. From Katz's analyses the following data will show how far this view is confirmed.[6]

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[1] Potter, O. L., Handbook of Materia Medica, Pharmacy, and Therapeutics, Philadelphia.

[2] Calcium hydrate introduced in man or dog tends to the secretion of calcium carbamate in the urine, as Abel has demonstrated. This is of special physiological interest, since carbamic acid is the precursor of urea, as Nencki and Drechsel have shown.

[3] Suppl. zu Virchow's Arch., Vol. CLI.

[4] Zeitsch. f. Phys. Chem., 1899, Vol. XXVI.

[5] It may be pointed out here that lime compounds also seem to play an important rôle in the coagulation of the blood, as this can be prevented by the addition of some soluble oxalate. Myosin, which possibly plays a part in the coagulation of the muscular plasm, also contains lime. Moreover the actions of rennet and of pectase are connected with the presence of lime.

[6] Pflüg. Arch., Vol. LXIII, p. 1.

There were found in 1,000 parts of fresh muscle of a—

	Part calcium.
Dog	0.0685
Hog	.0806
Deer	.0959
Cat	.0846
Man	.0748

or an average of 0.0809 part calcium. On the other hand Oidtman[1] found in the liver, the largest gland in mammalia, 0.284 part of calcium for 1,000 parts, or nearly three and a half times as much as the average in the muscle.

Embryos and young animals show a higher percentage of nuclear mass in the muscles than do full-grown animals, hence the fact that the muscles of the calf contain more lime than those of the cow[2] is in full accord with the writer's inference. Zoologists have further observed that the muscles of fishes and batrachia are relatively richer in nuclear mass than are those of mammalia. The fact that Katz[3] has found two to three times as much lime in the muscles of such animals as in those of mammalia is therefore strictly in accord with the writer's view. There is in 1,000 parts of fresh muscle of the—

	Parts calcium.
Frog	0.1566
Shad	.2206
Eel	.3913

or an average of 0.2562 part calcium.

The importance of lime for the division of cells even in the lower animal organisms is shown by Herbst's statement[4] that the most important salt for the development of the sea urchin's eggs is calcium phosphate, in the absence of which not even the completion of segmentation is possible. The calcium of this salt is just as important as the phosphoric acid. It happens that this salt is present in the sea water in very small quantities only, hence it must be assumed that these eggs have a great absorptive power for it.

A relative increase of magnesia can be observed in certain organs in which the nuclear mass is small. Thus, according to Geogehan, the human brain contains about ten times as much magnesium phosphate as calcium phosphate, and the muscles of mammalia contain in most cases more magnesia than those of batrachia and fishes, as shown by Katz's results.[5]

[1] Prize Treatise, Würzburg, 1858. This author found 1.1 per cent inorganic substance in the liver, and in 100 parts of this ash 3.62 per cent of lime and 0.19 per cent of magnesia. Calculating from these data, there are contained 0.2842 part of calcium and 0.0125 part of magnesium in 1,000 parts of fresh liver.

[2] The lime content of the liver cells is also larger, according to Krüger (1895), in the calf than in the cow, which suggests the necessity of further microscopic comparison as to the relative size of the nuclei.

[3] Loc. cit.

[4] Arch. f. Entwicklungsmechanik, Vol. V, p. 667.

[5] Loc. cit.

There is in 1,000 parts of fresh muscle of the—

	Part magnesium.
Dog	0.2370
Hog	.2823
Deer	.2906
Cat	.2863
Man	.2116
Average	.2611

while there is in 1,000 parts of fresh muscle of the—

	Part magnesium.
Frog	0.2353
Shad[1]	.1670
Eel	.1782
Average	.1935

A comparison of the averages shows for the—

	Calcium.		Magnesium.		Calcium.		Magnesium.
Muscles of mammalia	1	:	3.23	or	0.31	:	1
Muscles of frogs and fish	1	:	.75	or	1.33	:	1
Liver of mammalia	1	:	.04	or	25.00	:	1

Since it is seen that glands contain more calcium than muscles, and that the muscles of lower animals contain more calcium than those of the higher animals, one can not help seeking for a law underlying these facts, which are in full accord with the writer's inference that the amount of lime must increase with that of the nuclear mass. On the other hand the high lecithin content of the brain may have a connection with the relative increase of magnesia in it (p. 50.)

It would be very interesting to analyze the gray and the white substances of the brain separately, as they show a great quantitative difference in the nuclear masses. Moreover, the peripheral nerve threads being poorest in nuclear mass, should also be investigated in this respect. It is regrettable that so far no physiologist has undertaken the work.[2]

BEHAVIOR OF ANIMALS TO STRONTIUM SALTS AND OXALATES.

The replacement of calcium salts by strontium salts is just as impossible in animals as in plants (p. 39). Not even in the formation of the bones can strontium phosphate take the place of calcium phosphate. Craemer fed a rapidly growing young dog for several months with food poor in lime, and to which an addition of strontium phosphate was made, and as a result great softness of the bones and rhachitic alterations were soon obvious. Weiske[3] arrived at the same conclusions and refuted the contrary opinions of Papillion and König. In the presence

[1] The unusually large proportion, 0.3102 part, found by Katz in the pike, may possibly be due to an error.

[2] The gray substance of the brain is richer in nuclear mass than the white substance and therefore ought to contain more lime.

[3] Zeitsch. f. Biol., Vol. XIII, p. 421.

of sufficient lime the poisonous action of strontium salts upon animals is weak.

The writer's hypothesis as to the functions of lime salts makes the poisonous action of soluble oxalates upon animals also more intelligible than it has been heretofore. The chief property of oxalates is to transform the calcium of calcium compounds into calcium oxalate. If therefore the nuclei of the cells contain calcium protein compounds in their organized structure, the removal of this calcium and its replacement by the sodium or potassium of the oxalate applied must alter the capacity of imbibition and thus cause fatal disturbances of the organized structure (tectonic). Indeed, oxalates constitute a general poison for all kinds of animals.[1] The writer has demonstrated that in a 0.5 per cent solution of neutral potassium or sodium oxalate *Rotatoria*, *Copepoda*, and aquatic *Asellids* die in thirty to fifty minutes, leeches and *Planaria* succumb a little later, and finally *Ostracodes* and larvæ of insects are killed. *Infusoria*, *Flagellata*, and *Amoeba* were found to be dead in this solution after fifteen hours. Even a 0.1 per cent solution of sodium oxalate will kill some of the organisms named, such as *Copepoda* and *Rotatoria*. The poisonous action for vertebrates was known long ago, but the explanations were not entirely satisfactory. Some authors sought the cause in the obstruction of the vessels of the kidneys with calcium oxalate and in inflammation of the kidneys, and others believed in a decomposition of the oxalic acid with the production of the poisonous carbonic oxid, but the irritation and the final paralysis of the vasomotoric center pointed plainly to another cause.[2]

FINAL REMARKS.

The writer's deliberations have led him to conceive the probable rôle of calcium and magnesium salts in the living cells. This view is in full accord with various facts for which in former times no satisfactory explanation was reached.

It is now clear why magnesium is more movable in plants than calcium, and further, why the calcium content increases with the mass of nuclear substance and of chlorophyll bodies, and why magnesium salts increase wherever phosphoric acid is in increased demand for the production of lecithin and nuclein. It also makes it perfectly clear why on the one hand magnesium salts become poisonous in the absence of calcium salts, and why on the other hand the absence of magnesium salts in an otherwise complete culture solution leads to a gradual stoppage of all further development, and to final inanition. The formation of the nuclei and plastids requires calcium as well as magnesium salts,

[1] Noxious effects on the bones and kidneys and sometimes on the activity of the heart have been noticed after feeding cattle with vegetables containing soluble oxalates, such as leaves of the sugar beet.

[2] The fact that badly healing sores are produced when open wounds come in contact with oxalate solutions, a fact long known to photographers, deserves particular mention.

the former for the production of calcium nucleo-proteids and the latter for making possible the assimilation of phosphoric acid. If lime salts are in great excess in a neutral medium, the formation of magnesium phos phate and consequently the assimilation of phosphoric acid will be retarded, since the lime as the stronger base will withhold phosphoric acid when soluble phosphates come in contact with lime salts. Many plants, therefore, which have absorbed too much lime and relatively too little magnesia from the soil precipitate a part of the lime in the form of oxalate. Indeed Monteverde[1] observed that the amount of oxalic acid increases with the amount of lime absorbed.

The excess of lime is in reality the cause of an increased production of oxalic acid—a fact best explained by the assumption that before carbonic acid is finally produced by the combustion of carbohydrates, a series of organic acids, of which oxalic acid is one stage, is rapidly passed, this stage being fixed by the presence of lime. Similar observations were also made by Wehmer with fungi in culture solutions to which lime salts were added. In the presence of lime salts there was more oxalic acid formed than in its absence, or, more correctly expressed, more was preserved from being again destroyed by further oxidation.

The fact that seeds generally contain much more magnesia than lime may be considered an interesting case of adaptation. A rapid develop ment by an easy assimilation of the reserve phosphoric acid is thus assured—a favorable circumstance, as it lessens the danger of the molding and putrefying of the seeds sown in moist ground. The same plant after it develops chlorophyll, however, requires more lime in proportion to magnesia than does the seedling in its early stages. According to Wolff's calculations of the minima of lime and magnesia for oats there is required 0.2 per cent of each for the dry matter, but for plants with more abundant foliage the minimum of lime would be larger.

The proportion of these two constituents in the soils is a more potent factor in the resulting crop than is generally supposed. The many contradictory statements in regard to the influence of magnesia in the soils are easily explained by the aid of the above theory. A soil rich in magnesia will be damaged by liming with magnesian limestone, since this would increase still more the already large amount of magnesia, while a soil very poor in magnesia may be benefited by it. In the application of kainit and carnallit also the magnesia content of these potassa fertilizers has to be considered and eventually liming has to be carried on in conjunction with it.

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[1] Bot. Jahresb. f. 1890, p. 75.

BULLETIN No. 19. V. P. P.—71.

U. S. DEPARTMENT OF AGRICULTURE.

DIVISION OF VEGETABLE PHYSIOLOGY AND PATHOLOGY.

B. T. GALLOWAY, Chief.

STIGMONOSE:

A DISEASE OF CARNATIONS AND OTHER PINKS.

BY

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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
DIVISION OF VEGETABLE PHYSIOLOGY AND PATHOLOGY,
Washington, D. C., February 15, 1900.

SIR: I respectfully transmit herewith a report by Mr. Albert F. Woods, of this Division, embodying the results of an investigation of a disease of the carnation, to which he has applied the name "stigmonose." This disease, which is a serious drawback to the successful growing of the carnation, has until recently been attributed to bacteria and given the name "bacteriosis." Mr. Woods, however, has shown that it is due to the punctures of insects, principally aphides and thrips, and of mites. Although these are the inciting cause of the trouble, the pathological and physiological changes involved are dependent to a large degree on the condition of the plant and the time the punctures are made. The work deals with the subject largely from the standpoint of pathology and physiology, pointing out the conditions which influence the disease, and suggesting lines of treatment based mainly on a knowledge of the proper handling of the plants. We are indebted to Dr. L. O. Howard, Entomologist of the Department, for assistance in a number of matters connected with the work.

The carnation crop in this country represents an annual value of over $4,000,000 and is constantly increasing. In view of this fact and the many interesting and suggestive points brought out in the work, I respectfully recommend that the report be published as Bulletin No. 19 of this Division.

Respectfully,

B. T. GALLOWAY,
Chief of Division.

HON. JAMES WILSON,
Secretary of Agriculture.

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STIGMONOSE: A DISEASE OF CARNATIONS AND OTHER PINKS.

INTRODUCTION.

In the course of some investigations which the writer conducted several years ago on a disease of the Bermuda lily, his attention was attracted by the similarity between this disease and the one affecting carnations, and described by Arthur and Bolley[1] under the name "bacteriosis." As announced in a preliminary paper,[2] the writer carried on extended studies of the carnation disease, but was unable to obtain results similar to those described by Arthur and Bolley. Since publishing the paper referred to he has repeated and extended the work which it describes and has fully substantiated his former conclusions. In view of the fact that the disease is not due to bacteria, but is caused by the punctures of aphides, thrips, and occasionally of red spiders, the name stigmonose,[3] or puncture disease, is here suggested as an appropriate one for the malady.

Probably the first account of the disease was that given in Dr. Arthur's paper[4] read before the American Association for the Advancement of Science, at its meeting at Toronto, in 1889. In this paper Dr. Arthur proposed the name "bacteriosis," believing the disease to be due to bacteria.

Inasmuch as many pathologists and carnation growers remain in doubt regarding the true nature of the trouble, it is thought desirable at this time to give a full account of all the work that has been done on it, together with a detailed discussion of the conclusions reached by Arthur and Bolley.

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[1] Arthur, J. C., and Bolley, H. L., Purdue Univ. Exp. Sta. Bull. No. 59, 1896, Vol. VII, pp. 29, pls. 8.

[2] Bot. Gaz., September, 1897, and Centralbl. f. Bakt., Par., u. Infekt., 1897, 2 Abt., Bd. 3.

[3] Stigmonose is a combination of the two Greek words *στιγμή*, a puncture, and *νόσος*, a disease, the puncture, rather than the organism producing it, being made the basis of the name.

[4] Arthur, J. C., Proc. Am. Assn. Adv. Sci., 1889, Vol. XXXVIII, p. 280.

INVESTIGATIONS OF THE CARNATION DISEASE BY ARTHUR AND BOLLEY.

DESCRIPTION OF THE DISEASE.

The trouble was regarded by Arthur and Bolley[1] as one affecting the carnation leaf mainly. They describe it as follows:

It generally starts in the leaf when immature, and is best diagnosed in the younger but full-sized leaves nearest the upper end of the stem. Taking such a leaf, which on its surface presents no unusual appearance to the eye, and holding it toward a strong light, small, pellucid dots may be detected scattered irregularly through the leaf, sometimes having a faint yellowish color, which are the centers of infection. The appearance of the dots has a close resemblance to those of the oil glands in the leaves of the common St. John's wort (*Hypericum perforatum*), a rather abundant weed, or in the leaves of the false indigo (*Amorpha fruticosa*), a native shrub, except that they have no regular disposition. Sometimes the surface of the leaf is slightly raised over the dots, making watery pimples.

After a time the surface of the leaf above the dots changes enough to indicate their presence and finally shows a distinct spot. As the disease extends inside the leaf the surface tissues dry, the internal tissues collapse, and whitish, sunken spots appear. In some colored varieties of carnation the spots vary somewhat by being more or less reddish or purplish. As the spots increase in size the leaves wither, still clinging to the stem. Such spots never show distinct central darker-colored specks and rarely any concentric circles, as do the spots made by parasitic fungi, such as Septoria (spot disease) and Heterosporium (fairy ring).

Very badly diseased plants, especially when much crowded and growing in damp atmosphere, have more yellowish green leaves than normal, of a more transparent appearance, and usually smaller. The lower leaves of diseased plants in any atmosphere or soil die prematurely and the vitality of the plant is so lowered as to check the growth and decrease the size and number of the flowers.

In addition to the above description, these translucent dots may be divided into three classes, representing three forms of the disease, which differ slightly from each other in general appearance and behavior. The first and most common form corresponds with the above description. The translucent dots increase more or less rapidly, according to the age of the leaf, until finally they reach a diameter of one to several millimeters, and often coalesce. The second form is characterized by the appearance of very small spots, scarcely visible to the naked eye, but easily detected when the leaf is held up to the light and examined with an ordinary hand lens. These small spots are exceedingly numerous, but in their further development, even on young leaves, scarcely ever reach a diameter of more than half a millimeter. The third form resembles the first in extent of development, but instead of being round, the spots are elongated and irregular, and the affected plants are usually more or less distorted.

Dr. Arthur said that in his earlier study of the disease "no cause, either parasitic or nonparasitic, could be found to account for the difficulty. The eye, either unaided or by the assistance of the microscope,

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[1] Arthur, J. C., and Bolley, H. L., Purdue Univ. Exp. Sta. Bull. No. 59, 1896, p. 18. All succeeding quotations from these authors are from this bulletin.

detected only a gradual shriveling of the tissues of the leaves. At first light-colored blotches made their appearance, which gradually extended, coalesced, and finally the whole leaf became dry and lifeless." A further examination made by Dr. Arthur in 1889 revealed the presence of the semitransparent dots described. He says:

Repeated microscopic examinations of the sections through these spots convinced us that the cells of the region were always infested with bacteria—often in considerable numbers. It was not difficult to see that the conspicuous dry blotches might be derived from the inconspicuous dots and that the latter possibly represented the beginnings of a genuine disease. There were now a number of difficult questions to answer, foremost of which was to show the causal or accidental relation of the bacteria seen in the cells to the degeneration of the tissues. The larger part of the work of the investigation from this time on until the main facts were established—a period of about eighteen months—fell to the lot of Mr. Bolley.

ISOLATION OF THE GERM.

Following out the suggestions resulting from their microscopical examinations, Arthur and Bolley made an attempt to isolate the germ supposed to be the cause of the trouble. It should be noted that their "repeated trials for a number of months gave such varying results that nothing of a substantial nature was learned. Saprophytic forms from the air and from the leaves of the plant took possession of the cultures, obscuring or destroying the slower-growing parasitic form." However, the addition of malic acid to the culture media retarded the growth of saprophytic bacteria and gave the slower-growing organisms a chance to develop. One of the most constant sorts obtained by Arthur and Bolley[1] in this way was a "coccus-like form of a yellowish color that grew slowly, but developed well in acid cultures," and this they believed, as the result of infection experiments, to be the cause of the disease in question.

No spores were found in any stage of growth. The bodies discovered in the cells of the host and believed to be bacteria agreed in size and general appearance with *Bacterium dianthi*. The cells were not united into filaments, but were almost or quite separate from one another, exhibiting no independent movement and undergoing no marked variation in form during growth.

It is not necessary in this paper to enter into a full discussion of the biology of this germ, but a few of the most important points may be mentioned. In plate cultures of 10 per cent acid nutrient gelatin the body of the colony is made up largely of zooglœa, giving an "irregular

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[1]They describe the species as "*Bacterium dianthi* Arthur and Bolley n. sp. Cells oval to elliptical, single or rarely united, 0.9–1.25 by 1–2 μ; in rich fluid media more united, in part forming short filaments, at first motile, afterwards forming distinct, elongated, somewhat convoluted zooglœa; on solid media becoming yellow in mass. * * * The color accumulates slowly as the bacteria grow and is apparently not deposited within the cell, but is an excretion from it."

outline and a lobed and wrinkled appearance to the surface, the color being a light, clear orange. When growth is strong the colonies pile up in pronounced yellow, viscid drops." In plate cultures of neutral gelatin the colonies consist after a time of a few light-colored zooglœa, "with a surrounding irregular area of actively growing bacteria, the whole having a light cream color." The germ liquefies gelatin slowly. The formation of zooglœa is also particularly marked in fluid culture media, such as a broth made of corn seedlings or of potato tubers. The germ stains readily in all stages of development with most of the dyes in general use, especially aqueous solution of fuchsin and of gentian violet.

DIFFICULTIES MET WITH IN ISOLATING THE ORGANISM.

As before stated, Arthur and Bolley found more or less difficulty in isolating the germ from the diseased tissues, even the acidifying of the gelatin only partially preventing rapidly growing organisms from overrunning the cultures. Attempts to free the surface of the leaves from other germs by washing with corrosive sublimate (1:1,000 solution) always gave negative results. They believed that "some of the poison passed over into the culture and prevented growth, even when the leaf was well washed with distilled water after its treatment with corrosive sublimate. Most of the work was done with cultures obtained by passing the leaf quickly through a Bunsen gas flame two or three times, thus destroying all surface molds and bacteria in both spore and vegetative condition, and then cutting the leaf into thin sections with flamed scissors, allowing the sections to drop into the nutrient medium."

The first point to be investigated was the adequacy of this method of surface sterilization. Numerous experiments by the writer have shown conclusively that unless the epidermal cells of the carnation are killed by the heat the organisms lodged in crevices of the cuticle are not always killed, but often grow readily when a portion of the flamed though still living epidermis is put into nutrient media. Flaming the leaf, therefore, in the manner described is sufficient to remove from it only the most exposed and least resistant organisms.

It is to be regretted that Arthur and Bolley did not describe the poured plate cultures made direct from the diseased tissues, as this is a much more accurate method of research than simply dropping fragments of tissue into tubes of culture media and then making poured plates from the growth thus obtained. If the diseased mesophyll cells contain even a few germs, hundreds of colonies ought to be obtained by breaking up these cells and making poured plates from them direct. If only a few colonies develop after the cells are broken up in quantity and such plates made, the direct evidence that the germ had anything to do with causing the disease would be very inconclusive, especially if the colonies are of different varieties. However, if such plates should uniformly yield numerous colonies mostly of one sort, the evidence would be favorable, but still not conclusive.

INFECTION EXPERIMENTS.

Arthur and Bolley's first infection experiments were made with liquid cultures developed from cutting up diseased leaves into nutrient fluid. When the fluid became cloudy "application of the liquid was made with a camel's hair brush to the surface of four young leaves of a a small, healthy carnation plant growing in a greenhouse." After fifteen days indications of change were detected in the infected region, and in nineteen days the characteristic dots were seen where the infusion was applied, "the remainder of the plant remaining quite free from any such appearance." Another plant, covered by a bell jar, was similarly treated a few days later, and in seventeen days showed distinct evidences of the disease. Nothing is known with regard to the organisms which this culture may have contained.

After the isolation of the yellow germ described, many surface infections were tried, but, according to the authors, "the purity of the cultures could not always be guaranteed, or else the trial plants developed diseased spots outside the inoculated area and thus absolute certainty could not be obtained." The investigators named make the following statements in regard to their infection experiments:

January 15, 1890, an infection of three seedling carnations in the greenhouse, two protected with bell jars and one uncovered, was made as previously described, using a potato infusion. This infusion had been infected the day before with the yellow coccus-like germs from a pure culture on solid media, which had originally been obtained from diseased carnation leaves on November 18, 1889. The affected areas began to show disease in six days, and in eleven days more all the leaves became "infected at the points of application, and at these points only," as stated in the record book, and remained so for a month and a half or more. It was now believed that the germ causing the bacteriosis was found, and although many subsequent infection experiments were carried out with varying success, the remainder of the winter was chiefly given up to the biological study of the specific germ.

The best method for applying the contagium was for a time uncertain. The method used in studying pear blight, the well-investigated bacterial disease of pomaceous trees, which consists in abrading the surface so that the germs may at once come in contact with the internal juices and tender tissues of the plant, proved inapplicable to the carnation disease. No clearly marked cases of the disease were obtained in this way. The wounds showed in some cases a slightly yellowish margin, but otherwise gave few indications of results differing from those which might arise from accidental abrasions.

Surface application (wetting the uninjured surfaces of the young leaves with the germ-laden fluid) was finally adopted as the proper method of infection. Experience showed that success could only rarely be attained when the infections fluid was applied to mature leaves. The best results were always secured when the application was made to the small appressed leaves at the end of the stem. They were drawn back and well wet with the fluid, and if growing vigorously usually showed the characteristic pellucid dots by the time the leaves were full size. A difficulty was experienced in securing perfectly healthy plants, for it was found that nearly all carnation plants, whether grown in the greenhouse or out of doors, in pots or in beds, showed more or less evident traces of the disease when examined critically.

It was thought by Arthur and Bolley that the germs gained entrance to the tissues through the stomata, and sometimes through insect punctures, especially those made by aphides. They say that "the common green fly, or aphis, of the greenhouse may in some instances prove such an efficient bearer of the contagion that every leaf on a plant may be inoculated at hundreds of points, and the whole plant be turned a sickly yellow by the growth of the bacteria in the tissues."

The evidence of these infection experiments, so far as reported by Arthur and Bolley, is rather in favor of the bacterial nature of the disease, but the experiments they instituted were too few and there is no report of the isolation of the germ from spots produced artificially.

Besides the supposed production of the disease in the carnation, these investigators state that it can be transferred also to "*Dianthus caryophyllus*, *D. plumarius*, *D. japonicus*, *D. chinensis*, and *D. barbatus*, but not to the shoots, leaves, or tubers of potato or to other non-caryophyllaceous plants." These apparently successful infection experiments can be readily explained by assuming that the leaves of the inoculated plants had been previously punctured by aphides. If the leaves were not making a rapid growth they would appear to be perfectly healthy, showing no spots for some days after being punctured, as will be explained farther on. This fact not being known at the time it was almost impossible to avoid mistakes.

INVESTIGATIONS OF THE DISEASE IN WASHINGTON.

PRELIMINARY STUDIES.

In 1897 the plants in one of the large carnation houses belonging to the Government Propagating Gardens were badly affected with the disease. They were making poor growth, and the leaves were filled with innumerable translucent spots and blotches, and in many cases were deformed and twisted. The house had been kept rather dry, and in watering the plants the foliage had been wet as little as possible. It was not clear, therefore, how bacteria could have developed in sufficient numbers on the surface of the dry leaves to gain entrance to the tissues.

An extended experiment was carried on with different germicidal substances. One block of the plants was thoroughly sprayed with corrosive sublimate solution (1 to 1,000). It was very difficult to wet the foliage, but by using a fine spray much of the fluid remained attached to the surface of the leaves. In order to make the test more thorough, the waxy bloom on the younger leaves of some of the plants was removed with cotton moistened in the corrosive sublimate solution, special care being taken to disinfect the young growing point as thoroughly as possible in this way. A similar experiment was made with formalin 1 to 1,000, and a third one with formalin 1 to 500, it being thought that the formalin would be effective in penetrating between the young leaves and thus destroying the germs. Although these applications were continued twice a week for a month, the young growth continued to be as badly diseased as ever, there being no apparent difference between the treated and the untreated plants. A few thrips were observed working on the plants and also a few aphides, but it was not believed at the time that these could possibly account for the trouble, and they were looked upon simply as distributers of bacterial infection.

Finally it was decided to make no further attempt to control this disease, but to keep the houses a little warmer and moister, force the flowers into bloom, and get as much out of them as possible. The plants were therefore syringed on bright days and the air of the house kept quite moist. Much to the writer's surprise, they began to grow out of the trouble and produced some fine flowers. These peculiar results, together with the similarity of the disease affecting the lily, as before stated, led to a careful study of the trouble.

MICROSCOPICAL INVESTIGATIONS.

Besides the affected plants in the carnation houses at Washington, other plants showing the trouble were obtained from many of the large carnation-growing sections, including some plants that Dr. Arthur kindly sent in from Mr. Fred Dorner's place at Lafayette, Ind. Leaves showing various stages of the disease were killed by both the chromic acid and the absolute alcohol method, and then were dehydrated with alcohol and infiltrated with paraffin in the usual way. Microtome sections were then cut and mounted in series, and these were stained with Ziehl's carbol fuchsin, and also, according to Gram's method, with aniline water gentian violet. The ordinary aqueous solutions of fuchsin and gentian violet were also tried along with other stains. About two thousand sections, representing all phases of the disease from different localities, were prepared and stained.

The cells of the diseased spots were found to be much larger than normal, and thin-walled and œdematous (figs. 1, 2, and 3, and Pl. III, figs. 1, 2, 3). In the early stages of the disease the chloroplasts were undeveloped or smaller than in the healthy cells and were colorless or yellow. Even after the most thorough and careful staining no parasitic or saprophytic organisms could be detected in the tissues of these spots until after the epidermal cells collapsed, when, in some cases, fungi and bacteria were readily distinguished, although usually only in small numbers. A very curious structure was always present in the earlier stages of the common form of the disease. It stained slightly with carbol fuchsin and gentian violet, and reminded one of a very thick, resistant, slightly branched mycelium (figs. 2 and 5, and Pl. II, fig. 4). In the later stages it was found to break up, the pieces remaining for some time between the cells (fig. 2). This was later shown to be the substance left by aphides in puncturing the tissues, and will be described more in detail farther on. Nothing of this kind was found in the form of the disease characterized by the minute spots, which do not increase much in size, or in the elongated spots with irregular outlines.

The only bodies in the diseased cells that might be mistaken for

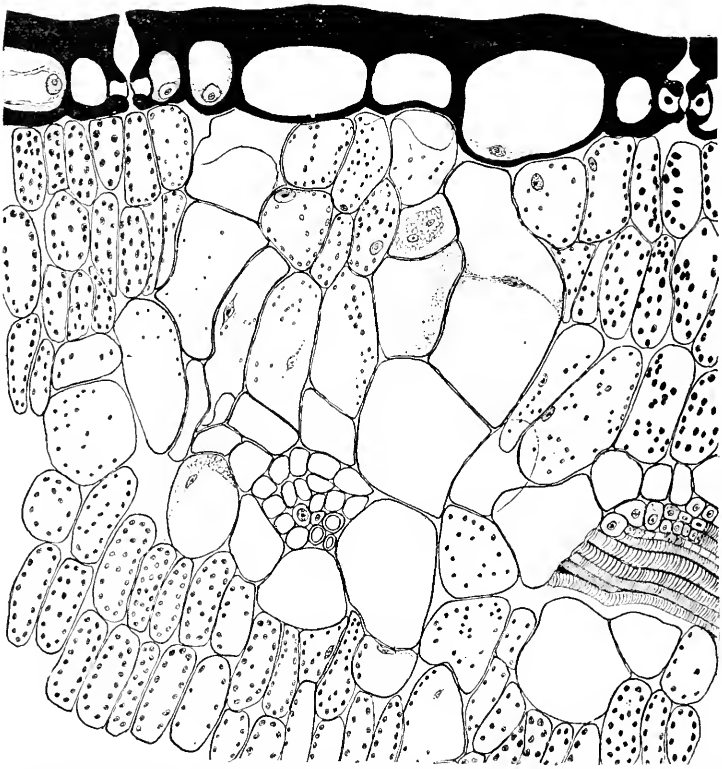

FIG. 1.—Cross section through a fully developed spot in a mature carnation leaf, the section being cut a little to one side of the lines of puncture. The diseased cells are greatly enlarged and have lost most of their chloroplasts. (Drawn with Zeiss camera lucida, × 261 diameters.)

bacteria were small proteid granules, resembling proteosomes, which stained with difficulty, swelled up, and lost their shape in 5 per cent potash. The chloroplasts of the diseased cells either do not develop at all or after having lost their color shrink to about half their normal size, and, like the proteosomes, stain with difficulty.

The microscopical examination therefore indicated that the disease could not be attributed to bacteria, for had these been present in the cells in considerable numbers they would have been readily detected, especially in the stained material.

CULTURES.

Microscopical examination alone is of course not sufficient to absolutely settle a point of the kind in question. The tissues must be carefully examined according to the best culture methods. After many trials in washing and flaming the leaf it was found that it was impossible, as before stated, to free the cuticular portion from saprophytic organisms without heating the leaf to such an extent that

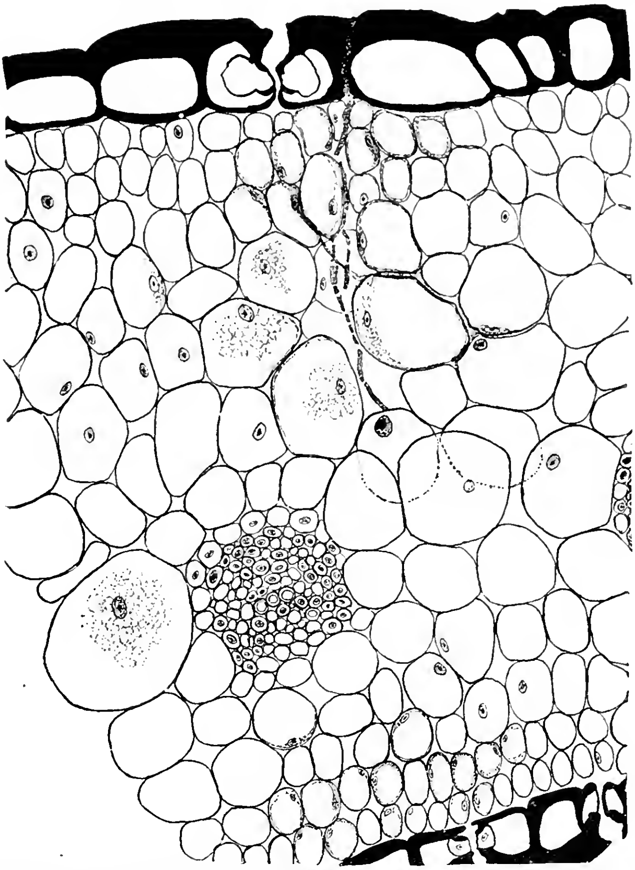

FIG. 2.—Cross section of a carnation leaf several days after it had been punctured by an aphid. The proteid sheaths between the cells mark the line of puncture. The cells on both sides have become abnormally large. (Drawn with Zeiss camera lucida, × 248 diameters.)

internal forms would also be destroyed. In cases where heating had not been continued long enough to kill the epidermal cells, surface cultures of the cuticle of flamed leaves often developed both molds and bacteria. Cultures were therefore made from the diseased mesophyll direct by carefully peeling off the epidermis of the leaf and scraping out the inner tissues with a flamed scraper which had been allowed to become perfectly cool. After the removal of the epidermis in this way—a very easy process, requiring no cutting, except enough to start the peeling—the diseased spots could be as readily detected as before. From one to twenty spots, varying in size from 0.5 to 2 mm. in diameter, were included in each culture. The cells were broken up as much as possible in scraping them out of the tissues, but great care was taken not to allow the internal tissues to become contaminated in any way.

During the first season's work about five hundred cultures were

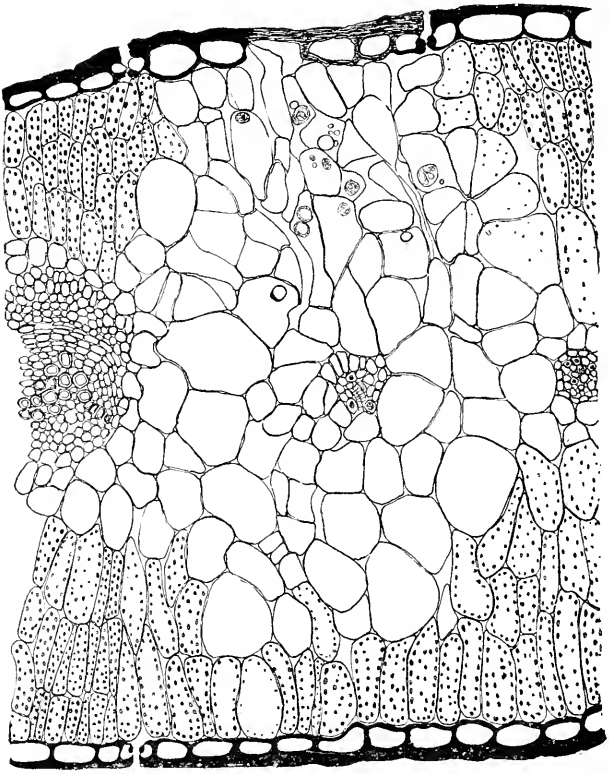

FIG. 3.—Cross section through the middle of a fully developed spot on a mature carnation leaf. All the epidermal cells in the spot have collapsed. Most of the enlarged diseased cells have lost their chloroplasts, and many of them contain globular vacuolate masses, which are portions of the disorganizing cell structure. (Drawn with Zeiss camera lucida, × 135 diameters.)

made, various media being used—for instance, slightly acid, neutral, and slightly alkaline beef broth, with and without peptone; potato broth of various strengths; cauliflower broth; potato cylinders; agars of various composition; gelatin (acid, neutral, and alkaline to litmus and to phenolphthalein), etc. These cultures included many poured plates made direct from the crushed tissues. In no case, however, were organisms found in any cultures made from a spot before the epidermal tissues had collapsed.

In preparing the material for the cultures, only that known to be free from outside contamination was used. Whenever there was the slightest doubt as to its purity it was either discarded or the tubes were marked "contaminated." Frequently tubes marked in this way, however, remained free from any organism. In cultures made from spots which had collapsed various fungi and bacteria were occasionally obtained, but this was not constant nor were the organisms always of the same sort. Cultures including the epidermis frequently contained various organisms, among these being a yellow bacterium, which occurred frequently on the surface of both diseased and healthy leaves. The morphological characters of this bacterium and its growth in the various media, with the exception of acid gelatin and agar, agreed well with *Bacterium dianthi* as described by Arthur and Bolley. On the two media mentioned the colonies were surrounded by a peculiar light band, which was at first thought to be some contaminating organism, its structure being like exceedingly minute cocci, the largest less than five-tenths of a micron in diameter. Attempts were made to cultivate this supposed organism on various media, but all failed, and even with the two media mentioned it was not possible to obtain a colony of the yellow germ which was not accompanied by this peculiar external formation. On neutral or alkaline media, however, no such change took place. Further investigation showed that these coccus-like bodies were made up of something precipitated from the culture medium by the alkali which the germ produced. Nothing of this kind was described for *Bacterium dianthi* by Arthur and Bolley.

INFECTION EXPERIMENTS IN 1897.

As the orange yellow germ agreed in most respects so closely with *Bacterium dianthi* and as no other yellow organism that could possibly be confused with *B. dianthi* was found in the hundreds of leaves studied, it was determined to make special use of this germ for infection experiments, but several other common forms were also used, the principal one among these being a white organism which liquefied gelatin readily.

Great difficulty was experienced in finding healthy plants with which to work. Those finally selected were taken into the laboratory, thoroughly freed from aphides and thrips, and allowed to grow under moist bell jars for three weeks. During this time the disease developed in some of the leaves which were apparently healthy when brought into the laboratory. The spots in such case were marked with india ink so that they would not be confused with spots that might result from infections. After the period of incubation had passed and a series of plants had been obtained which were reasonably free from spots, and also from aphides, thrips, and red spiders, rapidly developing fluid cultures of the germ were thoroughly brushed into the surface of the youngest unfolded leaves and also into the healthy portions of the older ones. Besides brushing in the cultures, abrasion inoculations and also hypodermic injections with an ordinary hypodermic syringe were made.

Ten plants were thus treated with *B. dianthi* during the season of 1897, the three methods of infection being followed in the case of different branches of each plant, but the disease was not produced in any case. An occasional spot developed on some of the plants after treatment, but such spots were always close to a spot which had been previously marked with India ink, and so could not be attributed to infection by the germs applied. Negative results also were obtained with the white germ mentioned.

Further infection experiments with *B. dianthi* were carried out in 1898, and these will be described later on in this bulletin. The results of the writer's work so far showed no evidence that the disease was caused by bacteria, and a search was therefore instituted for other possible external causes.

FIRST COLONIZATION EXPERIMENTS WITH APHIDES.

Arthur and Bolley regarded aphides as "such efficient bearers of the contagion that every leaf on a plant may be inoculated at hundreds of points," and indeed the writer observed that the spots were extremely common on many plants which had been attacked by the aphides. A careful study revealed the fact that carnations are seldom, if ever, entirely free from aphides—they may often be found between the young appressed leaves of plants apparently free from them. Ten young plants were taken into the laboratory and entirely freed from the insects by first picking off all that could be found, and then fumigating the plants lightly with hydrocyanic acid gas. The plants were kept under moist bell jars, and as soon as growth free from spot had developed aphides were colonized on various leaves. In the case of the youngest, most rapidly growing leaves spots could be detected with a hand lens three days after the tissues had been punctured by the aphides; in leaves somewhat older a longer time elapsed before the spots became visible; while in leaves half size, especially if the plant was making slow growth, the spots could not be seen for about two weeks after the puncture was made.

The spot appeared first as a minute translucent dot, accompanied by a slight swelling of the tissues. On some of the very young leaves the spots were unusually large, being from 2 to 3 mm. in diameter by the time the leaf had reached full size. Sections were cut from the spots so produced and were stained as before described, but no parasitic organisms could be found in the tissues. The cells had enlarged and the chloroplasts had lost their color and had failed to develop or had shrunk in the manner characteristic of the disease. The peculiar mycelial-like structure believed to be left by the aphis was always present, extending from the surface of the leaf down to the soft bast of the vascular bundle, and often beyond into the central mesophyll portions of the leaf (figs. 2 and 5, and Pl. II, fig. 4). Large numbers of cultures were also made from spots known to be produced by aphides, but with the same negative results as before described.

Similar experiments with thrips showed conclusively that they are the cause of the elongated spots (fig. 4, and Pls. I and III) and the distortion of the foliage, and it was also found that the red spiders working on the immature leaves produced the very minute spots by sucking the nourishment from the epidermal cells and those immediately underlying.

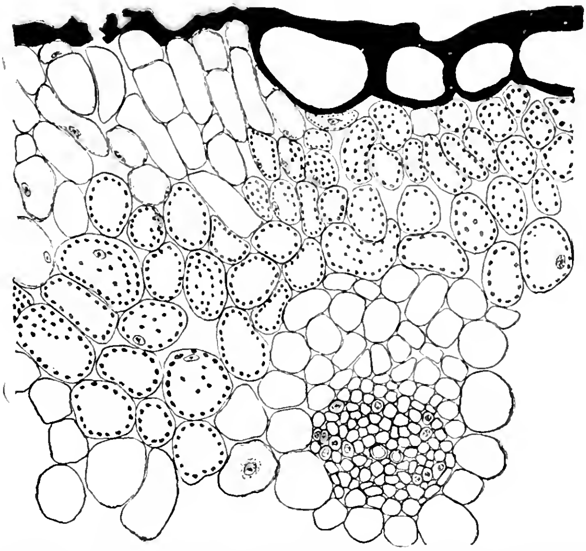

Fig. 4.—Cross section through a fully developed spot produced by thrips. The epidermal cells have collapsed and the underlying palisade parenchymal cells are somewhat elongated and have lost most of their chloroplasts. (Drawn with Zeiss camera lucida, × 282 diameters.)

It was thought desirable to get more accurate information in regard to the manner in which aphides obtain their nourishment from the tissues, and for this purpose leaves upon which they had been colonized were carefully cut from the plant while their sucking apparatus was still inserted in the tissues. These leaves were dropped into 75 per cent alcohol saturated with corrosive sublimate, and many of the aphides were thus killed before they had time to withdraw their beaks or puncturing bristles. Portions of the leaf with the beaks attached were then cut out, carefully dehydrated, and infiltrated with paraffin, the sections being then cut and mounted in series, and thus preparations showing the puncturing apparatus in place in the tissues obtained (fig. 5, and Pl. II, figs. 2 and 3). The puncturing bristles always extended at least to the soft bast, that is, nearly halfway through the leaf. The proteid sheath secreted by the insect while inserting its puncturing bristles was well stained with carbol fuchsin and gentian violet by allowing the sections attached to the slide to stand in the stain at a temperature of 55° C. for two hours. A slight and transient staining is thus obtained in fifteen minutes.

These sections showed, as Büsgen[1] pointed out in the case of many other plants, that the puncturing apparatus does not lacerate the cells, but passes between them, curving around obstructions and following the middle lamella as shown in the figures cited, the gelatinous sheath being secreted from the mouth parts of the insect as a support for the fine bristles as they wedge their way between the cells. The tip of the puncturing apparatus stops in the region of the elongated soft bast cells, which it punctures and from which the proteid contents are removed. Sugar is also sucked out of the cells in this region, passing through the alimentary canal and appearing on the plant as honeydew. It is probable that part of the sugar is used as food by the insect, but the larger part is excreted, while most of the proteid substances are retained and evidently constitute for the insect the principal food element extracted from the tissues.

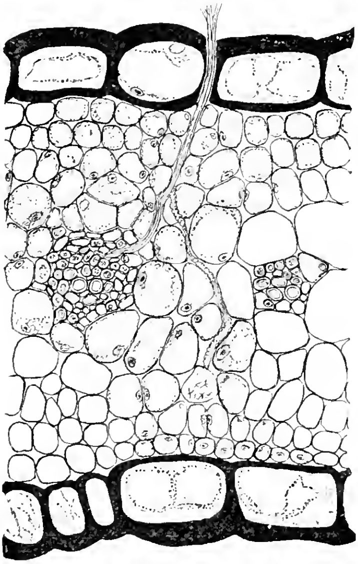

FIG. 5.—Cross section of a young carnation leaf showing an aphid's sucking apparatus in the tissues. The tip of the beak is in the soft bast of the vascular bundle. The first puncture passed to the right between the two bundles, and after the withdrawal of the beak from this region the proteid supporting sheath secreted by the insect remained between the cells. No apparent change has yet taken place in the cells. (Drawn with Zeiss camera lucida, × 225 diameters.)

INFECTION AND COLONIZATION EXPERIMENTS IN 1898.

The experiments described proved pretty conclusively that the disease in question must be attributed to the punctures of insects and mites, it having been shown definitely that plants kept free from these animal organisms remained perfectly free from the disease, and that when they were present it invariably developed. In order to settle the matter beyond any possible doubt, colonization experiments with insects were carried on under perfectly antiseptic conditions and inoculation experiments made with bacteria upon plants which had been kept absolutely free from puncturing insects and mites.

[1] Büsgen, M., Der Honigtau. Biologische Studien an Pflanzen und Pflanzenläusen, Bes. Abdr. a. d. Jen. Zeitsch. für Naturwis., Bd. XXV, N. F. Bd. XVIII.

For these experiments young rooted cuttings of the Scott, McGowan, and Garfield carnations, as free as possible from the disease, were obtained, 50 of each variety being set out in a small house, in which the conditions could be easily controlled, and 50 each in a larger house. In addition to these, seedlings of as many of the species and varieties of Dianthus as could be obtained were also grown, one lot in the small and the other lot in the larger house. The plants in the small house were fumigated with hydrocyanic acid gas and tobacco, and were carefully examined once a week to see that they were perfectly free from aphides, thrips, and red spiders, while on the other hand the corresponding lots of plants in the larger house were colonized with aphides and thrips.

All the young growth that developed in the small house during two months remained free from the disease, although the house was constantly shaded and half of each lot of the plants were syringed each day overhead—a treatment supposed to favor the development of the disease. It was found that those which were syringed were, on the whole, a little better developed than those left dry, but otherwise there was no difference. In the larger house, however, a marked difference was apparent at the end of this period between the two sets of plants, those which had been syringed overhead showing 50 per cent less spot than those kept dry. This difference is readily explained by the fact that the syringing prevented the excessive multiplication of aphides and the increase of red spiders, and also drove off many of the thrips. Had bacteria had anything to do with the disease the plants syringed overhead should have suffered most. Not only did the carnations become spotted from the punctures of aphides, thrips, and spiders, but all the varieties of Dianthus reacted in a similar manner. The thick-leaved forms developed spots much like those on the carnation, while on the thin-leaved forms the spots dried out more quickly, and the leaves showed greater distortion when attacked by thrips.

BACTERIAL INOCULATIONS.

At the close of the experiments above described the plants in the small house, having an abundant new growth and being absolutely free from insects and mites, were in prime condition for bacterial inoculation experiments. *Bacterium dianthi* from a fresh, rapidly growing liquid culture was therefore inoculated into ten plants of each of the three varieties of carnations mentioned; three plants each of *Dianthus arenarius*, *D. chinensis* (two varieties), *D. caesius*, *D. barbatus*, and *D. plumarius*, and sixteen horticultural varieties of these species; and five varieties of seedling carnations—a total of 6 species and 26 varieties, including the three varieties first named (111 plants in all). All the young growth, including many of the mature leaves, was thoroughly washed with water and beef-broth solutions containing the germs.

Besides the surface application of the germ, many slight abrasions with a fine needle were made on the surfaces of the inoculated leaves of three plants of each of the first three varieties of carnation mentioned. The house was kept shaded and the surface of the leaves was moistened each day by a light sprinkling in order to give the germs a good opportunity to develop, but not a single spot that could be attributed to the bacterial inoculation developed on any of the plants during a period of six weeks. The abrasions in many instances showed swollen edges and became slightly yellow, as in the case of the abrasions described by Arthur and Bolley. They did not increase in size and could not be attributed to the action of the germ, especially as the abrasions made on the control plants behaved in exactly the same manner.

ANTISEPTIC COLONIZATION.

Four plants of each of the three varieties of carnations, or twelve plants in all, were taken into the laboratory at the beginning of the inoculation experiments and were placed under large bell jars. These plants had a new growth which had never been injured by insects or spiders and were perfectly free from spots. One plant of each variety was used for a control experiment, no aphides being permitted on them; aphides were colonized on another lot, also consisting of one plant of each variety; and every leaf of another lot, consisting of two plants of each variety, was carefully washed with corrosive sublimate solution, 1 to 1,000 parts of water, all the glaucescence being carefully removed from the leaves and stems, it being easy in this way to determine when the plants were thoroughly wet and consequently disinfected. Previous to this a colony of aphides (*Rhopalosiphum dianthi* Schrank) had been grown upon a similarly sterilized plant until there were about 300. Out of this number 25 were selected at random, mashed up, and cultures made from the mass, but these cultures were perfectly free from bacteria or fungi. Before colonizing the other aphides they were allowed to crawl over the surface of moist agar in test tubes to determine whether they were free from bacteria, and as none of the latter developed, it was known that each individual used in the colonization experiment was free from germs.

The experiment was begun May 17, 5 aphides being put on each plant except the controls. On May 20 several spots could be plainly seen in the region where the aphides had been working on the most rapidly growing young leaves, and from this time on numerous spots appeared. On May 24, just one week after the aphides had been colonized, there were on one of the sterilized plants 30 aphides and 250 spots could be seen with the aid of a hand lens, on another there were 20 aphides and 170 spots, on a third 20 aphides and about 170 spots, and on a fourth 40 aphides and about 250 spots. The other two plants of the sterilized series and all the unsterilized plants except the controls kept free from insects, showed an equally rapid development of aphides and spots. After this no exact account was kept of the rapidity of increase of aphides or spots in any case, but the young leaves, as well as those which had matured, and also the stems, were completely peppered with spots, and the plants assumed a sickly yellowish appearance.

It was not thought necessary to make cultures from the spots on the sterilized plants, owing to the facts that the work had been done under thoroughly antiseptic conditions; that the entirely negative character of the previous culture work was deemed sufficient; and that the three control plants, upon which no aphides were allowed to develop, remained absolutely free from spot. The evidence of these experiments, it is believed, settles beyond any doubt the fact that the disease in question is not due to bacteria, but is the work of aphides, thrips, and red spiders.

CAUSE OF THE INCREASE IN THE SIZE OF THE SPOTS.

It may be asked why in the absence of parasitic and saprophytic plant organisms the work of aphides, thrips, and red spiders is followed by such marked pathological changes in the tissues, and why do the spots increase in size after the insect or mite has done its work. This question was investigated to some extent, and it is believed that an explanation is at hand. As previously pointed out, the aphides do not lacerate the mesophyll cells between which they force their sucking apparatus and excrete the supporting tube, but still the cells along the line of insertion show the change first, the chloroplasts not developing and becoming yellower and the cells becoming somewhat enlarged and œdematous.

It is difficult to determine the relative acidity of the tissues involved, the spots being small, but as nearly as could be determined, the diseased cells were apparently less acid than the healthy ones. Another difference between the diseased and the healthy cells was more marked and could be readily determined. After the epidermis of the leaf had been carefully peeled off, the surface of the exposed mesophyll cells was moistened with a 2 per cent solution of gum guaiac in absolute alcohol, and in a moment or two the diseased spots became a deep blue, while the surrounding healthy cells showed but a slight reaction, which could be detected only by the apparent deepening of the green. This test was applied in still another manner. Diseased tissues removed from the leaf were first treated with 95 per cent alcohol and then transferred to a small amount of distilled water, in which they were crushed and allowed to stand for half an hour. The solution was then tested with guaiac tincture, and for comparison an equal amount of a solution made similarly from healthy tissue of the same leaf was also tested in like manner. The action of the diseased extract on gum guaiac was about twice as strong as that of the healthy extract. It seems very probable that this remarkable increase in the oxidizing power of these cells must be the result of some irritating substance, perhaps either an organic acid or some other substance from the mouth parts of the insect which it injects into the tissues at the time it punctures them. It may be that the increase of the oxidizing enzym in the cells is an attempt on the part of the latter to destroy the injected irritant.

As the writer has shown in his paper on the relation of oxidizing enzyms to the destruction of chlorophyll,[1] the destruction of the chloroplasts can probably be explained by the increased oxidation taking place in the cells. The nucleus of the cells involved is not destroyed in the earlier stages of the trouble. The nutrition of the cell, however, is interfered with and the chloroplasts do not develop normally. As before pointed out, the rapidity of the increase in size of the spots on the young leaves is coordinate with that of the growth of the leaf. In a mature leaf, however, the size of the spots may increase very slowly, and this must be due to either a gradual diffusion of the irritant injected by the insect or to the direct effect of diseased neighboring cells.

The former supposition is more likely to be correct, as the same kind of a mechanical wound is followed in the case of different insects by markedly different results. For example, thrips, aphides, and the ordinary little green leaf hoppers found on *Chenopodium album* produce only a slight translucent spot on the leaves, this developing only after a week or ten days from the time the puncture is made. On the other hand, a little reddish leaf hopper, which is usually found working on the lower surface of these plants, produces in eighteen hours from the time a puncture is made a purple spot 1 mm. in diameter which rapidly increases until it is 4 to 5 mm. in diameter. Evidently this insect injects some quite rapidly diffusing substance into the tissues.

The writer has carried out careful colonization experiments with this red leaf hopper and has endeavored to determine what the injected substance is, but so far has not settled this point. In the case of the Bermuda lily, a great difference has been noted in the relatively slight injury produced by the common green aphis, *A. mahaleb*, and the greater injury produced by the large green aphis belonging to the genus Siphonophora. The same is true of the brown or black aphides and the green aphides which attack the violet, the former producing a marked stunting of the plants and the latter doing but little injury outside of distorting the flowers. The work of the San José scale on

[1] Centralbl. f. Bakt., 1899, Abt. 2, Bd. V.

the apple and pear as compared with the work of other scale insects is also a case in point, the increase in the oxidizing enzym which follows its attack being enormous and the evident injury spreading frequently 6 to 8 mm. from the point of puncture.

Besides the irritants injected and the consequent changes which take place in the neighboring cells, account must be taken of the elaborated plant food extracted by the insects in question, as the waste of saccharin materials in the form of honeydew is often enormous, and the proteid material used by the insects themselves must be quite considerable, especially when they are numerous. The stunting of the plant is probably in part due to the loss of food material in this way.

The work of aphides, thrips, and red spiders often produces in other plants changes similar to those following their attacks on carnations. This is especially true of rather thick-leaved plants, such as Bryophyllum, tulip, etc. It was found that as a rule plants rich in oxidizing enzyms react more strongly to punctures of this kind, and that plants which have been weakened by long-continued forcing, and consequently have made a poor, starved growth, are much richer in these oxidizing enzyms than are the stronger-growing, more vigorous individuals of the same variety. It is also an interesting fact that the aphides are especially fond of these weak plants and increase rapidly on them.

EFFECT OF THE DISEASE ON THE PLANT AS A WHOLE.

The effect of the disease on the plant as a whole depends upon the individual vigor of the plant and upon the number of punctures. A few punctures made by aphides, thrips, or red spiders will not seriously injure a plant, but a large number will cause it to become prematurely stunted and yellowish and also more susceptible to injury from various causes, especially parasitic fungi, which attack the weak stems and roots. Thrips, even though not numerous, may often cause the leaves of healthy, vigorous plants to become much distorted and show light blotches where they have been punctured. The value of flowers punctured in this way is of course materially reduced.

Red spiders seldom do much injury unless the foliage of the plants has been kept very dry. The stunting of the plants which follows a severe attack of any of these animal organisms brings about a premature ripening of the lower leaves, especially if the plants are rather crowded, and such leaves gradually turn yellow and die. Any other cause which stunts the plants growing under the conditions mentioned, however, will bring about a similar maturing and death of the lower leaves.

The susceptibility of different varieties of carnations to the injury seems to be as a rule proportionate to the normal vigor of the variety under the conditions in which it is growing when attacked. The constitutions of certain varieties seem to be very sensitive to injuries of this kind, while others are not, and while the sensitiveness, or resistance, as the case may be, is influenced to a large extent by the conditions of growth and the manner of propagation and selection of cuttings, yet this natural inherent constitution of each variety is the only explanation for the different degrees of susceptibility of different varieties.

Among the varieties which the writer has had under observation, Uncle John, Alaska, Della Fox, and McGowan as a rule proved to be very sensitive to the punctures of not only aphides, but also to those of thrips and red spiders. Vigorous plants of the variety Storm King spot readily as the result of the punctures of aphides, but do not appear to be otherwise injured much, while weak plants of this variety become badly stunted and lose many of their leaves. The same may be said of Bridesmaid, Sweet Brier, Scott, Garfield, Daybreak, Meteor, and Jacqueminot. Garfield and Daybreak are much more injured by thrips than by aphides. Among the other species of Dianthus, *D. arenarius* is particularly sensitive to aphis punctures, especially if the stem is much injured, in which case the plants often die. *D. fanatica*, *D. caesius*, *D. chinensis*, *D. atrobens*, and *D. plumarius* are less sensitive, but spot readily from punctures of aphides, thrips, and red spiders. *D. chinensis heddewigii* and its varieties, especially the thin-leaved sorts, are particularly sensitive to the punctures of aphides and thrips, and are quite sensitive also to the punctures of red spiders.

METHODS OF CONTROLLING THE DISEASE.

As the result of their investigations, Arthur and Bolley recommended that aphides be kept down as thoroughly as possible and that particular care be taken not to wet the foliage in watering. These recommendations were based on their theory that the aphides serve in a measure as carriers of the disease and that water facilitates the development of the bacteria that were believed to be the cause of the malady.

There is much to commend in the methods of watering suggested by Arthur and Bolley, and their efforts in stimulating search for better methods of staking the plants so as to keep the foliage more exposed to light and air have also resulted in much benefit. The increased vigor resulting from the use of these improved methods, however, was not due to a decrease in the number of spots, as was first believed, but to the fact that the total injury resulting from punctures was reduced.

The genus Dianthus is adapted to dry situations,[1] but all the species

[1]Williams, F. N., Jour. Roy. Hort. Soc., 1891, Vol. XII, p. 464; Arthur and Bolley, l. c.

are nevertheless often exposed to drenching rains when growing under natural conditions, and the thick-leaved varieties are well adapted to shed water. Growers generally believe that the proper syringing of plants with water under a pressure of 20 to 25 pounds is valuable, and the writer's observations lead him to the same conclusion. It must be remembered, however, that this work should be done in bright, clear weather, so that the foliage will dry thoroughly before night. Proper syringing of plants instead of favoring stigmonose is an important factor in holding it in check, as it keeps down red spiders, and in a measure helps to reduce the number of aphides, thrips, and similar insects. To keep down aphides, however, tobacco in its various forms must be mainly relied on. Carnation growers are so familiar with the methods of using tobacco that nothing need be said upon this subject here. It must be borne in mind, however, that healthy plants can not be obtained unless the insects and spiders are prevented from getting too much of a start, hence fumigation and syringing should be so timed and so carried on that these pests will be held in check.

The various forms of tobacco extract used in liquid form, and also when evaporated by means of hot irons, bricks, etc., have certain advantages, chief of which is that the flowers are less injured by the disagreeable odors. Hydrocyanic acid gas has been found effective, but it can not be recommended unqualifiedly, owing to the fact that it is likely to injure certain varieties. Scott, Garfield, Meteor, and McGowan can stand one-tenth gram of 98 per cent potassium cyanide per cubic foot of space for fifteen minutes without material injury. This will kill about 90 per cent of the aphides, but will not kill thrips or spiders. A stronger dose of gas or a longer exposure can not safely be recommended.

It has been found that different plants of the same variety react very differently to the punctures of both insects and spiders, and this shows the importance of a rigid method of selection for the purpose of building up a vigorous strain of plants. In propagating plants preference should always be given, other things being equal, to those which show the least evidence of stigmonose. Some plants will be found almost entirely free from it, and it would probably be well to start selection work on a small scale from such stock and continue it from year to year until a more resistant strain is obtained. The writer is satisfied that such a practice would result in much benefit at once, and that within three to five years the vigor of the stock might be materially increased.

CONCLUSIONS.

(1) The disease of carnations characterized by the symptoms described in this bulletin is widespread, and under certain conditions unfavorable to the plant it is quite injurious.

(2) So far as can be determined by the most careful microscopical study and bacteriological tests, neither fungi nor bacteria are present in the earlier stages of the disease.

(3) As the disease progresses various fungi and bacteria may appear, but their presence is not constant.

(4) Infection experiments with bacteria and fungi, especially with the germ described as *Bacterium dianthi*, carried out under the most rigid bacteriological conditions, resulted negatively in every case.

(5) A disease having all the characteristic symptoms of the so-called "bacteriosis" except the presence of bacteria, is produced by the punctures of aphides, as was repeatedly demonstrated by colonizing these insects on carnations.

(6) That aphides and not bacteria are responsible for the trouble is shown by the fact that the injuries produced are not accompanied in the earlier stages by fungi or bacteria. The aphides therefore can not be looked upon as simply carriers of some fungus or bacterium, as they produced the disease on plants growing under perfectly antiseptic conditions as quickly as upon those not protected by antiseptics.

(7) Injuries similar in many respects to those produced by aphides also result from the attacks of thrips—insects which are often present on carnations growing under glass, although sometimes overlooked by growers. Another form of the disease is produced by red spiders.

(8) No matter how badly diseased plants may be, if otherwise vigorous they will grow out of the disease entirely and the young leaves and shoots will remain free from spots if kept completely free from aphides, thrips, and red spiders.

(9) As the disease is not due to bacteria the name "bacteriosis" is inappropriate and therefore stigmonose is suggested for the trouble.

(10) The carnation is readily influenced by the conditions under which it is grown, and as a result its reaction to the injuries of the aphides, thrips, and spiders, and its susceptibility to their attacks, not only varies in different varieties, but also in individuals of the same variety. Plants grown under improper conditions, therefore, show more of the characteristic injuries from a given number of punctures than do plants growing where all the conditions are favorable. Certain plants rich in oxidizing enzyms have been shown to react more quickly to the work of puncturing insects and mites than plants poor in these enzyms.

(11) The size of the spots made by the punctures of aphides increases in proportion to the rapidity of growth of the leaf and the susceptibility of the plant, and also depends to some extent on the genus and the species of insect which makes the puncture. It is believed that the insect injects some irritating substance of an acid or enzymic nature into the wound, that this substance causes the increase of oxidizing enzyms in the cells which it reaches, and that these enzyms

interfere with the nutrition of the cell by destroying the chlorophyll and setting up other changes which finally result in death.

(12) Besides the carnation and different species of Dianthus, many other plants react similarly to the puncture of aphides and other sucking insects, and also to mites.

(13) The grower can successfully combat this disease by the proper selection of cuttings; careful propagation of stock; good soil; the proper amount of moisture, light, and air; and by the reduction of aphides, thrips, and red spiders to a minimum.

EXPLANATION OF PLATES.

Plate I.—Spots produced by aphides and thrips. Figs. 1, 2, 3, and 4 show the early, intermediate, and late stages of the disease produced by aphides, as seen when examined by transmitted light. (Natural size.) Figs. 5, 6, 7, 8, and 9 show the distortion of the leaves and the spots produced by thrips. (Natural size.)

Plate II.—Photomicrograph of sections to show early stages of stigmonose produced by aphid punctures. Fig. 1 shows a section of a healthy mature leaf. The chloroplasts show as small dots lining the palisade parenchymal cells. There are very few in the large water storage cells surrounding the vascular bundles in the middle of the leaf. (× 30 diameters.) Figs. 2 and 3 show the sucking apparatus of two aphides passing between the epidermal and mesophyll cells of a young leaf to the soft bast of the vascular bundle. The aphides were killed on the surface of the leaves and the section cut after dehydration and infiltration with paraffin. (Fig. 2 × 120 and fig. 3 × 70 diameters.) Fig. 4 shows the proteid sheath secreted by an aphis while inserting its sucking apparatus in the tissues of a young leaf. A part of another sheath is shown in the lower right-hand portion of the section. (× 200 diameters.)

Plate III.—Photomicrograph of sections to show later stages of stigmonose produced by aphid punctures and thrips. Fig. 1 shows a cross section illustrating enlargement of cells and loss of chloroplasts on both sides of the line of puncture. (× 75 diameters.) Fig. 2 shows a more advanced stage. (× 65 diameters.) Fig. 3 shows a cross section illustrating a late stage, many of the cells being broken down and the cell contents in a number of instances forming globular plasmode structures. (× 85 diameters.) Fig. 4 shows a spot produced by thrips. The epidermal cells have collapsed completely and the cuticle has become disorganized, but still remains. Most of the immediate underlying cells have lost their chloroplasts. (× 85 diameters.)

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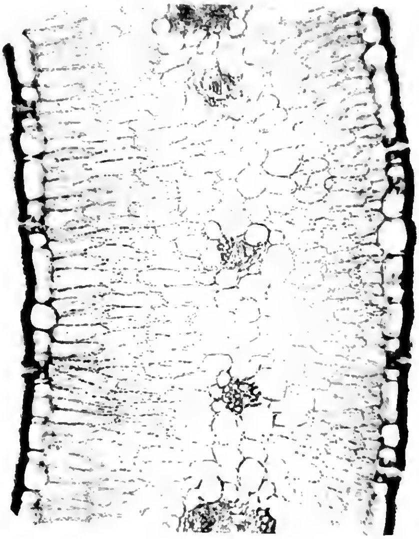
A. Hoen & Co. Lith. Baltimore.

SPOTS PRODUCED BY APHIDES AND THRIPS.



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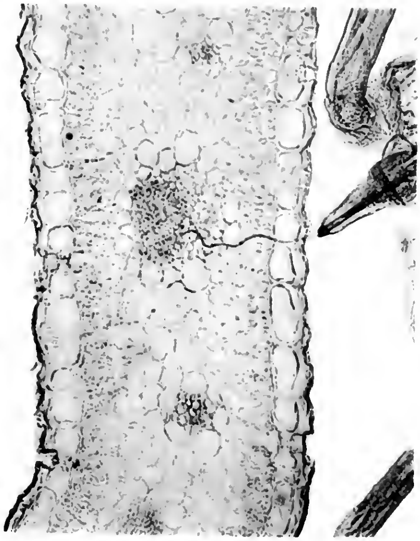

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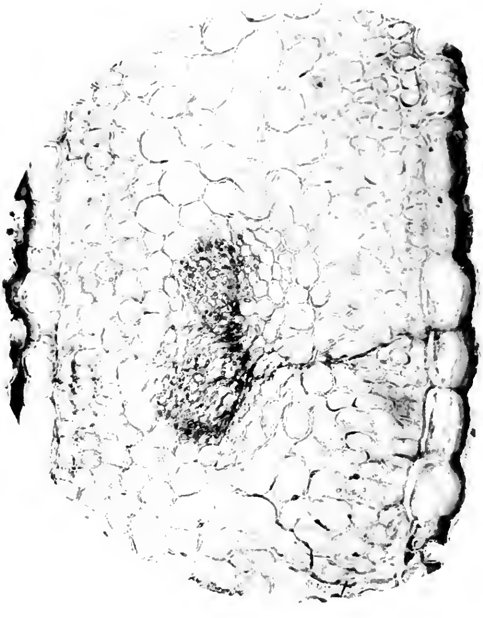
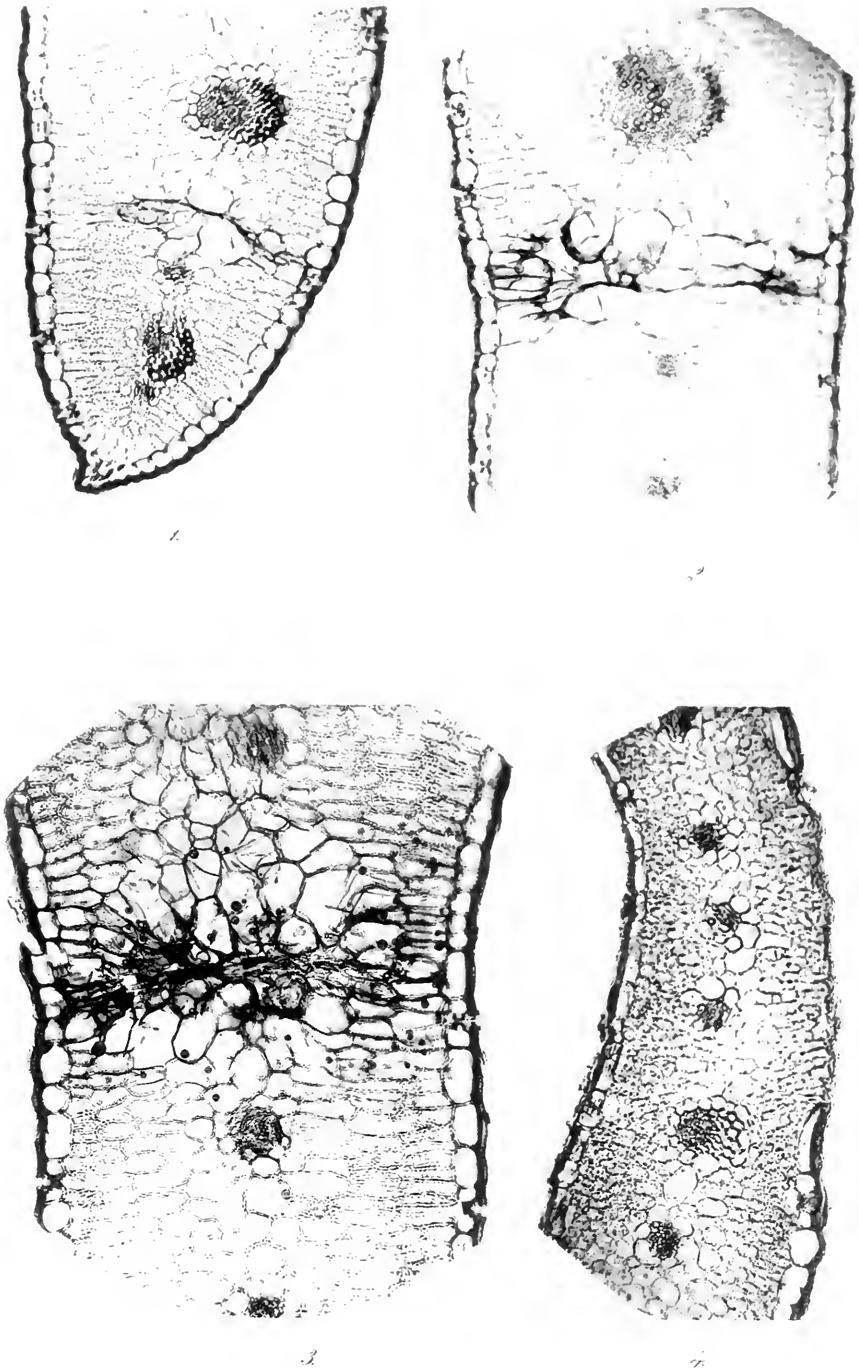


4.

Photomicrograph of sections to show early stages of stigmonose produced by aphid punctures.



Photomicrograph of sections to show later stages of stigmonose produced by aphid punctures and thrips.

BULLETIN No. 20. V. P. P. 72.

U. S. DEPARTMENT OF AGRICULTURE.

DIVISION OF VEGETABLE PHYSIOLOGY AND PATHOLOGY.

B. T. GALLOWAY, Chief.

PEACH LEAF CURL:

ITS NATURE AND TREATMENT.

BY

NEWTON B. PIERCE,
In Charge of Pacific Coast Laboratory, Santa Ana, California.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1900

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LETTER OF TRANSMITTAL

U. S. DEPARTMENT OF AGRICULTURE,
DIVISION OF VEGETABLE PHYSIOLOGY AND PATHOLOGY,
Washington, D. C., February 20, 1900.

SIR: I respectfully transmit herewith a report on peach leaf curl, prepared by Mr. Newton B. Pierce, who has charge of the work of this Division on the Pacific coast, and recommend that it be published as Bulletin No. 20 of the Division. The report embodies the results of investigations and experiments carried on for a number of years, and shows conclusively that peach leaf curl can be controlled by comparatively simple and inexpensive treatment.

Respectfully,

B. T. GALLOWAY,
Chief of Division.

Hon. JAMES WILSON,
Secretary of Agriculture.

LETTER OF SUBMITTAL.

PACIFIC COAST LABORATORY,
Santa Ana, Cal., December 15, 1899.

SIR: I herewith submit a report of investigations on the nature and treatment of peach leaf curl. The experiments described were conducted under the most varied conditions of soil, climate, etc., in all the leading peach centers of the United States, and it is believed that the recommendations for treatment here given are equally applicable wherever peaches are grown.

Respectfully,

NEWTON B. PIERCE,
In Charge of Pacific Coast Laboratory.

MR. B. T. GALLOWAY,
Chief, Division of Vegetable Physiology and Pathology.

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Curl-infested peach shoot from Biggs, Cal. Leaves of this character are badly infested with *Exoascus deformans*. The greatly broadened and distorted leaves, which are characteristic of this disease, are shown, and the whitened, spore-covered surface of some of the more elevated portions of the upper surface may be distinguished. The petioles of the affected leaves are greatly enlarged, the branch is much bent and distorted, and the internodes of the diseased portion of the branch are greatly shortened. A branch thus badly diseased is apt to die during the year unless conditions for growth are very favorable. It is in shoots of this character that the mycelium occurs in greatest abundance, but the hyphae have been seen to spread only a short distance beyond the parts showing the hypertrophy. (Compare with Pls. V and VI.)

PEACH LEAF CURL: ITS NATURE AND TREATMENT.

By Newton B. Pierce.

CHAPTER I.

PRIMARY CONSIDERATIONS RELATIVE TO PEACH LEAF CURL.

INTRODUCTION.

This bulletin has been prepared to place before the peach growers of the United States the results of experiments conducted during several years past for the prevention of peach leaf curl. The losses arising from this disease frequently amount to several millions of dollars annually, and it is believed that a wide dissemination of the results obtained by the experiments here outlined will lead to a large saving to the peach industry. During the progress of the Department's work over one thousand six hundred peach growers in all peach-growing States have been requested to test the preventive measures here recommended. A large number have done so, and some of the more important results of their work are also given. From conservative data it has been estimated that the experimental work thus widely set on foot by the Department has saved to the country in a single year the sum of three-fourths of a million dollars. This is but a fraction, however, of what may easily be saved in the future, when all growers have obtained a more thorough understanding of the disease and its prevention.

The obscure views held by many growers in the past upon the true nature of peach leaf curl, and the total lack of preventive measures up to a recent date, make it desirable to thoroughly consider the subject at this time and to record the detailed work upon which the conclusions reached are based. These conclusions are that peach leaf curl may be prevented with an ease, certainty, and cheapness rarely attained in the treatment of any serious disease of plants, and that there is no longer a necessity for the losses annually sustained from it in the United States.

GENERAL CHARACTERISTICS OF THE DISEASE.

The disease of peach trees here considered is variously known in different regions and languages. In the United States it is commonly know as peach leaf curl, or curl leaf of the peach; in England and all British possessions, as leaf blister, leaf curl, or curly leaf; in France, as cloque du pêcher; in Germany, as Kräuselkrankheit; in Italy, as Fillorissema, etc.

Peach leaf curl is a disease which seriously affects the leaves, flowers, tender shoots, and fruit of the peach. Its action is most severe in the spring of the year, shortly after the leafing of the trees, and the greatest injuries are caused in wet seasons and in humid localities. The leaves become enlarged, thickened, much curled, and distorted. As the disease progresses the healthful green of the foliage is changed to a yellowish, sickly appearance. The leaves soon fall, and the newly formed fruit ceases to grow, yellows, wilts, and likewise falls. The total loss of foliage and crop is common in seasons favorable to the disease. A second growth of leaves develops more or less rapidly, according to the severity of the disease and the favorable or unfavorable soil and atmospheric conditions prevailing at the time. If the soil and atmosphere are dry and the temperature high, new foliage may appear slowly and much of the terminal growth may die throughout the orchard. In severe attacks young trees are frequently killed. The second crop of leaves, appearing on affected trees after the spring defoliation, usually remains comparatively free from curl for the rest of the season. The amount of disease which will appear upon this later crop of foliage depends largely upon the humidity or dryness of the atmosphere, excessive moisture favoring a continuance of the trouble. The action of the disease upon spring branches causes them to enlarge, become curved and distorted in various ways, and often to dry up and die.

GEOGRAPHIC DISTRIBUTION.

Peach leaf curl exists in most peach-growing countries. Its distribution in the United States extends from the Gulf of Mexico to Canada and from the Atlantic to the Pacific. The centers of greatest prevalence, and where the greatest losses are sustained from this cause, are in the leading peach-growing districts bordering the Great Lakes, especially in Michigan and western New York; in the central, northern, and coast regions of California; and west of the Cascade Mountains in Oregon and Washington. The disease is less serious, or is of minor importance, in those peach-growing counties of New York most distant from the lakes, in Pennsylvania, Ohio, Indiana, Illinois, and in southern California. Still less injury is reported from New Jersey, Delaware, Connecticut, Rhode Island, Massachusetts, Maryland, Virginia, West Virginia, Kentucky, Tennessee, North Carolina South Carolina, Arkansas, Oklahoma, Louisiana, Mississippi, Alabama, and Florida, but in most of these regions occasional serious outbreaks are reported in seasons favorable to curl or in particular localities. It prevails rather more seriously in portions of Georgia, Kansas, and Missouri. In Texas, New Mexico, Arizona, and Colorado it has occasioned but little loss and is not widely known. Reports from Utah and Nevada are meager, but it is probable that the disease prevails to a limited extent in both States. The more northern States not mentioned here have either failed to report the prevalence of the disease or are properly included within that portion of the United States unsuited, by rigor of climate, to successful peach culture.

In Canada both Ontario and British Columbia, which are the leading peach-growing provinces, are favorably situated for the serious development of peach leaf curl in wet seasons. Mr. John Craig, horticulturist of the Central Experimental Farm, Ottawa, writes that the disease "obtains in Canada in all the peach-growing districts, including British Columbia and the Province of Nova Scotia." It is known to cause considerable losses of fruit in some sections.[1]

Peach leaf curl exists also in some if not all the peach-growing countries of South America. In Chile the peach is widely grown, being planted from the snow line of the Andes to the Pacific Ocean, and from Copiapo south as far as Valdivia, a distance of 800 miles. Mr. C. T. Ward, Jr.,[2] of the Hacienda Loreto, Department of Limache, says that the parasite of peach leaf curl "exists all over the country where the peach grows," but that no satisfactory method of control is yet practiced there.

In Europe Dr. R. Sadebeck[3] records the disease from Denmark, Germany, Austria, Switzerland, and Italy. He states that in central Germany it prevails more extensively than in the vicinity of Hamburg.[4] Among the many German scientists who have written upon this

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[1] Mr. L. Woolverton, secretary of the Fruit Growers' Association of Ontario, said, in 1890, in a paper entitled, Points on Peach Growing in the Niagara District, published in the Annual Report of the Society for that year, pp. 56 and 57: "The peach has its share of enemies and diseases, chief among which are the curl, curculio, the borer, and the yellows. For the curl I know no remedy. It is not often severe, but sometimes with the diseased leaves the fruit also drops." Mr. John Craig, in writing from Ottawa under date of October 7, 1897, says, relative to the disease in Ontario: "It is only severely injurious here during years of unusually heavy rainfall. This year it was very bad."

[2] Letter of March 22, 1896, to Mr. J. M. Dobbs, U. S. Consul at Valparaiso, Chile.

[3] Sadebeck, Dr. R., Die parasitischen Exoasceen. Eine Monographie, Hamburg, 1893, p. 94.

[4] Sadebeck, Dr. R., Untersuch. über die Pilzgattung Exoascus, Hamburg, 1884, p. 115.

disease and its cause are Sadebeck,[1] Winter,[2] De Bary,[3] von Tavel,[4] Hartig,[5] Zopf,[6] Tubeuf,[7] Ludwig,[8] Sorauer,[9] Frank,[10] Kirchner,[11] Fuckel,[12] and others. Winter says (l. c.) that the fungus of this malady causes great damage by early defoliation of the trees, and that it even kills the diseased trees by its repeated occurrence.

In Great Britain peach leaf curl has been common for a great many years. In 1821 it was accurately described by an English gardener under the name of "blight." He says:[13] "Under this denomination [blight] are frequently confounded two varieties of disease materially different in their appearance, and which I shall distinguish by the appellation of *blister* and *curl*. The former is generally confined to such peach trees as have glandular leaves, which are mostly subject to it in the months of April and May, and when attacked it is not until the latter part of the season, if at all, that they become healthy. The leaves so attacked are crisp, and assume a swollen, crumpled, and succulent appearance; the shoots themselves are affected by it in the same manner, and never produce either good blossom or healthy wood." Berkeley[14] has described the fungus causing this disease, and it has been mentioned by Bennett and Murray[15] and many other English writers. (Consult a popular article on Peach Blister, by W. G. Smith, *Gardeners' Chronicle*, Vol. IV, pp. 36, 37.)

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[1] Sadebeck, Dr. R., see locations cited; also Einige neue Beobachtungen und kritische Bemerkungen über die Exoascaceæ, Bot. Ges., 1895, Band XIII, Heft 6.

[2] Winter, Dr. Georg, Die durch Pilze verursachten Krankheiten der Kulturgewächse, Leipzig, 1878, p. 47; also Rab. Krypt. Flora, 1885, II, p. 6.

[3] De Bary, Prof. A., Comparative Morphology and Biology of the Fungi, Mycetozoa, and Bacteria, English edition, Oxford, 1887, p. 265; see also in the same volume various other references to the arrangement and position of the Exoascus group.

[4] Tavel, Dr. F. von, Vergleichende Morphologie der Pilze, Jena, 1892, pp. 55, 56.

[5] Hartig, Dr. Robert, Lehrbuch der Baumkrankheiten, Berlin, 1889, p. 118; also the English edition, Text-book of the Diseases of Trees, London, 1894, p. 132.

[6] Zopf, Dr. Wilhelm, Die Pilze in morphologischer, physiologischer, biologischer, und systematischer Beziehung, Breslau, 1890, pp. 236, 282.

[7] Tubeuf, Dr. Karl Freiheer von, Pflanzenkrankheiten durch kryptogame Parasiten verursacht, Berlin, 1895, pp. 167–188.

[8] Ludwig, Dr. Friedrich, Lehrbuch der Niederen Kryptogamen, Stuttgart, 1892, p. 205.

[9] Sorauer, Dr. Paul, Handbuch der Pflanzenkrankheiten, Zweiter Theil, Die parasitären Krankheiten, Berlin, 1886, p. 278.

[10] Frank, Dr. A. B., Die Krankheiten der Pflanzen, Band II, Die Pilzparasitären Krankheiten, Breslau, 1896, pp. 249, 250. Edition of 1880–81, Vol. II, p. 526.

[11] Kirchner, Dr. Oskar, Die Krankheiten und Beschädigungen unserer landwirtschaftlichen Kulturpflanzen, Stuttgart, 1890, pp. 324, 407.

[12] Fuckel, L., Symbolæ mycologicæ, 1869, p. 252.

[13] See quotation in Report of Michigan Pomological Society for 1873, pp. 16, 17.

[14] Berkeley, M. J., Introduction to Cryptogamic Botany, 1857, p. 284, and Outlines of British Fungology, London, 1860, pp. 376, 444, tab. 1, fig. 6.

[15] Bennett, A. W., and Murray, George, A Handbook of Cryptogamic Botany, London, 1889, p. 379.

Tulasne,[1] Prillieux,[2] and others (Cours complète d'agriculture, T. XV, p. 255, art. Pêcher) have studied this disease more or less carefully in France, where it often develops in a serious form. In June, 1890, the writer saw the peach trees near the Mediterranean, particularly about Montpellier, in anything but a healthy condition. On the 3d of June leaf curl was bad, and the ends of branches were seen to be dying in some cases. In Italy Briosi and Cavara,[3] Berlese,[4] and Comes[5] are among those who have described this malady. The disease varies in its prevalence through Italy in accordance with its habits elsewhere. The trees of northern Italy appeared more healthful than in the south of France during the visit of the writer in 1890, but considerable gummosis, perhaps due to the same cause, was observed in both regions. In western Sicily, near Palermo, leaf curl was again encountered in severe form. The situation in Spain and Portugal is not known, but in the more humid coast regions it should not be materially different from the condition found in Italy. In Greece, as stated by Prof. P. Genardius,[6] the disease rarely causes any damage of importance, because of the dryness of the climate, and for this reason, he states, no treatment has been tried. In Austria-Hungary the situation respecting leaf curl is much the same as in Italy. Dr. Johann Bolle, director of the Institute of Experimental Agricultural Chemistry, at Gorizia, writing from the island of Cherso, under date of October 25, 1897, states that in rainy weather the disease appears some years with great intensity and causes great damage. In Roumania the situation is much the same. Prof. Wilhelm Knechtel, of the Agricultural School of Herestrau, states in a letter dated Bucharest, October 17, 1897, that in that country leaf curl of the peach is also a troublesome and destructive disease to which the trees are subject in many years. He states that Roumania has in the region of the lower Danube almost a steppe climate—in summer very hot and dry, in winter cold, with very abrupt temperature changes, so that the variations of temperature within twenty-four hours not infrequently amount to from 10° to 15° R. (22.50° to 33.75° F.). When such changes of temperature occur in the spring at the time of leaf development the disease is certain to appear. The growth of the vegetation, which has been favored through the preceding warm days, is checked during succeeding days of lowered temperature, when

[1] Tulasne, L. R., Ann. d. Sci. Nat., 1866, ser. 5, T. V, p. 128.

[2] Prillieux, Ed., Bull. de la Soc. Bot. de France, 1872, T. XIX, pp. 227–230; Compt. Rend. 3; also Maladies des Plantes Agricoles, Paris, 1895, T. I, pp. 394–400.

[3] Briosi, G., and Cavara, F., Fungi Parassiti d. Piante Coltiv. od Utili, essicc., delin. e descr., 1891, fasc. 5, No. 104.

[4] Berlese, A. N., I Parassiti Vegetali d. Piante Coltiv. o Utili, Milano, 1895, pp. 124–126.

[5] Comes, O., Crittogamia Agraria, Napoli, 1891, pp. 163, 165–167, 549.

[6] Letter dated Athens, Sept. 12, 1895.

the development of the fungus begins, so that in June all leaves at the ends of the young branches are curled and deformed and perhaps all the blossom buds fall off. If the more developed leaves at the base of the young shoots prove more resistant to the fungous action, then fresh shoots are formed in June, even if not in normal condition, but yet somewhat healthy, so that the tree remains intact. In the more protected hill regions of the vineyards, at the foothills of the Carpathian Mountains, this disease is also troublesome, but less intense than in other parts of the country.

Peach leaf curl exists in South Africa, and probably also throughout Algeria and other peach-growing portions of the continent. Professor MacOwan, of the department of agriculture of Cape Colony, has written of the disease in South Africa, giving his views as to the proper manner of treating the same.[1] He also writes that it is "a great plague at the Cape."[2]

A peach grower of Drysdale, Frere, Natal, in writing to the Cape Colony agricultural department under date of October 31, 1893, says that he has a good many peach trees of the yellow, white, and St. Helena varieties, and that they are all affected with the discolored and curled-up leaves characteristic of this disease; that several of his neighbors are complaining that their peach trees are suffering like his; and that the disease seems to be spreading. The young trees were similarly affected.[3]

Perhaps no foreign country has suffered more from peach leaf curl than New Zealand. Mr. W. M. Maskell, of Wellington, writes as follows:[4] "The curly blight has been for many years prevalent in this country—so much so that whereas in the early days peaches were exceedingly luxuriant and fine, they have dwindled to comparatively very small and poor trees and in many parts of the colony almost died out. In the last two or three years the people have been advised to employ remedies, and have done so to some extent, so that there is a marked improvement in the peach orchards. * * * I can myself recollect, early in the sixties, when the most splendid peaches used to grow wild in the warm northern districts, where now scarcely a tree is seen; and the curly blight has been a dreadful curse all over the colony."

Australians report peach leaf curl among their serious plant diseases. In South Australia it "has been known quite twenty years,"[5] and probably longer, and occasions considerable losses in seasons favoring it. The situation is much the same in New South Wales.

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[1] MacOwan, Prof. P., Agricultural Journal, published by the department of agriculture of Cape Colony, 1892, Vol. V, pp. 252, 253.

[2] Letter dated Cape Town, Oct. 26, 1895.

[3] Agricultural Journal, Cape Colony, Vol. VI, No. 23, p. 451.

[4] Letter dated Wellington, New Zealand, December 24, 1895.

[5] Observations of Mr. A. Molineux, general secretary for the agricultural bureau of South Australia, letter dated Adelaide, February 11, 1895.

Prof. N. A. Cobb,[1] pathologist for the agricultural department of that colony, has described the malady quite fully, and although he fails to specify particular localities, it is probable that his descriptions are drawn from observations made in the colony for which he writes. He says that in the most severe cases of the disease "the fruit falls about three weeks after setting, and not a peach is left to ripen. This occurs on trees on which the disease is chronic and severe. * * * Such trees are worthless, nay, worse than worthless; they are a constant menace to the peach trees in the neighborhood. The sooner they are cut down and burned, and thus utterly destroyed, the better it will be for the peach industry. * * * I have now described the disease in its worst form, a form in which it is not common. The milder forms of the disease are much more frequent."

Peach leaf curl also prevails in Victoria, where it has been placed, according to Mr. D. McAlpine,[2] pathologist for Victoria, among the specified diseases in the vegetable diseases bill, recently passed in that colony. Mr. McAlpine also says that according to Mr. George Neilson, chief inspector under the vegetation diseases act, it has been known in Victoria since 1856, and affected peach trees were just as bad then as now. Mr. McAlpine adds: "The disease is distributed all over the colony. In the cooler districts it is generally more severe than in the northern and warmer districts, and it is generally more prevalent in a moist and cool spring than in a dry, warm one."

The situation in Japan has been learned through the obliging and careful inquiries of Prof. K. Miyabe,[3] of the Sapporo Agricultural College. He writes that *Exoascus deformans* is at present a serious pest to the peach trees at Sapporo, north island, and states that his attention was first called to its presence in that place some three or four years since, but that there is no doubt of its existence from the time of the first introduction of American peach trees, about twenty-three years ago. The Japanese flowering (double red) peach trees and nectarines were introduced at Sapporo by a florist about six or seven years ago from Echigo Province in the northern part of the main island or Honsiu. These varieties were found to be attacked to some extent during these few years. American varieties are now most seriously affected, and many persons have been obliged to cut down their trees on account of the disease. Respecting the distribution throughout Japan, Professor Miyabe says: "As to the rest of Hokkaido [the northern island] I found the fungus in 1890 at Mombetsu, a farming village on Volcano Bay, settled about twenty-seven years ago by the people from Sendai. I could not tell whether the peach trees cultivated there were of American or Japanese origin. In Honsiu, or

[1] Cobb, Prof. N. A., paper in the Agricultural Gazette, 1892, Vol. III, pp. 1001–1004.
[2] Letters dated Melbourne, Australia, July 14, 1896, and Oct. 12, 1897.
[3] Letter dated Sapporo, Hokkaido, Japan, Nov. 22, 1897.

Main Island, the peach curl seems to be prevalent only in the northern provinces. * * * I sent letters of inquiry relating to this question to the graduates of our college, who studied especially about the parasitic fungi in our laboratory, and whose opinions I can trust. From Mr. Y. Takahashi, at Morioka, in Rikuchu Province, I received the following answer: 'Peach curl is very prevalent in this town. Almost every tree is more or less attacked by the fungus. I saw some trees entirely attacked. At the end of summer [spring?] all the diseased leaves fell to the ground and new leaves were produced.'" In the southern island, Kumamoto, a correspondent reported to Professor Miyabe that the disease had not been seen there by him. From Tokyo Professor Shirai, of the College of Agriculture, reports that he has not yet found the disease in that section of the main island.

In China, as the writer is informed, peach leaf curl prevails to a very large extent, and the losses are probably considerable from this cause.[1]

ORIGIN OF THE DISEASE.

The country of origin of peach leaf curl is not positively known. It was hoped that the inquiry as to distribution would develop positive information respecting this point, but such has not been the case. That seedling peaches are remarkably susceptible to the disease, and that the Chinese Saucer peach is among those most subject to it, appears to indicate that the home of the peach is the source of the disease, and that the two may have come to us together from a common point of origin. Recent studies have been constantly tending to reduce the number of species of plants once thought to be subject to curl. At present it is believed that it is confined almost wholly to the peach or its derivatives, as the nectarine and peach-almond. The exceptions to this, where the disease has been noted on the plum, almond, etc., are rare, and not sufficiently numerous or general to materially affect the evidence that the peach is the natural host of the fungus. Thus far, however, it has been impossible to learn if the peach in the interior of China, its supposed home, is affected by this trouble, though in the coast regions it is said to prevail extensively. Such information as has been obtained from Japan indicates the recent introduction of the disease in that country, and that the United States is probably its source rather than the near-by continental coast. In Australia, however, this may properly be questioned, for, as already mentioned, Mr.

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[1] Letter from Augustus White, Esq., forwarded April 3, 1896, through the kindness of Mr. Rufus S. Eastlack, then U. S. Deputy Consul-General at Shanghai, China. Mr. White says, in concluding his statements, that the Chinese, ignorant of the use of the knife in pruning, trust solely to an annual inspection of the trees at the time the blossoms set, when they carefully pick off all excess of fruit, and with it all diseased leaves, etc., but allow these to fall to the ground and remain under the trees to rot or reproduce the plague, as nature thinks best.

George Neilson, chief inspector under the vegetation diseases act of that colony, states that peach leaf curl has been known in Victoria since 1856. This dates the presence of the disease in Australia back to a time when its importation from America to that country would be doubtful. Its European origin, however, may not be improbable.

The severity of the disease in the gardens of China and the fact that the peach probably reached Europe and America from the East make it still desirable to learn if the trouble is prevalent among the wild or escaped peach trees in the interior of the Chinese Empire.

It may be pertinent to state, in view of the fact that Darwin holds the peach to be derived from the almond, that none of the many widely cultivated varieties of the almond in California, either of local or foreign origin, are subject to peach leaf curl, even when growing beside peach orchards denuded by it. Trees which are apparently the result of almond and peach crosses are somewhat affected, however, and several of the nectarines, which are derived from the peach, are quite subject to it. Seedling peaches, as stated, are very commonly attacked, but of some forty to fifty varieties of seedling almonds examined by the writer none has thus far shown the disease.

LOSSES FROM THE DISEASE.

The direct annual losses to the peach interests of the United States from peach leaf curl are very large, and are usually much greater than is suspected by the growers themselves, as the nature and action of the disease are misunderstood by them, and its effects frequently attributed to other causes. In case an orchard is so affected that it fails to hold the crop, or sets but a partial crop, the grower has but little ground for an opinion as to what the yield would have been had curl not prevailed, hence the estimates of losses made by growers are frequently very unsatisfactory. In case curl occurs after a severe cold spell in spring, as is quite commonly the case, the orchardist is apt to charge the loss of fruit to the low temperature rather than to the disease. The preventive spray work conducted by the Department has shown, also, that the loss estimates are nearly always too low.

By preventing the disease upon a portion of the trees of an orchard the amount of injury sustained by the untreated trees has been determined most accurately by direct comparison. Such comparative work has now been conducted for several years in many of the leading peach-growing centers of the country, and these tests enable the writer to state that the losses sustained by the peach industry are probably not overdrawn in the following estimates: Of a large number of peach growers who replied to a circular letter sent them in 1893, there were 251, living in 35 peach-growing States and Territories, who stated whether or not their orchards were affected by curl.

Sixty-three per cent of these (158 growers) reported that their orchards were affected, and 37 per cent (93 growers) reported that their trees had not been troubled by it. Of the 158 whose trees were affected, 66 per cent (104 growers), or about 42 per cent of the 251 orchardists reporting on this disease, reported more or less loss. The growers who reported loss were residents of 21 States, and were scattered from the Atlantic to the Pacific. The losses sustained varied from a small amount of fruit to the entire crop, and in some instances many of the young trees were killed. Of the entire number of reports received as to the presence or absence of curl in the orchard of the grower, 93 came from States or sections of the country where little leaf curl prevails, as Texas, Delaware, Florida, Kansas, etc., so that the data should be strictly representative of the peach-growing country as a whole. The replies received were from Alabama, Arizona, Arkansas, California, Colorado, Connecticut, Delaware, Florida, Georgia, Idaho, Illinois, Indiana, Kansas, Kentucky, Louisiana, Maryland, Massachusetts, Michigan, Mississippi, Missouri, Nebraska, New Jersey, New Mexico, New York, North Carolina, Tennessee, Texas, Virginia, Washington, and West Virginia.

The amount of loss sustained by the 42 per cent of the growers reporting losses is given in the replies in various ways. Some growers have reduced their loss to dollars and cents; others have indicated the loss in percentage of crop; while still others have used some term, such as "slight" loss, "small" loss, etc., as a reply to the inquiry. In estimating the true loss sustained by these growers a uniform system has been adopted. Where the loss has been stated in dollars the amount has been recorded as given. Where the loss is given in percentage of crop the cash loss has been determined from the basis used by the United States Census Bureau in determining the value of peach crops for the Eleventh Census. A full peach crop was valued at $150 per acre, and all portions of a crop at the same rate. Where the report of the grower was indefinite, the statement being that the loss was small, it has been placed at $2.50 per acre, which amounts to about 2½ cents per tree as usually planted. It is probable that this is much below the average loss in such cases, as a loss so small as this would usually escape notice. In all the calculations in these estimates an effort is made not to overrate the loss. These calculations gave a loss to the growers averaging $10.95 per acre for the acreage reported as suffering from the disease, or 42 per cent of the full area. This is equivalent to about $4.60 per acre for the entire acreage, or about 4 cents per tree. At first thought this may seem high, but this is more apparent than real. If one 10-acre orchard loses its crop from curl, valued at $150 per acre, the loss amounts to $1,500. There may be 32 other orchards of 10 acres each all about this orchard where not a peach is lost, yet the average for such a district is the same as that stated. This is perhaps a clearer manner of putting the matter than by placing an average loss for all orchards. The loss may be viewed in still another manner. If an orchardist has grown peaches for 32 years and lost only one crop during that time from leaf curl his loss for the third of a century will average as high as here calculated.

There are large sections of the country where curl is scarcely known, as in portions of Texas. For such regions the preceding estimates may appear high. On the other hand, there are other prominent sections of the country devoted to peach culture where these estimated losses will certainly be far too low.

If the preceding calculations and statements are accepted as fairly representing the situation throughout the country, the annual losses from curl in the United States may be approximated. The Eleventh Census reports the orchards of peach trees in the United States at that time (1889–90) as 507,736 acres, and from replies to our circular we are led to believe that curl was present in 63 per cent of these orchards and that 42 per cent sustained some loss from the disease.

Most of the orchards included in the 42 per cent sustained only a slight loss, but a very small percentage sustained a heavy loss, sometimes amounting to the entire crop. The average loss for the 42 per cent of the orchards is found to amount to $10.95 per acre, or about 10 cents per tree, averaging the trees at 108 per acre. The total acreage of the country being 507,736, the loss should be calculated upon 42 per cent of this, or 213,249 acres, which gives a total estimated annual loss from peach leaf curl of $2,335,076. In this estimate no account has been taken of the great injury to the growth of trees, the injury to nursery stock, the death of young orchard trees, nor the loss to succeeding crops from the reduced number or quality of fruit buds on affected trees. There is also the loss arising from the cultivation and pruning of unproductive orchards, which, if it could be determined, would probably bring the entire annual loss to the country up to $3,000,000 or more.

Since 1893, when the investigation of this disease was undertaken by the writer, a very large amount of correspondence has been conducted with peach growers in all parts of the Union who have sustained losses from curl, and this correspondence has resulted in the accumulation of a large number of facts respecting these losses. These data, however, have not been drawn upon in the above estimates, as it might be claimed that they were from growers only who have suffered from the disease, and consequently would not fairly represent the industry as a whole—a claim which can not be made against the circular letter, the basis of the estimates, which was addressed to peach growers in general in all parts of the United States. In fact there appears to have been a larger percentage of replies received from sections of the country where curl is scarce than from the more affected portions.

CHAPTER II.

NATURE OF PEACH LEAF CURL.

The study of the nature of plant diseases is intimately linked with the study of plant physiology, and the true science of vegetable pathology is largely, as Ward has defined it, the study of abnormal physiology. (Introduction to Hartig's Text-book of the Diseases of Trees.) These facts become evident when studying the etiology of peach leaf curl and the conditions attendant upon its widespread development. The direct cause of peach leaf curl has long been known as a parasitic fungus, *Exoascus deformans* (Berk.) Fuckel, but it is evident from a careful study of the disease that the injurious development of the fungus is distinctly correlated with special physiological phenomena of the peach tree itself. These conditions of the tree are in turn dependent upon such external influences as temperature, the humidity of the soil and atmosphere, and others. Such facts were foreshadowed by the theories advanced by peach growers as to the cause of the disease. Many growers have considered peach leaf curl as the direct result of excessive moisture and low temperature or sudden changes, and as these physical conditions certainly have an important bearing upon the injurious development of the disease, they are considered together with the direct relations of the parasite to its host. However, too much stress can not be placed upon the fact that the fungus alone is responsible for the injury to the tree. Without the parasite not a leaf would curl nor a peach fall on account of this malady—in fact, no such disease would exist. This is shown by the work hereafter detailed. It is fortunate that the direct cause of peach leaf curl is a parasitic fungus rather than unfavorable atmospheric conditions, for the latter could not be controlled, while the control of the fungus has been found practicable, simple, and inexpensive.

PHYSICAL CONDITIONS INFLUENCING THE DISEASE.

The influences of temperature, humidity, situation, soil, etc., upon leaf curl are often so well marked that they have frequently and in fact quite generally been mistaken for the active cause of the disease. Indeed a very large percentage of peach growers have maintained, to within the past ten or fifteen years, that sudden changes of temperature occurring in conjunction with wet weather are the sole cause of the curling and loss of foliage. Notwithstanding the number of known facts to the contrary, there are even now many growers who retain this idea to the utter and needless loss of their crops. The writer has met men who so firmly believe that leaf curl is due to uncontrollable climatic influences that they would not consider other explanations, being unwilling to visit the orchard, though the crop was being lost through curl and by so doing future crops might have been saved.

To gather the experience of peach growers in general respecting the conditions under which leaf curl develops most severely, a circular of inquiry was addressed to several hundred orchardists in November, 1893. The replies to some of the questions are presented. Among the inquiries the growers were requested to state if they had observed the disease to be more prevalent after a cold spell in the spring. To this question 97 replies were received, 89 affirmative, 6 negative, and 2 growers said they had observed no difference, which shows that the orchardists are almost unanimous in holding that a cold spell in the spring favors the development of curl.

To the second question, as to whether the trees were most affected by curl in a wet or dry season, there were 104 replies. Of these, 78 stated that peach trees were most affected in wet seasons, 8 that they were most affected in dry seasons, and 18 that there was no difference. Here again is seen a marked agreement in the replies, a great majority of the growers recognizing that wet years favor the disease.

The above-considered conditions—a cold spell in the spring and wet weather—may be explained by stating that such conditions favor, on the one hand, the serious development of the fungus causing the disease, and, on the other, they result in a much greater susceptibility of the tissues of the peach leaves to the attacks of the parasite. Where both cold and rain occur together in the spring, about the time the leaves are pushing, the disease is liable to develop seriously and few varieties can then resist it. The action of wet, cold weather upon the tissues of the peach, making them much more subject to curl than they otherwise would be, has been considered in relation to other plants in a paper by Prof. H. Marshall Ward,[1] who says that *when the combined effects of the physical environment are unfavorable to the host, but not so or are even favorable to the parasite, we find the disease assuming a more or less pronounced epidemic character.* He is not here speaking of curl, but the statement holds perfectly true for that disease. A cold, wet spell succeeding warm spring weather, has a tendency to saturate and soften the tissues of the peach, as in the case of other plants. The sudden checking of active transpiration, due to lowered temperature and saturated atmosphere, soon results in the tissues of the plant being suffused with water. "The stomata," as Ward puts it, "are nearly

[1]Ward, Prof. H. Marshall, The Relations between Host and Parasite in Certain Diseases of Plants, Croonian Lecture, Proc. Roy. Soc., Vol. XLVII, No. 290.

closed, the cell walls bounding the intercellular passages and the air in the passages themselves are thoroughly saturated with water and aqueous vapor, respectively, and the movements of gases must be retarded accordingly; turgescence is promoted, and the water contents accumulate to a maximum, owing to the disturbance of equilibrium between the amounts absorbed by the active roots in the relatively warm soil and those passing off into the cold, damp air; much more water is absorbed by the roots in the relatively warm soil than passes off as vapor in equal periods of time." Further than this, Ward states that "the low temperature, feeble light, and partially blocked ventilation system have for a consequence a depression of respiratory activity and the absorption of oxygen generally." This must give a lowered vitality and an accumulation of organic acids. The reduced light also leads to a decided reduction in the assimilative power of the leaves. "The turgid condition of the cells, and the diminished intensity of the light," Ward says, "will favor growth." If this takes place, "the tendency will be for the very watery cell walls to become relatively thinner than usual, as well as watery, because the ill-nourished protoplasm does not add to the substance of the walls in proportion. This being so, we have the case of thinner, more watery cell walls acting as the only mechanical protection between a possible fungus and the cell contents."

It is generally known that the conditions of moisture and shade, which are above shown as making the tissues of a host plant more tender and watery (more subject to fungous attacks), are also the conditions most favorable to the development of fungi. This holds equally as good for *Exoascus deformans* as for other forms. In speaking of these conditions in relation to a fungus known as *Botrytis*, Professor Ward gives some generalizations equally applicable to *Exoascus deformans* in its relation to curl. He says that just those external climatic conditions which are disturbing the well-being of the green host plant are either favorable to the fungi considered or, at any rate, not in the least inimical to their development. "Thus," he says, "the oxygen respiration of the fungus goes on at all temperatures from 0° C. to 30° C. and higher, and although we still want information as to details, experiments have shown that the mycelia flourish at temperatures considerably below the optimum for higher plants. Moreover, light, so indispensable for the carbon assimilation of the green host, is absolutely unnecessary for the development of the fungus. Then, again, the dull, damp weather and saturated atmosphere, so injurious to higher vegetation, if prolonged, because they entail interference with the normal performance of various correlated functions, as we have seen, and render the plant tender in all respects, are distinctly favorable to the development of these fungi; consequently the very set of external circumstances which make the host plant least able to withstand the entry and devastation of a parasitic fungus like *Botrytis*, at the same time favor the development of the fungus itself."

The writer thinks, as the result of observations in the field, that *Exoascus deformans* is favored in both its entrance and spread within its host by the conditions which have just been considered. It is a widely observed fact that leaf curl usually develops sparingly in a uniformly warm and dry spring, and it is also noticed that where infection has occurred a return of warm, dry weather, or even the occurrence of a hot, dry wind, will check the development of the fungus within the tissues. An infected leaf may fail to develop the spores of the fungus under such circumstances. The thin, saturated cell walls and the moist intercellular spaces thus appear to be closely correlated with the active vegetation of the fungus. The growth and consequent tenderness of the tissues is also important in this connection. Where soil, elevation of orchard, and atmospheric conditions are unfavorable to a saturated condition of the plant parenchyma, the disease is not likely to run more than a short and feeble course. Soil and elevation are here considered with atmospheric conditions, for it is found that on the same farm a difference of elevation or soil moisture may determine the degree of virulence of the disease. The influence of elevation may be of only secondary nature—that of maintaining a higher temperature—but its action on the disease is frequently well marked. Of 92 orchardists who expressed their views as to whether trees are affected by curl most on high or on low land, 48 say that trees suffer most on low land, 14 on high land, and 30 think there is no difference. While the majority claiming that trees on low land are most affected is not as large as some of the majorities obtained in replies to other questions, it represents over one-half the replies received to the question under consideration and is more than three times as great as the number who believe trees to be most affected on high land, hence is sufficient to establish confidence in its reliability, even if it were not indorsed by many published statements to the same effect.

Mr. Thomas A. Sharpe, superintendent of the experiment farm at Agassiz, British Columbia, has made several comparative reports on the action of peach leaf curl on trees planted in the valley and upon the more elevated bench lands of the farm. A few brief statements from these reports should be of value in connection with the above statements.[1] In 1892, Mr. Sharpe says, the peach trees suffered from a severe attack of leaf curl. "Only 5 varieties of those planted in the valley escaped" the disease. "The trees planted on the bench lands did not suffer so much, and appeared to recover much more rapidly than those in the valley" (l. c., p. 278). In 1893, it is said,

[1] See reports of experimental farms, Ottawa, Canada, for the years indicated.

the curl leaf in the peach and nectarine trees was worse than it had ever been before, the Malta being the only variety that was entirely healthy on level land. The varieties received from England and planted on the level land were just as badly affected as the others. The first and second bench orchards suffered alike with those on the level ground, but the orchard highest up, at an elevation of 800 feet, had no curl in any case, and the trees appeared to have suffered less from cold than those lower down (l. c., p. 342). Mr. Sharpe says that in 1896, "as heretofore, the trees on the upper benches, both nectarine and peach, escaped the curl leaf entirely" (l. c., p. 449). Again, it is said that "the peach crop on the level land this year [in 1898] was almost an entire failure. The curl leaf was very prevalent, nearly every tree being seriously affected by it." Relating to the orchard on the bench lands, it is stated that "curl leaf did not affect the foliage there; in fact, it has never injured the foliage on either peach or nectarine trees on the benches over 300 feet above the valley" (l. c., p. 403). These facts have an especial interest and value in that they were recorded by a single observer on one farm and during successive years and epidemics of curl, and they are in perfect harmony with the experience of a majority of the growers whose views are presented above.

The soil may exert its influence by abundantly or feebly supplying the transpiration stream, in accordance with the degree of accessibility of the moisture it contains, to the root hairs of the tree. It may be said, however, that as leaf curl commonly develops at the beginning of spring growth or at the close of the winter's rains, the soil will rarely be found so deficient in moisture as to greatly retard the development of the disease where other conditions are favorable. It is probably equally true that the excess of water usually found in the soil in the spring is favorable to the special development of the disease at that season in its worst form.

Besides the influence of temporary excessive humidity of the atmosphere upon leaf curl, which has already been considered, there are other atmospheric influences and relations of importance, which depend upon the local or general geographic, topographic, and climatic features of country. Some of these more prominent atmospheric influences may here be briefly considered, together with their most probable causes.

Proximity to large bodies of water, whether salt or fresh, greatly favors the development of curl. The cause for this clearly rests in the resulting greater humidity and lower temperature of the atmosphere. Plants growing in a constantly humid atmosphere have normally more succulent and tender tissues than those growing in a drier region. The reasons for this have already been alluded to for special cases of extreme atmospheric humidity and lowered temperature. Near large bodies of water spring fogs commonly occur, and these lead to the increase of the atmospheric humidity at a time when the foliage is tender and growing rapidly, thus stimulating a development of curl almost annually and over wide stretches of country. Independent of fogs, the atmosphere about large bodies of water is also much more humid than in an inland region. Instances of the influence of large bodies of water on the general prevalence and frequent occurrence of curl in a region are found in western New York, near the shore of Lake Ontario; in Ontario, Canada, near Lakes Erie and Ontario; in Michigan along the shore of Lake Michigan; in California about the bay of San Francisco and at other points along the Pacific coast; in Washington and British Columbia about Puget Sound; and in many similar situations in all portions of the world where the peach is grown. The writer believes, however, that the influence of large bodies of water upon the development of curl depends in part upon the normal spring temperature of the region, and likewise upon the source of the prevailing winds. Where the prevailing spring winds are from a dry, inland region instead of from the water, the atmosphere does not feel the influences of the latter. Moreover, where the spring temperature is high, transpiration may proceed normally even in the neighborhood of large bodies of water, and curl may not commonly prevail.

In contrast to the influences of large bodies of water are those of neighboring dry and arid plains or desert regions. In the midst of such influences peach leaf curl can rarely attain to an epiphytotic development, and then only under special favoring seasonal conditions. The atmosphere is normally too dry in such situations to exert a predisposing action upon the host, and it certainly does not favor the serious development of the parasite. Exemplifying these conditions are large areas in Arizona, New Mexico, Nevada, Utah, Colorado, Texas, Kansas, and California. Little or no curl is reported from the more arid portions of these sections of the country, its absence being due, at least in part, to the influences here considered.

Another of the broader influences affecting the general and permanent prevalence of curl over extensive regions is the normal annual rainfall. Comparisons of this kind must be made, however, between regions of approximately similar temperature. Under such conditions it may be said that the general annual prevalence of leaf curl increases with the increase of normal annual precipitation. Comparisons of this kind can hardly be justly drawn in the Mississippi Valley or on the Atlantic coast, as the temperature conditions vary too greatly in those regions from north to south. On the Pacific coast, however, owing to the modifying influence of the Pacific Ocean, the temperature prevailing from Lower California to British Columbia, a distance of about one thousand three hundred miles, presents no such great variations as are found in a like distance from south to north on the Atlantic coast, so that the relations of annual rainfall to the constant prevalence of curl may be more fairly decided.

In the following remarks on this subject I have left out of consideration the temporary influence of exceptional seasons and, as far as possible, the special influence of local features. The subject should be viewed from the broad field above pointed out. In southern California leaf curl is not recognized as a generally prevalent and serious trouble, but there is evidence which shows that its prevalence increases from San Diego northward to the San Bernardino Mountains. The average annual rainfall varies from about 10 inches at the former place to 16 inches at Los Angeles, which is not far from the mountains. In the San Joaquin Valley the prevalence of curl increases as a whole from the south central portion toward Sacramento and the north. The average annual rainfall, which is 7 inches at Tulare, 9 inches at Fresno, 11 inches at Merced, and 14 inches at Stockton, reaches 20 inches at Sacramento, about which center curl is quite prevalent. The average rainfall at Oakland is 23 inches, and curl is quite troublesome there. In the Sacramento Valley curl is frequently quite prevalent, and the rainfall varies from 20 inches at Sacramento and Chico to 34 inches at Redding. About Ashland, in southern Oregon, the rainfall is 23 inches, and the disease is about as in the Sacramento Valley. Farther north in Oregon curl becomes decidedly more prevalent and injurious at the west of the Cascade Mountains, and increases as Portland is approached. The rainfall is 35 inches at Roseburg, 46 inches at Albany, and 49 inches at Portland. From Albany to Portland the peach industry has been greatly injured by curl, and on its account many growers in this region have considered peach culture a failure.

Curl, it seems, was introduced into the central part of the Willamette Valley, Marion County, nearly half a century ago. Prior to that time the peach was successfully grown in that region in spite of the humidity of the climate. In the Patent Office Report for 1855, p. 298, there is a statement of the situation in Polk and Marion counties from 1852 to 1855. This statement was from Mr. Amos Harry, of Farm Valley, Polk County, Oreg., and is of special interest in this connection. Mr. Harry says: "The peach in this county has been affected with a disease known as the 'curled leaf,' which threatens to destroy the trees. It made its appearance at Mill Creek, in Marion County, in 1852, and extended considerably on that side of the river (Willamette River) in 1853, but had reached most parts of the valley in 1854–55. Some trees seem to escape it much more than others, but if the malady increases for two years to come as it has for two past, I fear we shall come entirely short of this delicious fruit. Some think it is owing to cold, wet weather, and recommend shortening all the limbs as a remedy, and some experiments seem to favor this idea. Others think it is produced by an insect, and that no remedy will save the trees unless it can be applied to the whole surface of the leaves."

The rainfall at Portland, as already said, is 49 inches, and curl is commonly prevalent and severe. At Umatilla, east of the Cascade Mountains, but about the same distance north as Portland, the rainfall is only 10 inches, while on that side of the mountains the peach industry is extensive and everywhere prosperous, leaf curl being much less prevalent and of secondary importance. This shows that it is not the distance north and the consequent lower temperature which makes curl more severe at Portland than at Los Angeles for instance, but that it is the excess of rainfall, for at the east of the mountains, near Umatilla, the temperature goes equally as low or lower than at Portland, and curl is of little importance there. In the Puget Sound region peach culture has never developed extensively, the general prevalence of curl and its injurious action being one of the chief reasons. The rainfall is 50 inches at Seattle and 56 inches at Olympia. It is only 7 inches at Kennewick and 9 inches at Ellensburg, on the east side of the Cascade Range. The peach orchards of North Yakima and neighboring sections on the east side of the Cascades and near Ellensburg, where this rainfall is taken, are noted for their extent, thrift, and general health, and curl is not a serious trouble. This case is parallel with that of Portland, already considered. The rainfall at the west of the mountains is 50 to 56 inches or more, while at the east it is only 7 to 9 inches. In the former region peach growing is not listed by the Washington Board of Horticulture as one of the horticultural industries, but in the latter region the peach is a leading fruit, being extensively and successfully grown. The winter temperature east of the mountains should range fully as low where the peaches are grown as at the west of the range. The contrast in peach culture in the two situations results from the difference of rainfall, and the heavy rainfall at the west of the Cascades results in a development of curl almost prohibitive to peach growing.[1]

In replying to a circular letter sent to the peach growers of Maryland, November, 1893, Mr. T. C. Stayton, of Queen Anne, makes some statements which bear directly on the matter here considered and are of much interest as resulting from personal observation. After speaking of the conditions in Maryland, Mr. Stayton says: "I was in Washington State during the months of April, May, June, etc., this year, and I find they can not grow peach trees west of the Cascade Mountains or in western Washington, as that part of the State is called, as that is a very wet part of our country." He adds that this was especially true in 1893, and continues: "About all the young trees that had been planted in that part of the State died from curl leaf, or so nearly so that they were worthless, but over in eastern Washington I did not notice any curl leaf, the climate being dry."

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[1] For a full and accurate account of the rainfall conditions prevailing on the Pacific coast, see Report of the Rainfall on the Pacific Slope for from Two to Forty Years, Washington, 1889; also other reports of the Weather Bureau.

Peach leaf curl appears to be more prevalent in late than in early springs. This is probably due to the lower temperature and greater rainfall usually accompanying the former. Of 80 growers who gave their experience in relation to this matter, 43 stated that curl affects trees most in late springs, 23 believed it affects them most in early springs, and 14 had noticed no difference.

The question as to whether peach leaf curl affects trees most after a cold or warm winter was submitted to the growers, and of the 67 who replied, 27 stated that trees were most affected after a cold winter, 21 that they were most affected after a warm winter, and 19 growers had observed no difference.

The question of the influence of heavy dews on curl was also submitted to the orchardists, and the views expressed in their replies exhibit a remarkable agreement, 47 out of the 58 expressions of opinion received stating that the disease is no worse after a series of heavy dews. To the writer it appears probable that these answers are in perfect accord with the facts. Heavy dews can exert but slight influence upon the tissues of the peach, as they occur at night, when transpiration from the leaf is largely checked by the reduced light and lowered temperature of the atmosphere, resulting in the stomata being nearly closed. With the return of light and warmth the dew evaporates with the resumption of transpiration, and can have but little influence upon the tissues of the leaf. It might seem that dew would have a direct action on the germination of the spores of the fungus and in that way lead to a serious development of the disease after one or more heavy dews. This view, however, is not supported by observations either in the field or in the laboratory. In regions having little cloudy weather, with exceptionally clear sky, as in many portions of the Southwest, the heat of the soil radiates rapidly after sunset. In such sections of the country the days are hot and the nights cool or cold in comparison, the range of temperature between night and day being often considerable. In such regions dew is common and often heavy, but it is here that least curl occurs.

Relative to the action of dew on the germination of the spores of *Exoascus deformans*, it may be said that something more than dew is required for such germination. The writer has tested this matter most thoroughly, not only with dew, but with many forms of culture media at various temperatures and with varying supplies of oxygen. Brefeld has also shown that moisture alone is not sufficient for germination, he having utterly failed to induce germination in a single instance after months of work with culture media in liquid form. Budding of the spores is easy to obtain in all liquids, and is more abundant and continuous in suitable nourishing cultures than in dew or rain water. Fifty-eight growers replied to an inquiry on this subject, 47 stating that the disease is no worse after a series of heavy dews, 7 that it is worse, and 4 that no difference was observed.

THE FUNGUS CAUSING THE DISEASE.

The fungus causing peach leaf curl, now known as *Exoascus deformans* (Berk.) Fuckel, is a member of the subfamily of fungi known as *Exoasceæ*. The *Exoasceæ* are low or simple *Ascomycetes*, or fungi bearing their spores in cases or asci.

The classification of the *Exoasceæ* which now lays greatest claim to scientific permanence is that outlined in the recent writings of Sadebeck, who has given careful study to these forms.[1]

Of the five genera which he recognizes, only the last directly concerns us at this time, as it is to this genus (*Exoascus*) that the peach curl fungus belongs, as well as numerous other species injurious to horticulture. In considering this genus Sadebeck[2] has grouped thirty of its species according to certain characters of development. He recognizes the following characters of the genus:

EXOASCUS Fuckel.

A. The mycelium is perennial in the inner tissues of the axial organs.

a. The development of the hymenium occurs only in the floral leaves of the host plant. Eight species.

b. The development of the hymenium occurs only in the foliage leaves of the host plant. Seven species, including *E. deformans*.[3]

c. The development of the hymenium occurs upon the leaves as well as upon the fruits. One species.

B. The mycelium is perennial in the buds of the host plant and develops only subcuticularly in the leaves.

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[1] Sadebeck, Dr. R., Die parasitischen Exoasceen, Hamburg, 1893, p. 43.

Sadebeck recognizes five genera in the *Exoasceæ*, which he arranges and characterizes in the following manner:

EXOASCEÆ: Ascomycetes whose asci are not united in a fruit body.

A. The asci arise as swellings at the end of the branches of the mycelial threads.

1. *Endomyces* Tulasne. Four-spored asci, no conidia within the same; the sterile threads develop chlamydospores and oïdia.

2. *Magnusiella* Sadebeck. Parasitic. Asci with more than four spores; usually conidia formations in the ascus. Oïdia and chlamydospores wanting.

B. The asci take their origin from a more or less loose hymenium.

3. *Ascocorticium* Bref. Saprophytic on bark. The ascus layers are arranged in a loose hymenium upon the mycelium.

4. *Taphrina* Fries. Parasitic. Without perennial mycelium. In the formation of the ascogenous cells differentiations of material occur. Forming leaf spots.

5. *Exoascus* Fuckel. Parasitic. With perennial mycelium. In the formation of the asci no differentiations of material appear. The subcuticular mycelium changes directly to ascogenous cells. Causing sprout deformations.

[2] Sadebeck, Dr. R., Einige neue Beobachtungen und kritische Bemerkungen über die Exoascaceæ, pp. 277, 278, reprint from den Ber. d. deutsch. bot. Ges., 1895, Bd. XIII.

[3] Dr. von Derschau has described the occasional fruiting of *Exoascus deformans* in the blossoms of the peach. The figures given by this author do not show the normal development of ascogenous cells in the blossoms which are so common in the leaf blade of the peach. His figures show the asci as arising from lateral branches of a continuous mycelial hypha, and this mycelium is situated beneath the epidermal cells instead of between the cuticle and epidermis (Landw. Jahrb., Berlin, 1897, pp. 897–901, and Table XLI).

a. The development of the hymenium occurs only in the floral leaves of the host plant. Three species.

b. The development of the hymenium occurs only upon the foliage leaves. Ten species.

c. The resting mycelium extends intercellularly in the deformations of the leaves. One species.

It may be seen under A *b* of this arrangement that *Exoascus deformans* is said to possess perennial mycelium, inhabiting the inner tissues of the axial organs, and that the development of the hymenium occurs only in the foliage leaves of the host plant. As will be seen in another part of this bulletin, it is perhaps a perennial nature of the mycelium of *E. deformans* which makes it difficult to thoroughly rid an orchard of curl by means of spray treatment, but this matter requires further careful consideration.

The synonymy of *Exoascus deformans* (Berk.) Fuckel has been given by numerous writers. Sadebeck[1] gives it as follows:

Ascomyces deformans Berk. Intro. to Cryptogamic Botany, 1857, p. 284.
Ascosporium deformans Berk. Outlines, 1860, p. 449.
Taphrina deformans Tul. Ann. Sci. Nat., 1866, V. Sér., t. 5., p. 128.
Exoascus deformans Fuckel. (*a*) *Persica* Fuck. Symbolæ Micolog., 1869, p. 252.

This fungus has been very commonly observed and frequently described by botanists since Berkeley called attention to it in 1857. It has thus been known as the cause of curl for a little less than half a century. The peculiar behavior of peach foliage under its action has been observed by horticulturists, however, for a much longer time. The disease was well described in England in the early part of the present century.

In spite of the very common appearance of *Exoascus deformans* upon peach foliage in peach-growing countries, the descriptive literature relating to its life history is not free from conflicting statements. Several species of *Exoascea* have been confounded with this species in some instances, and subsequent writers have perpetuated the confusion.

Some earlier writers believed this species inhabits a considerable number of host plants, thus resulting in the description and distribution of several distinct species as *Exoascus deformans*. To avoid such confusion it would be best to confine remarks upon this species to the fungus as it develops upon the peach (*Prunus persica* L.), which if not its only host, is certainly its most common one.

At least two modes of infection of the peach tree by *Exoascus deformans* are said to exist—(1) by means of perennial mycelium, and (2) by means of the spores of the fungus.

Sadebeck[2] is authority for the statement that the mycelium winters over in the youngest portions of the one-year-old branches of the host

[1] Sadebeck, Dr. R., Die parasitischen Exoasceen, Hamburg, 1893, p. 53.
[2] Idem, l. c.

plant, and may be seen in the primary cortex, in the medulla, and in the medullary rays of the first shoots of each period of vegetation, but has not been observed in the soft bast. With the beginning of the new season of growth the mycelium, according to Sadebeck, extends into the leaves of the young shoots, penetrates first the inner tissue of the leaves, and finally progresses to the development of the subcuticular hymenium. From what foundation of experimentation Sadebeck has arrived at these views respecting this particular species, I am unable to state, but he has given the outlines of his investigations upon other species.[1]

The facts given by De Bary[2] can not be cited here, for this work was done upon the Exoascus infesting the cherry tree, and which is now considered to be distinct from *E. deformans*.

The general acceptance of the view that spring infection of the peach foliage is largely due to the extension of the internal perennial mycelium into the new shoots and leaves from the shoots of the previous summer, has probably considerably retarded the progress of preventive treatment. Pathologists have thought it improbable that any considerable amount of disease could be prevented after a tree was once generally affected, as the perennial mycelium, being internal, could not be readily reached by external sprays. Prillieux,[3] writing in 1872, advises the gathering of the diseased leaves and the cutting away and burning of the diseased branches. Frank[4] has made like recommendations in both editions of his work on plant diseases. Assuming the mycelium to be perennial, he says that the curing of the disease might be aimed at through cutting back of the diseased branches and the prevention through quick removal of the diseased leaves. Winter[5] suggests a somewhat similar line of treatment, with the additional recommendation that the trees be protected from rain during the unfolding of the leaves. Dr. Cobb,[6] as late as 1892, after speaking of the perennial mycelium of this fungus, discusses preventive and curative measures, such as the destruction of diseased leaves, prunings, etc., while in the more severe cases he says the sooner the trees are cut down and burned the better it will be for the peach industry.

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[1] Sadebeck, Dr. R., Die parasitischen Exoasceen, Hamburg, 1893, pp. 24–28.—Das perennirende Mycel der Exoascus-Arten.

[2] De Bary, A., Com. Mor. and Biol. of the Fungi, Mycetozoa, and Bacteria, English edition, 1887, p. 266.

[3] Prillieux, Ed., Bul. de la soc. bot. de France, 1872, T. XIX, p. 230.

[4] Frank, Dr. A. B., Die Krankheiten der Pflanzen, Breslau, 1881, Part II, p. 526; second edition, 1896, Vol. II, p. 250.

[5] Winter, Dr. Georg, Die durch Pilze verursachten Krankheiten der Kulturgewächse, Leipzig, 1878, p. 47.

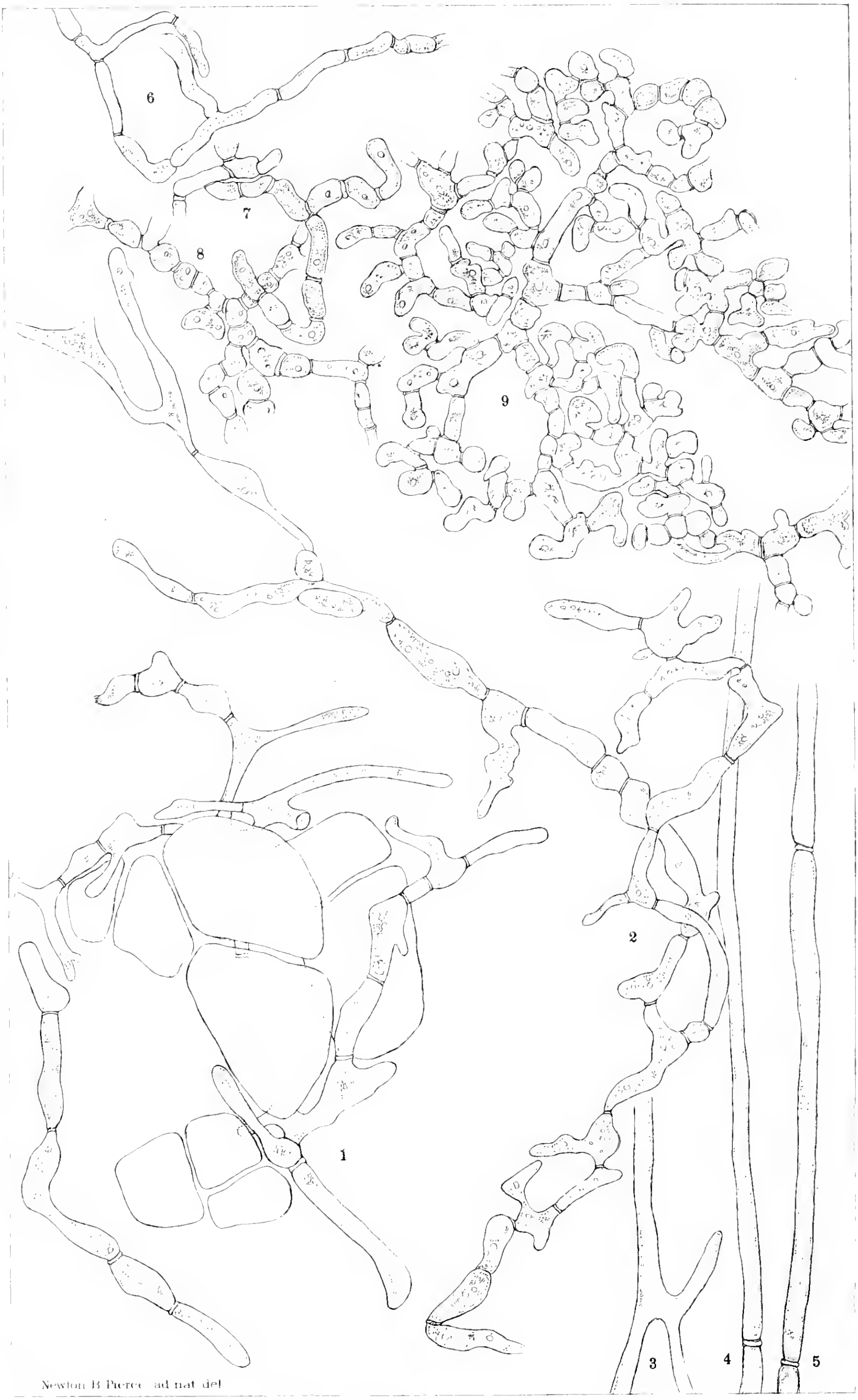
[6] Cobb, Dr. N. A., The Agricultural Gazette, Sydney, New South Wales, 1892, Vol. III, pp. 1001–1004.

Relative to the use of fungicides the same writer says: "These treatments are of doubtful value as far as the curl is concerned, and were it not that they are useful in other ways I would not mention them." It is evident that these views are the result of Dr. Cobb's belief that the perennial mycelium is responsible for the major portion of the spring infection of the tree. The writings of others to the same effect could be cited, but the views of the workers already named are sufficient to show that their recommendations for treatment have been based upon the hypothesis that the spring infection could not be prevented by treatment with fungicides, as it arose mainly from internal mycelium rather than from the germination of external spores. That this view has held back the preventive treatment of the disease, as already claimed, can not be doubted, and that a perennial mycelium is not responsible for more than a very small percentage of the spring infections seems evident from the results of the present experiments; in fact it may even be questioned if such infection takes place except under exceptionally favorable conditions. Our experiments have demonstrated that as high as 98 per cent of infections may be prevented by a single thorough application of a suitable fungicide. This is as high a percentage of control as is often obtained in the treatment of fungous diseases where no perennial mycelium exists, and it seems probable that the infections by this means may not commonly exceed 5 per cent of each spring's infections. Were this not the case we would be forced to assume that the spray has a direct effect upon the hibernating mycelium, which certainly would be unusual and scarcely to be expected.

The second mode of spring infection—that by means of spores—is probably much more general and important in this disease than has been supposed. That 90 to 98 per cent of the infections of the tree are prevented by a single spraying suggests that at least such percentage of the infections is by means of spores.

The mycelium of *Exoascus deformans* as found in the peach, shows great differences in the form and appearance of its hyphæ. These differences depend upon the stage of development of the fungus and the various functions of the mycelium. The writer recognizes three types of hyphæ, which may be termed vegetative, distributive, and fruiting.

The vegetative hyphæ are found most commonly in the leaf parenchyma, but are also met with in the leaf stalk and cortical parenchyma of badly diseased and distorted branches. These hyphæ may be most distinctly seen, and are most highly developed, in infested leaves which have not yet formed the hymenium of ascogenous cells, but in which the parasite has been present a sufficient time to entirely alter the character of the palisade tissue and cause the loss of the chlorophyll. In the leaf blade the palisade tissue first shows the serious action of



MYCELIUM OF EXOASCUS DEFORMANS, THE FUNGUS CAUSING PEACH LEAF CURL.

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DESCRIPTION OF PLATE II.

Mycelium of *Exoascus deformans* (600/1). Figs. 1 and 2, normal vegetative hyphae, as found in the leaf parenchyma, showing characteristic septation, modes of branching, etc.; figs. 3, 4, and 5, usual type of distributive hyphae found in swollen branches in the cortical parenchyma and medulla; figs. 6, 7, 8, and 9, fruiting hyphae, showing successive stages in the development of ascogenous cells from the subcuticular mycelium (6) to the half-formed ascogenous cells (9). (See Pl. III for further stages in the development of the ascogenous cells and asci.)

the vegetative hyphæ, which are usually found somewhat later among the cells of the spongy parenchyma, below the vascular network. The loss of chlorophyll from the two classes of leaf parenchyma commonly preserves the order here given. The form of the vegetative hyphæ is very irregular, and their elements, or cell members, are often of different size, length, and shape. The cells vary greatly in diameter from one end to the other, are frequently much curved and twisted, and oftentimes appear triangular in cross section. The branches may arise from greatly enlarged triangular bifurcations, or in other instances directly from the sides of the cells. These vegetative hyphæ are all intercellular so far as observed, but are commonly found adhering closely to the cell walls of the host, frequently wrapping about the parenchyma cells. The walls of the hyphæ are semitransparent but firm, commonly having a slight yellowish cast. The septa present peculiar characters. Two adjoining cells of a hypha have the appearance of being separately closed at the end and united with each other by means of an intervening plate, which if it should be dissolved or lost would leave the cells separated but closed. These peculiar septa are remarkably refractive and characteristic. They are well shown in the drawings of Sadebeck (Die parasitischen Exoasceen, Hamburg, 1893, Tab. II, figs. 7, 8). The predominating characters of the vegetative hyphæ are shown in Pl. II, figs. 1 and 2, of this bulletin. The hyphæ there shown were carefully separated from the leaf parenchyma and drawn under the camera. The vegetative hyphæ of the branch are much like those of the leaf, and have been seen most commonly among the looser parenchyma cells of the cortex just exterior to the bast fiber bundles. Thus far they have never been found by the writer in the cambial tissues. Sadebeck states that the mycelium has been found in the pith and medullary rays.

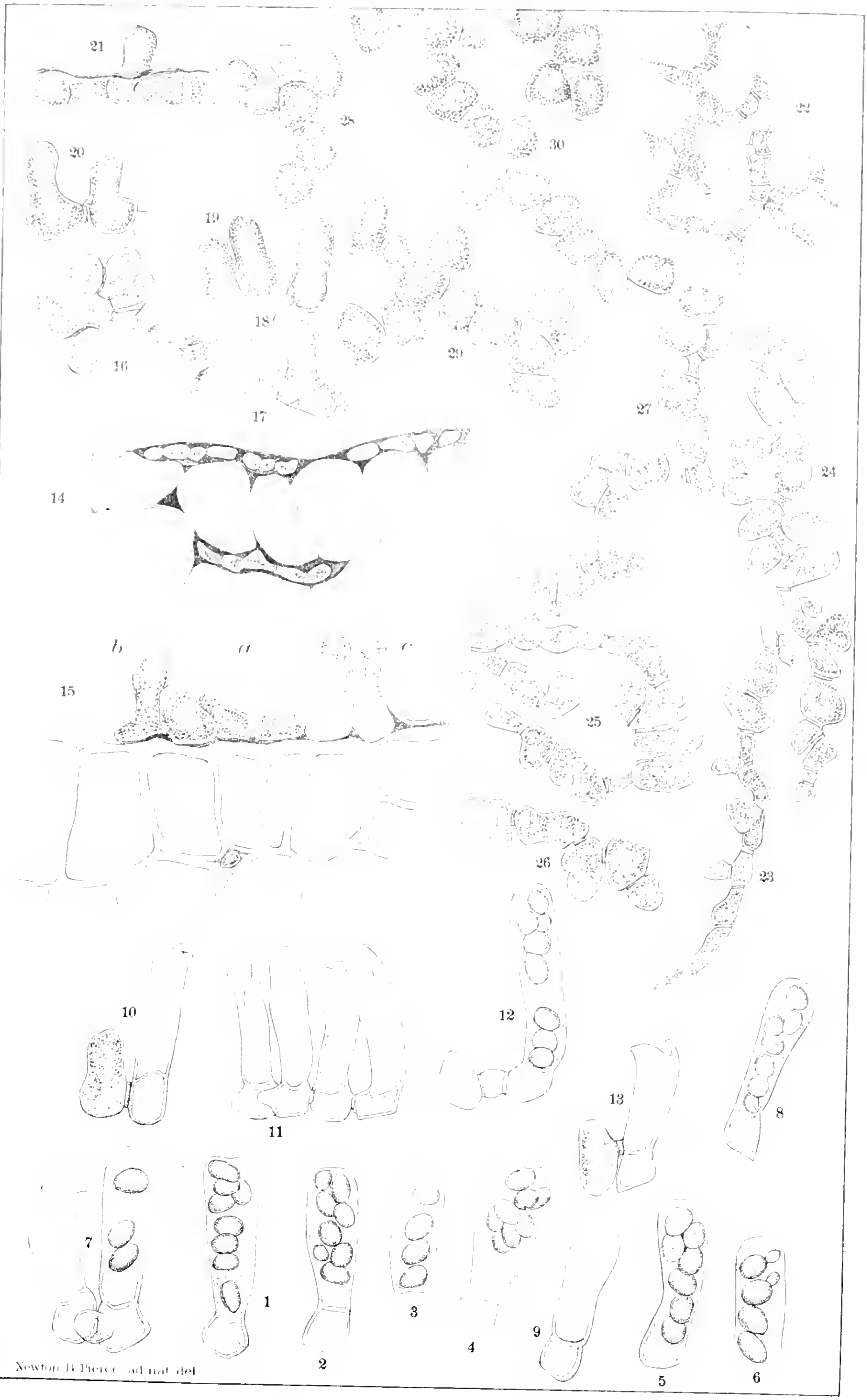
The distributive hyphæ are shown in Pl. II, figs. 3, 4, and 5. They have been found by the writer in the tissue lying close beneath the epidermal cells of diseased peach twigs, and in great abundance in the pith. They are occasionally found in groups of several hyphæ but slightly separated from each other and following a course parallel to the longitudinal axis of the shoot. The cells composing these hyphæ are much longer than either the vegetative or the fruiting forms, while they are nearly straight and of more uniform diameter. The septa are characteristic of those found in the other forms of the mycelium of this fungus. Such distributive hyphæ have been followed for some little distance in the swollen portions of the peach twig, and the name has been given them from their apparent function of spreading the fungus in the branch. Such hyphæ branch by bifurcation, the branches commonly assuming a course parallel to the parent hypha and the direction of the peach limb.

The fruiting hyphæ have been seen to arise in *Exoascus deformans* from the vegetative hyphæ after the latter have become well developed in the parenchyma of the leaf. Large, well-nourished vegetative hyphæ commonly develop just below the epidermal cells of the upper leaf surface.[1] From these hyphæ arise branches which penetrate between the cells of the epidermis, and press themselves between the epidermis and the cuticle. Such hyphæ may be seen both in section and surface view. These subcuticular hyphæ now branch freely, and follow with more or less regularity the triangular space formed by the juncture of two adjoining and somewhat rounded epidermal cells with the cuticle. This is presumably the line of least resistance to the advance of the hyphæ. By opening and following these channels the mycelium assumes the outlines of a quite uniform network beneath the cuticle. While this manner of following the line of juncture of adjoining epidermal cells with the cuticle is common, it is not invariably the practice of the fungus, cases occurring where apparently no such agreement exists. Series of straight and parallel hyphæ, at regular distances apart, are sometimes met with beneath the cuticle as the precursors of the hymenial layer. These send off lateral branches on either side, which by enlarging, branching, and curving eventually occupy most of the surface of the epidermis between the main hyphæ. It is probable that the path followed by the first subcuticular hyphæ depends largely upon the firmness with which the cuticle is attached to the epidermal cells, and which may largely depend upon the amount of water in the tissues and upon the age and rapidity of their growth. With the leaf tissues full of water and making a rapid growth, the hyphæ could naturally pursue a more direct course beneath the cuticle than under contrary conditions. After the establishment of a much-branched filamentous network of subcuticular hyphæ, the cells of which are usually slender, of medium length, thin-walled, and of comparatively uniform diameter (Pl. II, fig. 6), these cells begin to distend, and are shortened by the formation of new transverse septa (Pl. II, fig. 7, and Pl. III, fig. 22). About this time all septa become much more distinct. At a later stage the cells become still more distended and subspherical (Pl. II, fig. 8). As these enlarged cells

[1] Miss E. L. Knowles (Bot. Gaz., Vol. XII, No. 9, p. 217) has called attention to the fact that Winter's statement that "the asci break through the lower side of the leaf" does not hold good for the peach (Kryp. Flora, Asco., p. 6, and Krank. Kultur-Gewächse, Leipzig, 1878, p. 47). Winter is not alone in stating that the asci of *E. deformans* arise on the under surface of the leaves. Robinson says: "The asci are borne on both sides of the leaf, but in greater numbers upon the lower surface" (Robinson, B. L., Notes on the Genus Taphrina, Ann. Bot., Nov., 1887, Vol. I, No. 11, p. 168). Atkinson also says: "The asci are developed on both surfaces of the leaf" (Atkinson, Geo. F., Leaf Curl and Plum Pockets, Cornell Agr. Exp. Sta. Bull. No. 73, 1894, p. 325). These and other like statements have probably arisen from a study of other foliage than that of the peach, and of other species of *Exoascus*, and qave been perpetuated through insufficient reference to nature.

DESCRIPTION OF PLATE III.

Fruiting stages of *Exoascus deformans*. Figs. 1 to 13 (600/1), various stages and conditions of the asci and ascospores of the fungus. Fig. 14, section of peach leaf, showing subepidermal and subcuticular mycelium, the latter already partially differentiated into ascogenous cells. Fig. 15, section of peach leaf showing three successive stages in the formation of the asci from the ascogenous cells: *a*, the pushing of the ascogenous cells; *b*, the ascus nearly full-formed, but with the contents still connected with the ascogenous cell; *c*, the asci separated by a septum from the ascogenous cell, which now forms the stalk cell of the ascus. Figs. 16 to 20 (600/1), the first stages in the formation of the asci from the ascogenous cells, the latter being ruptured above and the asci pushing upward. Fig. 21, the pushing of a forming ascus through the leaf cuticle (600/1). Figs. 22 to 27 (600/1), various stages in the formation of ascogenous cells from subcuticular mycelium. (For several early stages in this process see Pl. II, figs. 6 to 9). Figs. 28 to 30 (600/1) show fully developed ascogenous cells as seen from above.



FRUITING STAGES OF EXOASCUS DEFORMANS.

A. Hoen & Co. Lith. Baltimore

spread out between the epidermal cells of the leaf and the cuticle they are much distorted, curved, and lobed, the branches and lobes eventually filling, in a quite uniform and continuous manner, the entire space between the elevated cuticle and epidermis, so that a more or less perfect and continuous hymenial layer of ascogenous cells is formed (Pl. II, fig. 9; Pl. III, figs. 23, 24, 25, 26, and 27). At this time the cells become well rounded and heavy-walled, and they may or may not become loosened and separated from each other (Pl. III, figs. 28-30). These are now the fully developed ascogenous cells of the hymenium, and they are fully stored with nutritive materials for the development of the asci. In their compact, continuous, and rounded condition they resemble, when viewed from the surface, the stones in the pavement of an old Roman highway.

The various phases of the development of the hymenium of ascogenous cells may often be observed at one time in a single infected leaf. The center of a swollen spot frequently shows the fully developed hymenium, while at the margin of the spot the first filamentous hyphæ are just spreading beneath the cuticle. In such instances nearly all stages in the development of the ascogenous cells may be studied in a single well-prepared specimen. The development of a subcuticular hymenium has been observed in the petiole as well as in the blade of the leaf.

The formation of the asci from the fully developed ascogenous cells has been carefully followed in the study of a large number of preparations. Thus far no sexual phenomena have been observed in connection with the formation of the ascogenous cells or with the development of the asci. As already said, the walls of the ascogenous cells are heavy. The early steps in the development of the asci from these cells (the development of a papilla-like elevation on the upper surface of the cells) cause the rupture or dissolution of the heavy wall where the elevation occurs. The phenomenon is that of the germination of a heavy-walled spore, or, perhaps, more properly, the outgrowth or prolongation of an endospore through the rupture of the epispore (Pl. III, figs. 17, 18, etc.). The fact to be noted is the perfect resting condition into which the ascogenous cells may pass before the development of the ascus, as shown by the marked delimitation between the thin wall of the forming ascus and the heavy wall of the ascogenous cell. The entire isolation of single ascogenous cells or groups of cells from all sources of vegetative supply indicates that the ascus is entirely dependent for its nourishment upon the stored materials of the cell from which it arises. The pushing of the ascus after the complete development of the ascogenous cell instead of in direct continuation of the development of the latter, also points to a probable cessation and renewal of the reproductive activity of the ascogenous cell.

In view of these facts, it seems possible that the ascogenous cells may be capable of enduring, under especially favorable conditions, a resting period of considerable time. Such resting ascogenous cells have been sought for upon the swollen branches of the peach, however, without success. Further research along this line is desirable. As the fungus is already known to fruit upon the blade and petiole of the leaf and upon the blossom, and a vegetative mycelium is found growing thriftily in the swollen branches, there seems to be no good reason why the parasite may not fruit upon the infected twigs.

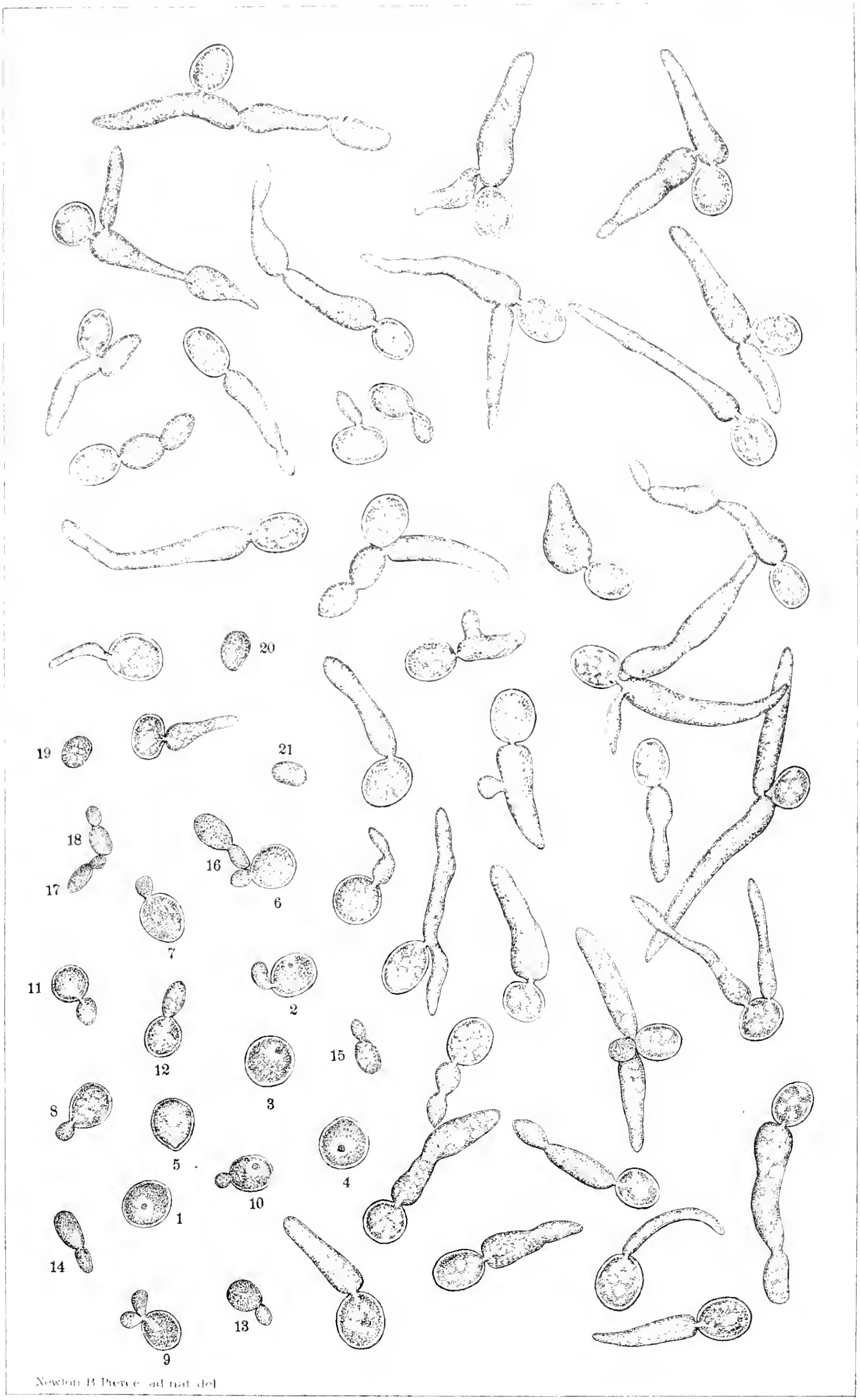
The perpendicular growth of the developing asci in the leaf soon ruptures or pierces the cuticle, and where large numbers of asci develop at the same time the cuticle is lifted, torn, and lost, the asci forming a more or less continuous plush-like surface growth. Isolated asci press through the cuticle so as to form separate perforations (Pl. III, fig. 21). The contents of the forming ascus are finely granular, and as the ascus elongates these contents crowd into the upper portion and a septum is formed across the basal part in such a manner as to cut off the now emptied ascogenous cell as a stalk cell for the ascus (Pl. III, fig. 15). When fully developed the asci are usually broader at the top than at the base, and often somewhat clavate in form. A series of asci measured varied in length from 34 to 44 μ, the average being 38 μ; the width of the asci ranged from 10 to 12 μ, and the height of the stalk cells varied from 8 to 13 μ, the average being slightly over 10 μ (Pl. III, figs. 1–13).

The formation of the ascospores in *Exoascus deformans* has not been carefully studied by the writer. Sadebeck has shown, however, for *E. turgidus*, that mitotic nuclear division occurs in the ascus in connection with spore formation (Untersuch. über die Pilzgattung Exoascus, Hamburg, 1884, Pl. III, fig. 20). The ascospores developed in the asci of *E. deformans* vary in number from 3 to 8, the latter being the full and typical number. When mature they are surrounded by a moderately firm cellulose wall, which is rather inconspicuous, owing to its transparency. The spores are usually somewhat oval in form, being longer than broad, but occasionally some are seen which appear nearly or quite spherical. Fresh ascospores sometimes show distinct nuclear phenomena. This has been observed with spores still within the ascus, as well as in many which have escaped. The nucleated appearance seems less common in budding or germinating ascospores than in those in a resting condition (Pl. IV, figs. 1, 2, 3, 4, and 10). The average length of the ascospores measured was $7\frac{9}{11}$ μ, the length varying from 6 to 9 μ, and the average width was $6\frac{3}{10}$ μ, varying from 5 to 7 μ. The ascospores escape from the ascus through an apical rupture of the latter.

Germination of the ascospores has been observed by the writer to proceed in two ways: (1) By means of budding or conidia formation; (2) by means of stocky germ tubes, often one branched and resembling promycelia.

DESCRIPTION OF PLATE IV.

Germination of the ascospores and conidia of *Exoascus deformans*. Figs. 1 to 12 (about 800/1), ascospores, of which five show nuclear phenomena and several are budding. Figs. 13 to 21 (800/1), thin-walled conidia, several of which are producing buds; the remaining spores, unnumbered, show various modes of promycelium formation or mycelial germination.



GERMINATION OF THE SPORES OF EXOASCUS DEFORMANS.

A Hoen & Co. Lith. Baltimore

Budding of the ascospores occurs either before or after the escape of the spores from the ascus. In the formation of the bud conidia the process may take place from the ascospore direct, one conidium after another being produced, or the contents of the ascospore may pass into a thin-walled conidium nearly or quite equal in size to the ascospore, this large conidium then assuming the function of bud production. Ordinarily the ascospore buds at one point only, but bud formation at two points has been seen. Budding occurs most commonly at one end of the ascospore, but occasionally lateral buds are observed. In the early stages of budding the ascospore sometimes shows a nipple-like swelling at one end, reminding one of the germinating end of the sporangium in the *Peronosporeæ*. The successive primary conidia budding from an ascospore may become loosened and turned to one side by the following conidium, which swells from the same germ pore of the ascospore. In other cases several conidia may remain united with each other, but when this condition is observed it is frequently the result of the secondary or tertiary budding of the primary conidium, several orders or generations of buds remaining united. When the process of primary conidial budding can no longer take place the empty ascospore may or may not become separated from the last primary conidium. With the exception of the case above referred to, the different orders or series of conidia (primary, secondary, tertiary, etc.) when grown in pure water, are each smaller than the preceding, and the conidia are considerably elongated in form, sometimes almost cylindrical. The walls of the conidia are more delicate than those of the parent spore. In a suitable nourishing fluid, as the extract of malt, the conidia take up nourishment and increase in size, thus enabling them to continue the budding process for considerable periods of time, as in the yeasts (Saccharomyces). Whether the conidia of *Exoascus deformans* are able to induce an alcoholic fermentation through their growth in saccharine culture media is not known, but Sadebeck states that the conidia of other species of this genus certainly possess this fermenting power.

The second method of germination of the ascospore of *Exoascus deformans*, that is, the pushing of germ tubes, is rarely met with except upon the host plant itself. Such mode of germination is shown in Pl. IV. The germ tube produced from the ascospore is usually much swollen near the spore and tapers considerably toward the extremity, though not infrequently considerable constrictions occur at one or more points in its course. It seems probable that this tube is in many cases capable of directly infecting the host, probably through a stoma, as observed by Sadebeck in *Exoascus tosquinetii*, and that its function is not wholly the abjointing of sporidia. Such separation of sporidia, in fact, has not thus far been observed. The germ tube, or promycelium, is connected with the spore by a very narrow and short tube, with straight and parallel walls. The same mode of connection is also observable in the formation of the bud conidia, and reminds one of the sterigmata bearing the sporangia of *Phytophthora infestans.*

Thus far efforts to induce filamentous germination of the bud conidia or of the ascospores of *Exoascus deformans* in culture media have proved unsuccessful. Brefeld has worked with this problem for months, and the writer has frequently attempted to obtain this form of germination.[1] Budding occurs, as already indicated, quite readily in various nutrient solutions, and short promycelia from the ascospores have been found in some cultures. In nearly if not all cases, however, the ascospores showing promycelia or short mycelial germination have shown that this germination occurred under natural conditions upon the peach leaf, the germinated spores being transferred from the leaf to the culture in preparing the latter. It may be added here that the bud conidia are also formed in vast numbers upon the surface of the infested leaf after the maturing of the ascospores. It is largely these conidia which give the infested leaf the marked white appearance commonly observed at the height of the disease. The leaf appears as if covered with flour or a heavy white bloom.

RELATIONS OF THE FUNGUS TO THE HOST.

Under a previous heading in this chapter the physical conditions which influence the serious development of peach leaf curl have been considered in accordance with the light which we now have relative to such influences, and there remain to be taken up at this time the more intimate and direct relations of the host and parasite. These relations include the action of the fungus upon the cell contents, the cell walls, and the cellular tissues of the host; the probable mode of infection and the spread of the parasite within the tissues; the wintering of the fungus upon the tree; etc.

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[1] A very considerable number of cultural experiments have been tried. The cultures of ascospores and conidia have been subjected to temperatures much below the freezing point and to various degrees of heat in the thermostat. Sudden changes of temperature have been tried. Increased and diminished amounts of oxygen, as contrasted with that of the normal atmosphere, have been tested. Even a chamber filled with nearly pure oxygen has produced no apparent effect. Water from various sources, such as rain water, dew, ice water, distilled water, tap water, etc., has been tested. Solutions of the various sugars, malt extract, sterilized beer, plum extract, etc., were tried. Hanging drop cultures of various nutrient media and plate cultures of potato-peptone-sugar gelatin have not shown germination. Drops of various nutrient solutions placed upon newly forming leaves dissected from unopened peach buds and these held in moist chambers have given only negative results. The same is true for peach pits brought near to germination and the cotyledons treated with a weak solution of diastase, the spores placed between them and held at various temperatures in moist chambers. Sections of such cotyledons with spores placed upon them were also prepared in moist chambers. A brief treatment of the spores with ether was tested without bringing about germination.

Prillieux states that attempts to artificially infect the leaves or shoots have not thus far succeeded (Mal. d. Plantes Agr., Vol. I, p. 399).

As already indicated, the writer's work with sprays seemed to show that not more than a small percentage of each year's infections ordinarily arise from a perennial mycelium. In the Lovell orchard, where the personally conducted work was carried out, it would appear that not to exceed 2 to 3 per cent of the infections could have arisen from that cause. On the other hand it would seem that at least 95 per cent of the infections arose from spores, for, as already stated, 95 to 98 per cent of the spring infections could be prevented by a single spraying, and this was actually accomplished where the spraying was done with sufficient thoroughness. It is believed by the writer, however, that these percentages will vary within moderate limits in different localities, with different varieties, and in different seasons. The following observations will explain these views.

The mycelium of diseased leaves is found to be connected through the leaf petiole with the mycelium of the infected limb. From the writings of Sadebeck and many others it might be supposed that the leaves were infected from the perennial mycelium in a majority of cases, and that the mycelium met with in the petiole of the leaf originated from the perennial mycelium of the branch. That such spring infection really occurs from the wintering mycelium of the branch should perhaps be admitted, but that such is the common mode of infection of the leaves is certainly doubtful. The writer's studies have shown that the mycelium in the branch close to a cluster of infected leaves diminishes in amount as it passes upward or downward in the branch from such leaves. This fact is as obvious from microscopic studies of the infested tissues as from the external hypertrophies observable to the eye. A macroscopic examination of diseased and swollen branches will show that the enlarged parts may extend upward or downward along the branch from the base of the petioles of the leaves, which seem to represent the center of infection. In a majority of cases these swollen ridges terminate before reaching another leaf bud, though in some instances they are seen to extend along the branch throughout the entire length of one or more internodes, and in such cases it is fair to suppose that the mycelium may have infected the young leaves of a second or third bud in its course. It should be remembered, however, that this mycelium, in a great majority of instances, indicates no connection with a previous year's mycelial growth, but has evidently just entered the branch from one or more infected leaves. The microscopic evidence supports these conclusions, which are, to some extent, in harmony with Benton's observations, to be hereinafter considered, but the writer is scarcely prepared to admit the large percentage of spring infections arising from new mycelium entering the branch which the observations of that writer seem to imply.[1] The microscope shows that the hyphæ which pass away from

[1] Pacific Rural Press, Aug. 2, 1890, p. 88.

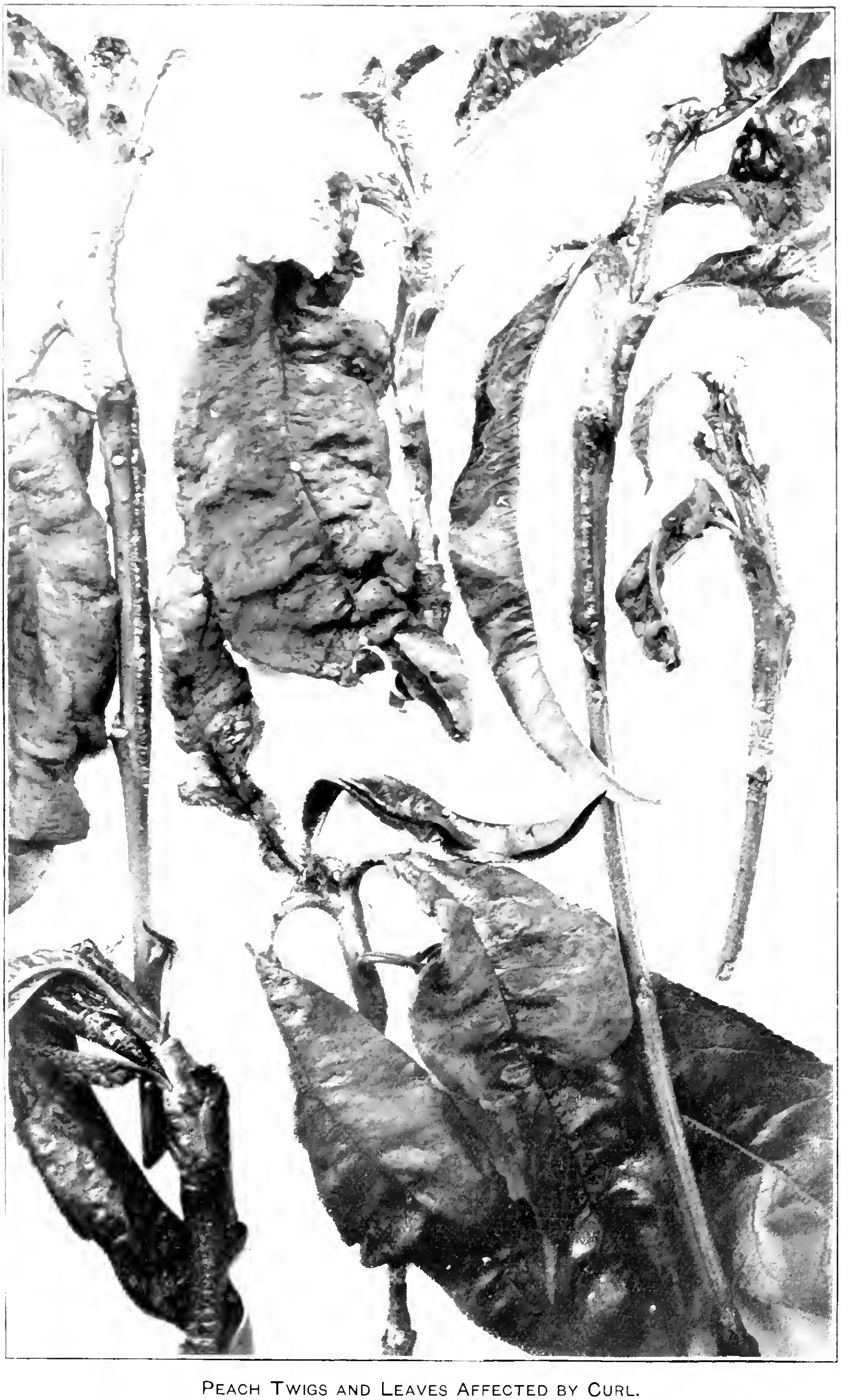
the base of the leaf petiole gradually decrease in numbers as they recede from the leaves, and they appear to be wholly lost at a short distance from the point of entrance into the shoot. As a rule, little or no mycelium has been found extending more than 1 or 2 inches beyond a point where external macroscopic evidence of disease exists.

The preceding facts lead to the belief that where mycelial infection of foliage takes place from the branch it is usually done in the spring from hyphæ arising from spore-infected leaves of the same season, and that this occurs only in comparatively few instances or in bad cases of disease. They also indicate that living perennial mycelium which succeeds in accomplishing spring infection, is comparatively rare. Badly infested and swollen branches are apt to die and dry out, thus affording no living tissue for the support of the infesting mycelium. Such branches, even if living until the following spring, are not apt to produce much growth, and frequently produce none whatever. Furthermore, the badly swollen mycelium-infested branches are comparatively few, and it is believed that the infested winter buds of these branches very rarely exceed 2 to 3 per cent of the total number of buds upon the tree. Most branches appear to suffer from the disease only in an indirect manner, that is, by the fall of affected foliage. It seems probable to the writer, therefore, that the swollen branches, in which the swelling is apparent to the eye, constitute the true and almost exclusive home of the perennial mycelium, and therefore supply the only possible source of spring infection by the wintering hyphæ, and consequently the only source of infection not controllable by sprays. This is in harmony with the results of widespread orchard treatment. All but 2 to 3 per cent of infections have been prevented by a single spraying. (See the results of work on half-sprayed trees.) That such spraying did not prevent the spread of the mycelium in the inner tissues of the host is shown by the fact that when it is delayed until the leaves have fairly started and have become infested, the treatment is ineffective and the disease will continue to develop and both foliage and crop may be lost. It is not the checking of the spread of the mycelium from the branch to the new leaves, therefore, that results from spraying, but the prevention of the early spore infections from without; and as all but 2 to 3 per cent of the year's infections may be thus prevented, all of such infections must be considered as arising from spores.

The limitation of the perennial mycelium of *Exoascus deformans* to the swollen branches or branch parts, as here held, is in harmony with observed facts respecting other species of *Exoasceæ*. It is not understood, for instance, that trees developing witches' brooms are infested in all their branches, but that the branch-infesting mycelium is limited in its distribution to those centers which develop the abnormal multiplication of shoots, the swellings and other external manifestations of disease. (See Pls. I, V, and VI, and descriptions, in connection with

DESCRIPTION OF PLATE V.

Terminal peach twigs badly affected by curl. The mycelium of the fungus has entered the growing end of these shoots, and the conditions being favorable, it has developed to such an extent as to prevent further elongation of the twig, thus forming a compact head, with greatly shortened internodes. It is in shoots of this character that the mycelium is found, and its extent is nearly coincident, so far as observed, with the swollen portions of the branch. Such swollen branches constitute a striking feature of the disease, but rarely involve more than 2 to 3 per cent of the buds of a tree. Specimens were collected at Santa Ana in the spring of 1899 and photographed natural size. (Compare with Pls. I and VI.)



PEACH TWIGS AND LEAVES AFFECTED BY CURL.

The distributive mycelium of the fungus is found in such swollen branches.

DESCRIPTION OF PLATE VI.

Sprayed and unsprayed branches of Lovell peach trees in the experiment block at Biggs, as they appeared in 1895. The sprayed branches at the left show the large amount of fruit and healthy foliage on the sprayed trees; the unsprayed branches at the right have lost most of their foliage and all the fruit from curl. These unsprayed branches show the typical and common effects of curl. Hypertrophy of the branch is not shown, and it is probable that these branches carry little if any perennial mycelium. Thorough winter treatment of such branches with proper fungicides will prevent 98 per cent of the spring infections and conduce to the development of foliage and fruit, as shown on the branches at the left. All these trees were equally infected by the fungus in 1893, when the orchard suffered severely from curl, and had the branches at the left not been sprayed before the leaf buds opened in the spring of 1895, they would have been in the same condition as those at the right of the plate. (Compare with Pls. I, V, and VII.)

TREATED AND UNTREATED PEACH BRANCHES.

At the right is shown the usual denuding action of curl without hypertrophy of the branch; branches at left were treated.

the present remarks on infested and noninfested branches.) It seems probable, therefore, (1) that most of the spring infections of the peach occur from spores which have wintered on the tree and about the newly formed buds; (2) that most of the infected leaves fall off without infecting the branch which bears them; (3) that the mycelium of badly diseased leaves sometimes infects the branch through the leaf petiole; (4) that such mycelium after entering the branch may pass upward or downward, and in some instances may follow the branch for the length of one or at most a few internodes, and possibly infect one or two adjoining buds; (5) that badly infested branches usually die during the year, while in comparatively few instances they may support a living mycelium capable of inducing spring infection of opening buds; (6) that most infected branches show by external hypertrophy the presence of the parasite, which may commonly be removed by pruning off the hypertrophied parts at a point a few inches below the swelling; (7) that seasons, atmospheric conditions, localities, and varieties may have a limited bearing on the extension of the mycelium in the branch and upon the amount of mycelium wintering in an active state, although the results of spraying in many parts of the country, continued for several years, have shown the variation in these respects to be confined within comparatively narrow limits.

The direct infection of the peach leaf by means of the spores of *Exoascus deformans* has not been seen. The efforts made to observe the germination and penetration of the fungus have already been touched upon. One thing seems certain, viz, that under ordinary conditions this form of infection occurs at a very early period in the development of the leaf, but evidently not before the opening of the leaf buds. Very young leaves are found to be already infected, but spraying just before the buds expand will prevent this infection, i. e., infection may be prevented by the treatment of closed buds, which would scarcely be true if a perennial mycelium were within. If we may judge by analogy, the germ tube of the fungus enters the leaf through a stoma. Sadebeck reports that such was his observation in *Exoascus tosquinetii*, in which species the germ tube creeps for a short distance on the leaf surface, and then enters a stoma, much as in the germination of the conidium of *Phytophthora omnivora*.

The major portion of the spring infection of foliage occurs while the latter is young and tender, but it is observed that new infections may take place for a considerable time if the various influencing conditions continue favorable to the fungus. These conditions act chiefly in suddenly retarding the transpiration of the host, and some of them have already been discussed. On the other hand, a short period of spore infection may be expected when external influences are such that transpiration is rapid and normal. The longer or shorter course of the disease in spring may be said to depend largely, therefore, upon the greater or less susceptibility of the tissues of the host, mostly resulting from atmospheric influences. The injury which the fungus may do after infection is also dependent, where development of the fungus has not progressed too far, upon a very nice balance of the atmospheric conditions. Newly infected leaves may be greatly distorted and fall at an early date, or they may be only slightly injured by the fungus, according to the atmospheric conditions prevailing and their influence toward softening or hardening the tissues and moistening the intercellular spaces of the host. A few days favorable to the drying and toughening of the parenchyma of the infested leaf may entirely check the spread of the fungus. The action of the mycelium of *E. deformans* upon the tissues of the leaf and branch of the peach has been widely remarked. The hypertrophies of peach branches, due to this parasite, are as striking and characteristic as are the witches' brooms caused on other hosts by various *Exoasceæ.* In the case of the peach, however, there is rarely if ever any increase noted in the number of shoots, as upon the cherry, the hypertrophy manifesting itself in enlargements and twistings of the infested branch. There is often a great reduction in the length of the infested portion of the shoot and a shortening of the internodes, so that the approximated and enlarged leaves give a tufted or plumed appearance to the shoot. An examination of transverse sections of such enlarged shoots shows that the enlargement is due to a great increase in the number of cells of the cortical parenchyma, and frequently an entire separation of such cells into a network or series of chainlike cells. The structure of the infested parenchyma is altered, the cells being enlarged and much more angular than normally, while the thickness of the tissue from the bast fibers to the epidermis is frequently eight or ten times as great as usual. The parenchyma cells lose the chlorophyll and all matter which the eye can detect, becoming quite transparent. The cell walls vary much more in thickness than normally, some of them being heavier and others lighter than in healthy cells. Transverse and longitudinal sections of swollen peach twigs show that the pith cells are greatly injured along the course of the infesting mycelium. The location of the mycelium may often be detected by treating transverse sections with Bismark brown, the infested medullary tissue taking less stain than that not harboring the fungus. The walls of the healthy cells of the medulla become reddish brown, while those of the infested tissue assume scarcely more than a light yellow or yellowish brown. The cells of the infested tissue are also much more angular and irregular than those in which the mycelium does not exist, while in some instances the cells collapse.

The action of *E. deformans* on the tissues of the peach leaf has been considered by different writers, as Prillieux,[1] Knowles,[2] and others.

[1] Prillieux, Ed., Mal. d. Plantes Agr., Vol. II, pp. 394–400; also Bull. de la Soc. Bot. de France, 1872, T. XIX, Comp. Rend. d'Sci., 3, pp. 227–230.

[2] Knowles, Etta L., Bot. Gaz., 1887, Vol. XII, pp. 216–218, with plate.

The badly infested leaves become greatly increased in thickness and breadth and the weight is often much increased above the normal, the tissues become stiffened in a coriaceous or cartilaginous manner, the cell walls become greatly thickened, and the cells become more compressed. The cells of the palisade tissue are increased in size and number, and suffer an entire loss of chlorophyll, as in the case of the cortical parenchyma of the branch. The walls of the epidermal cells become considerably thickened and the multiplication of the parenchyma cells on either side of the midrib causes a pronounced gathering and distortion of these tissues. As the midrib does not elongate in proportion to the increased extent of the parenchyma, it acts as a gathering string passing through the leaf from end to end, and the parenchyma becomes folded upon itself. The increase in the number of cells occurs more extensively among the palisade tissue of the upper half of the leaf than among the cells of the spongy parenchyma of the under leaf surface; hence the majority of badly diseased leaves are convex above and concave below, though this appearance is often lost sight of, owing to the number and variety of folds which the leaf blade assumes.

CHAPTER III.

HISTORY OF THE TREATMENT OF PEACH LEAF CURL.

THE EUROPEAN SITUATION.

That the present outline of the gradual development of methods for the treatment of peach leaf curl in the United States may be properly appreciated, it is desirable to first show the conditions prevailing in Europe as presented by some of the leading European writers on plant diseases. Prillieux, in an interesting paper on peach leaf curl, prepared in 1872, describes the fungus *Exoascus deformans* and its action on the tissues of its host.[1] He states that the fruiting fungus should be looked upon as the center of infection, and that it is desirable to remove the diseased leaves as thoroughly as possible and to destroy them. He also states that this work should be supplemented by the cutting off and burning of diseased branches. In 1878 Winter[2] stated that the only way to prevent this disease is to destroy the fungus by carefully removing the affected leaves, and by protecting the trees from rain during the unfolding of the leaves, as rain favors the spread of the parasite. The same year Felix von Thümen wrote of *Exoascus pruni*, the fungus causing plum pockets and closely related to *Exoascus deformans* of the peach,[3] but made no recommendations for its treatment. In 1885, however, he again spoke of the plum pocket disease and pointed out that it can not be removed except by severe cutting back of the new and old wood of the affected trees.[4] In 1880–81 Frank, in the second volume of the first edition of his work on plant diseases, recommends the cutting back of the twigs as a cure for leaf curl, and the quick removal of the diseased leaves for prevention.[5]

In 1886 the well-known work of Sorauer on plant diseases[6] appeared. The treatment recommended by this author is somewhat similar to that recommended by Frank. He says, in speaking in a general way

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[1] Prillieux, Ed., Bull. de la Soc. Bot. de France, 1872, T. XIX, pp. 227–230.

[2] Winter, Dr. Georg, Krankheiten der Kulturgewächse, Leipzig, 1878, p. 47.

[3] Thümen, Felix von, Die Pilze und Pocken auf Wein und Obst, Berlin, 1878, III, Fungi Pomicoli, pp. 88, 89.

[4] Thümen, Felix von, Die bekämpfung der Pilzkrankheiten unserer Kulturgewächse, Vienna, 1886, p. 71.

[5] Frank, Dr. A. B., Die Krankheiten der Pflanzen, Breslau, 1880–81, Theil II, p. 526.

[6] Sorauer, Dr. Paul, Handbuch der Pflanzenkrankheiten, second edition, Theil II, p. 281.

of the *Exoascea*, that it has been proved that the mycelium winters over in the youngest parts of the shoots and in the buds, and he recommends the removal of isolated slightly diseased leaves soon after the first appearance of the blister-like swellings. When through the attack of a majority of the leaves of a branch it is shown that the mycelium is already present in the axial organs, it is advised that all of the young wood of the affected branches be cut off. Hartig described peach leaf curl in 1889,[1] and again in the English edition of his work published in 1894,[2] but he leaves the subject without making any suggestions as to treatment. In 1890 Dr. Kirchner published a work on plant diseases,[3] in which he recommends the cutting off of diseased branches for the control of the disease. In 1891, Dr. Comes, in writing of this disease, states that no direct means for combating the parasite exists. He discusses the gathering and burning of diseased and fallen leaves, the cutting back of infected branches, and the application of cultural methods in their influence on the disease.[4] A most excellent work on plant diseases by Dr. Tubeuf appeared in 1895.[5] This writer groups the diseases caused by the *Exoascea* among those maladies which should be combated by the removal of the diseased living plants and plant parts (pp. 86, 87). The second edition of Frank's work on plant diseases appeared in 1896, fifteen years after the publication of the first edition, but the same recommendations for the treatment of curl are again made, word for word.[6] In all the preceding works there is no recognition of the methods of treatment being adopted and discussed in the United States and in Australia. The recommendations for cutting away the diseased branches so generally presented are the same as advanced by Ehrenfels nearly a century before for the control of mildew of the peach.[7]

It is hardly necessary to say here what most orchardists have learned by experience, that is, that it is impossible to eliminate the disease by ordinary cutting back of the branches, and that in the orchard it is equally impracticable to prevent the disease by the early removal of the diseased leaves.

About this time the work being done on this disease appears to have attracted the attention of Europeans. In 1894, in his work on vegetable parasites, Berlese recommends for this disease in Italy the use

[1] Hartig, Dr. Robert, Lehrbuch der Baumkrankheiten, Berlin, 1889, pp. 118, 119.

[2] Idem, The Diseases of Trees, London, 1894, pp. 132, 133.

[3] Kirchner, Dr. Oscar, Die Krankheiten und Beschädigungen unserer landwirtschaftlichen Kulturpflanzen, Stuttgart, 1890, p. 324.

[4] Comes, Dr. O., Crittogamia Agraria, Naples, 1891, Vol. I, pp. 167, 168.

[5] Tubeuf, Dr. Karl Freiherr von, Pflanzenkrankheiten durch kryptogame Parasiten verursacht, Berlin, 1895, pp. 86, 87, and 184.

[6] Frank, Dr. A. B., Die Krankheiten der Pflanzen, second edition, Breslau, 1896, Bd. II, pp. 249, 250.

[7] Ehrenfels, J. M. Ritter von, Ueber die Krankheiten und Verletzungen der Frucht- oder Gartenbäume, Breslau, 1795, p. 225.

of Bordeaux mixture in the spring, although he adds, as if doubting its utility, that the mycelium of the parasite winters over under the cortex of the branches.[1]

In France, in 1895, Prillieux published the first volume of a work on plant diseases, devoting several pages to the consideration of peach leaf curl.[2] In this work the recommendations for treatment appearing in his paper in 1872 are not given, but instead it is stated that treatments with the salts of copper seem sometimes to produce good results in preventing the multiplication by spores; but, as in the case of Berlese, he adds, as if in doubt of the value of such treatments, that they are without effect upon the perennial mycelium hidden in the tissues.

By the year 1898 the true idea of the preventive treatment of curl had been grasped in Germany. Professor Weisz, in his paper on plant diseases,[3] published that year, cites the present method of controlling curl. After renewing the older recommendations to cut off and burn the affected twigs, he says that the trees should be sprayed with copper-soda or copper-lime solution (eau celeste or Bordeaux mixture), the first time *before* the buds open. That these recommendations are not the results of work done by Weisz, however, appears probable, for his description of the disease is evidently quoted, as he falls into the error of Winter, Frank, Kirchner, and other writers in stating that the bloom produced by the fruiting of the fungus appears upon the under surface of the leaves. Had he worked upon this disease in the field he would not have been apt to follow the above authors in their erroneous description of the fruiting habits of the parasite.

DEVELOPMENT OF THE PRESENT METHODS OF TREATMENT.

The successful treatment of peach leaf curl dates from the time when fungicides were first applied to dormant peach trees. So far as learned, this treatment was first practiced in California, being introduced by the winter application of sprays for the destruction of the San José scale (*Aspidiotus perniciosus*). This insect was first discovered in the Santa Clara Valley about 1870, but some time had elapsed between the date of its introduction and the use of the stronger winter sprays for its control.

Caustic soda and potash were early tested against this insect, and afterwards sulphur was added, the sulphides of potassium and sodium being used by many growers. Somewhat later whale oil soap and sul-

[1] Berlese, A. N., I Parassiti Vegetali delle Piante Coltivate o Utili, preface dated 1894, pp. 124–126.

[2] Prillieux, Ed., Mal. d. Plantes Agr., Paris, 1895–97, pp. 394–400.

[3] Weisz, J. E., Die schädlichsten Krankheiten unserer Feld-, Obst-, Gemüse- und Garten-Gewächse, München, 1898, p. 45.

phur were combined by boiling, and still later a caustic spray containing lime was tested. All the above chemicals, even the milk of lime, were applied to dormant trees, and they are all known to possess sufficient fungicidal action to control peach leaf curl to a large extent if applied to the trees shortly before they bloom.

While many growers were using these caustic and sulphide sprays, another spray containing much larger quantities of sulphur was being used, and proved of much greater power, both as a fungicide and insecticide. This was a spray containing sulphur and lime, or a sulphide of calcium, and the history of its introduction is of special interest and is inseparable from the early history of the treatment of curl. Mr. Alexander Craw, quarantine officer of the California State Board of Horticulture, has published an account of the introduction of this spray in a recent number of the Pacific Rural Press,[1] but the following facts were gleaned from those who were the first to use and introduce the spray.[2] Mr. A. T. Covell, who first applied this spray to dormant peach trees, near Fresno, Cal., does not supply exact dates relative to the work, but Mr. N. W. Motheral, of Hanford, and Mr. I. H. Thomas, of Visalia, agree in placing its first use as a spray in the year 1880 or 1881. The writer is informed by Mr. Motheral that the lime, sulphur, and salt solution was originally used as a sheep dip in Australia, where it was known as the "Victoria lime-and-sulphur-dip" for scab. He states that it was recommended by a Dr. Rowe, and officially indorsed for a sheep dip in that country. This dip, it is also said, was introduced in California by Mr. Charles Hobler, of Hanford, and Mr. Hobler claims to have first recommended it to Mr. Covell, then living near Fresno, for the treatment of his infested peach trees. Mr. Covell disputes this claim, but holds that he (Covell) first used this solution as a spray upon his trees with success in the control of the San José scale. As soon as this spray was found to be a practical success, Mr. Covell, Mr. Thomas, and Mr. Motheral worked for its general adoption in the treatment of scale. Mr. Thomas states that he sprayed his own orchard the winter after seeing the action of the spray on Mr. Covell's trees, and about this time the facts were given to the press. Mr. Thomas writes that this spray was in general use in and about Visalia as early as 1883, 1884, and 1885, and in Mr. Motheral's section, near Hanford, at the same time. It may here be stated, however, that lime and sulphur had been united by boiling in water and used as early as 1852, at least in hothouses, for controlling the diseases of plants. (See Revue Horticole, 1852, p. 168, and Gardeners' Chronicle, 1852, p. 419.)

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[1] Pacific Rural Press, July 29, 1899, p. 68.

[2] Letters from I. H. Thomas, Visalia, Cal., Sept. 6, 1899; N. W. Motheral, Hanford, Cal., Sept. 6, 1899; and A. T. Covell, Woodbridge, Cal., Oct. 13, 1899.

It will be seen by the preceding outline that strong fungicidal sprays were in general winter use upon peach trees throughout much of California in the years 1880 to 1885, during which time the peach orchards of many portions of the State were badly affected by curl. In a report by Mr. W. G. Klee, who inspected the orchards in many counties of California from July to September, 1886, it is stated that in Alameda County the cultivation of peaches must be confined to such varieties as are very little subject to leaf curl; in Santa Cruz County, that "peaches, of course, are subject to curly leaf, and can not, as a general thing, be considered profitable;" and that in the Santa Rosa Valley the peach is "of course subject to curly leaf."[1]

As peach leaf curl was quite prevalent throughout California in 1880–85, and as a large number of peach growers treated their dormant trees with fungicidal sprays during that period, it is not strange that they soon learned that the winter sprays prevented curl. Mr. I. H. Thomas, of Visalia, informed the writer[2] that it was about the year 1885 that he noticed that the orchards sprayed with the lime, sulphur, and salt solution were entirely free from leaf curl, while orchards contiguous were affected so badly that all the foliage fell off.

In 1886 Mr. W. G. Klee said,[3] when speaking of an inspection he made of the orchard of Mr. A. Block, of Santa Clara, Cal.: "A treatment of peaches affected with curly leaf attracted my attention. Trees not subjected to this treatment were in very poor condition, while the others, favored with it, were in fine, healthy bearing." Mr. Block says respecting this work[4] that he was making experiments for the destruction of scale insects when he detected a perceptible difference in the amount of curl on the treated and the untreated trees. He thinks this was one or two years before Mr. Klee had seen his trees in 1886. After having noticed the action of the sprays applied for scale in the prevention of curl, he went to work to ascertain what particular ingredient caused the prevention of the fungous disease. These direct experiments, Mr. Block states, were carried out on a row of 23 trees in his orchard. Among the chemicals tested were caustic soda, caustic potash, carbolic acid, tobacco, and sal soda, all more or less combined with whale oil. Among the numerous sprays used, Mr. Block thinks that a strong solution of caustic soda gave the best results. All these sprays were applied while the trees were dormant.[5] The stronger

[1] Klee, W. G., Reports and Papers by the Inspector of Fruit Pests, read at Sacramento, November, 1886, Rept. Cal. State Bd. Hort., 1885–86, pp. 344, 347, 349, 350.

[2] Letter dated Visalia, Cal., Sept. 6, 1899.

[3] L. c., p. 347.

[4] Letters dated Santa Clara, Cal., Sept. 1 and 10, 1899.

[5] It may be noted that whale oil soap was thus used by Mr. Block with success against curl in 1885 and 1886. Prof. L. R. Taft, in a letter dated Agricultural College, Mich., Aug. 31, 1899, says that he had good results in the treatment of curl with limewater, lye, and whale oil soap. (See also records of experiments by the writer with milk of lime, etc.) Mr. F. M. Webster reports satisfactory results with whale

caustic spray recommended by Mr. Block consisted of 1 pound of 98 per cent caustic soda to 6 or 7 gallons of water. The same year, 1886, Mr. Sol. Runyon, of Courtland, Cal., reported that he had met with success in controlling a "blight" of peach trees, the name of the disease not being known to him. This blight had previously caused all the leaves to fall from every tree he had, especially the young ones. He used a caustic spray on the dormant tree, as did Mr. Block, and states that the trees which he treated were not affected by the blight at all, while the untreated trees, right beside the treated ones, were badly affected.[1] There is little doubt that Mr. Runyon was treating curl, as it is a very serious trouble in that section of the State. After the leaves had fallen in the autumn of 1886 and during the winter of 1886–87, Mr. Runyon sprayed many of his peach trees with a spray composed of 2 gallons fish oil, 10 pounds of caustic soda (98 per cent), and 5 pounds of copper sulphate to 100 gallons of water. This spray, as applied, was certainly a preventive of curl, and as a portion of his peach trees were left untreated the contrast should have been marked. Unfortunately, however, I have been unable to get further details of this early work with copper sulphate, as Mr. Runyon is no longer living.[2]

In November, 1888, Mr. W. G. Klee stated at the Chico meeting of the California State Board of Horticulture, that an experienced and successful fruit grower in San José had used successfully for the purpose of killing scale insects, the so-called sal soda and whale oil wash, and that he maintained that ever since he had been using that wash he had been free from leaf curl in his orchard.[3] Mr. Joseph Hale, of Stockton, Cal., reports[4] that he sprayed his peach trees, while dormant, in the years 1888, 1889, and 1890, as well as in subsequent years, and that as a result he sustained no loss from curl during these years. He used the lime, sulphur, and salt spray. Mr. G. W. Ramsey, of Lotus, Cal., states that he began spraying his orchard with lime, sulphur, and salt in 1890 or possibly in 1891. In 1895, in writing of his past spray work, he states that his trees had not been affected in the least by leaf curl since he had been using the above wash. He says: "It completely exterminated the scale the first two years I used it, but I continue to apply it to my trees once a year to prevent leaf curl." He further states that this wash must be applied when the buds are dormant, and that it is generally applied in February in his section.

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oil soap (South Australian Journal of Agriculture, March, 1899, Vol. II, No. 8, p. 630); see also the results reported by Henry Rofkar and W. V. Latham & Son, of Catawba Island, Ohio, as reported by A. D. Selby, Bull. No. 104, pp. 208, 209, Ohio Agr. Exp. Sta., March, 1899.

[1] Rept. Cal. State Bd. Hort., 1885–86, p. 221.

[2] Ibid., 1887–88, p. 93.

[3] Rept. Cal. State Bd. Hort., 1889, p. 172.

[4] Reply to circular letter of Nov. 25, 1893.

As early as 1890 the effectiveness of lime, sulphur, and salt against curl appears to have been observed in Oregon. Mr. J. D. Whitman, of Medford, Oreg., who was horticultural commissioner for the third district of that State, wrote under date of January 27, 1894, that four years' observation as commissioner had demonstrated beyond a doubt that a spray of lime, sulphur, and salt is an effectual remedy for leaf curl. He states that the application in every instance was made for the purpose of destroying the San José or pernicious scale, and generally on only a portion of the orchard, the other portion showing the curl as usual.

The first practical experiments with copper sprays on dormant trees for the control of curl, after the sprays applied by Mr. Sol. Runyon in 1886 and 1887, were conducted, so far as learned, in the year 1890. The summer use of these sprays had been tested in Australia, and probably elsewhere, for several years, but with slight success in the control of curl.

About the 1st of December, 1889, Mr. L. E. Benton, then of Berkeley, Cal., wrote to the United States Department of Agriculture for information relative to the nature and treatment of curl. These inquiries were answered at length, the literature on *Exoascus deformans* being quite fully cited. No method of controlling this disease was then known at Washington, and as winter spraying had not yet reached its present importance, the recommendations for treatment were necessarily inadequate, and were based upon the then accepted views respecting the strict perennial nature of the mycelium of the fungus, and the consequent difficulty of controlling the parasite by sprays.

After gathering such information as he desired, Mr. Benton instituted a series of spraying experiments in the university orchard at Berkeley in the spring of 1890. The work done by Mr. Benton, although limited in extent, was of the utmost practical importance, as well as of great theoretical interest. A summary of his results was published in August, 1890.[1] Three copper sprays were tested, the ammoniacal copper carbonate, basic copper acetate solution, and Bordeaux mixture. The ammoniacal copper carbonate was applied on February 28, 1890, before the opening of the buds. All three of the sprays mentioned were also tested soon after the leaves started. The results demonstrated that winter treatment of the trees with the salts of copper will effectively control the disease, but that summer treatment will not control it, and also that infection of the spring growth by perennial mycelium was the exception and not the rule with this disease—facts of the utmost practical importance for the orchardist. Mr. Benton's studies likewise led him to the view that the mycelium, passing from infected leaves to the stem, is able to infect new foliage

[1] Pacific Rural Press, Aug. 2, 1890.

by following close behind the growing point of the stem. His observations seemed to point to this young mycelium, resulting from the first spring infections, as the source of the later infections through the branches rather than the perennial mycelium of the previous year. He says that not only does the fungus live in the leaf of the peach, but it at once pushes its way into the young growing stem, following the growing point as fast as it lengthens and passing into the leaves as fast as they appear. On this account he concludes that no external applications can stop such a fungous growth, and spraying after the buds burst and the fungus has become established will have little effect. It may be added that several years' observation in large blocks of trees sprayed after the foliage had started has shown the writer that the disease can not thus be controlled, and that Mr. Benton's conclusions are correct. Whether this failure is due to the causes pointed out by Mr. Benton, however, or simply to the lack of the prevention of the infection by spores, or to both sources of infection, should be given further study. Mr. Benton states that in the spring of 1890, the time his experiments were undertaken, "no remedy was known; since, some practical growers have found successful means of combating it, and these experiments now deserve no further credit than that they were intentional and not a matter of chance." It is now known that curl had been controlled by numerous growers in widely separated regions in California through the use of various sprays many years prior to 1890. Mr. Benton says he was unaware of these facts when he began his work, and his experiments are worthy of full credit, not alone for the enterprise shown in undertaking them, but for the results of unquestioned value to which they led.

In 1891 the copper treatment for peach leaf curl was independently discovered and clearly demonstrated in Australia. The successful results of this work were observed in November and December, 1891, and were published in the South Australian Register of March 30, 1892. At a meeting of the Nuriootpa branch of the South Australian Agricultural Bureau, held in Angaston during November, 1890, the subject of fungous diseases affecting fruit trees was discussed and the appointment of a committee to conduct preventive experiments was considered. At a subsequent meeting Messrs. F. C. Smith, W. Sage, and A. B. Robin were selected for this work. During the interval before spraying, Mr. Smith corresponded with those in charge of the pathological departments in Australia, England, California, and Washington. The report in the South Australian Register says that among the replies received was a series of valuable reports from Professor Galloway, showing that up to 1889 modified eau celeste, ammoniacal copper carbonate, and Bordeaux mixture had proved most successful in the United States. "These were therefore selected by the committee for their experiments." Mr. Smith, of this committee, informed the writer that their work was based largely upon that of Prof. E. S. Goff on Fusicladium.[1]

The spray work was begun in July, before the trees leafed out, the main object being to control apple scab and the shot-hole fungus on the apricot. The sprayed apricot trees belonged to Mr. Trescowthick, and were treated with Bordeaux mixture. In the block was one peach tree, which was sprayed when the apricots were treated. This tree had suffered severely from curl, so much so, in fact, that it had not borne for four or five years, but after spraying it yielded eight cases of fruit of 50 pounds each, or 400 pounds, the curl being almost entirely prevented. Mr. Smith writes, respecting this work, that when applying Bordeaux mixture from July to October, 1891, for the various diseases with which they were coping he had not the slightest idea that this or any of the fungicides would have any effect whatever on curl leaf, and the members of the committee were the more surprised to see its marvelous effects in January and February. "It was the most conclusive of all our tests," it was stated.[2]

The work was continued the following season, and some contrasts obtained on the place of Messrs. Sidney Smith & Son, of Yalumba, are of interest in this connection. In an article published at that time it is stated that the effects of spraying with Bordeaux mixture upon both peaches and apricots were very noticeable. On one side of the fence was seen a healthy set of trees, well clothed with fruit and dark green foliage, and with no curled leaves, while on the other side, where spraying had not been done, was a block of apricots, among which were a few peach trees very badly attacked by leaf curl. At this time the orchard of Mr. A. B. Robin, of Nuriootpa, secretary of the committee for experiments, was inspected by Mr. Molineaux, general secretary of the South Australia Agricultural Bureau, and by several prominent horticulturists, and was found to have a splendid crop of fruit, nearly all the apricot and peach trees having been sprayed. One peach tree had been sprayed on only one side with the Bordeaux mixture, and on this side the foliage was clean and healthy, while on the unsprayed side it was curled. "Here again," says the reporter of this examination, "was absolutely conclusive evidence of the preventive effect of spraying for curl leaf."

In the United States, in 1892, the use of both the sulphur and copper sprays on dormant trees was much more common. The control of curl was a new discovery to several growers who had not heard of the published experiments. Mr. George Woolsey, of Ione, Cal., had been considerably troubled by a shot-hole fungus affecting peach twigs—a common trouble in the northern portion of the State. A bundle of the affected twigs was sent to Professor Woodworth, of Berkeley, who

[1] Letter dated Angaston, South Australia, Feb. 11, 1895.

[2] Letter dated Angaston, South Australia, Apr. 6, 1895.

advised the use of Bordeaux mixture; but as this fungus is active in the spring before the trees leaf out, Mr. Woolsey sprayed the trees while dormant. He says, in relation to his results, that he found Bordeaux mixture corrected the trouble with the twigs, and at the same time acted as a specific for the leaf curl.[1] His work for the control of curl in the following year was strikingly conclusive as to the effectiveness of this spray. Mr. D. W. Sylvester, of Geyserville, Cal., conducted some spraying experiments in 1892 with the direct object of controlling curl. His spray was composed of 12 pounds of copper sulphate and 20 pounds of lime to 100 gallons of water, and was applied to the dormant trees. Mr. Sylvester states that having formed the opinion that the disease was of fungous nature, and knowing of the value of copper sulphate as a fungicide, he determined to test it against curl. He believed better results would be obtained by killing the "germ" than by waiting until the disease appeared, and this, he says, induced him to make the application to the dormant trees. For the experiment he selected a row of 10 trees, spraying 5 and leaving 5 unsprayed for comparison. He states that the 5 sprayed trees held their leaves and fruit and bore a crop, but the others shed every leaf and every peach, and for more than a month looked as if a fire had gone over them. In spite of this experience, Mr. Sylvester neglected to spray in 1893, when, he states, the trees shed all their leaves and nearly all their fruit through curl,[2] and adds that the best time to spray is just as the buds begin to swell. A portion of the peach trees on the Rio Bonito ranch at Biggs, Cal., were sprayed with the lime, sulphur, and salt spray in 1892, the spray being applied to the dormant trees as elsewhere. The contrast that season between the sprayed and unsprayed trees was well marked, the unsprayed trees being much affected by curl, while those treated were practically free from it. These observations were made at the time by Mr. McDonald, the foreman, and by others on the ranch.

The preceding examples could be greatly extended if necessary, as winter spraying was a common practice in California after 1885. By 1892 the San José scale had also become more widely distributed in Oregon, and was being quite generally treated by winter sprays in that State. Mr. A. H. Carson, of Grants Pass, Oreg., began spraying his orchard about this time. In reply to a communication sent to him November 25, 1893, Mr. Carson says that his knowledge as to the lime, sulphur, and salt remedy for leaf curl was gained by observing that trees on which this remedy was used to destroy the San José scale were not affected by curl, although they were varieties much subject to the disease. On the other hand, he states that unsprayed trees, with the same conditions as to exposure, altitude, etc., were badly affected. Mr. J. H. Stewart, of Medford, Oreg., writes that he sprayed his peach

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[1] Letter dated Ione, Cal., Aug. 26, 1899.

[2] Letters dated Geyserville, Cal., Nov., 1893, and Sept. 18, 1899.

trees in 1892.[1] He says he used a spray in 1892, 1893, and 1894, which was effectual against scale and most fungi. This spray was composed of lime, sulphur, and sulphate of copper, and was applied in the winter.

In the East, about this time, mildew, brown rot, black spot, rust, and curl were attracting the attention of peach growers and causing serious losses in some sections, and a good many growers were trying summer sprays for the control of one or more of them. Mr. F. P. Herr, of Ridgely, Md., writes[2] that for three successive years prior to 1895 he sprayed with limewater, Bordeaux mixture, and arsenical mixtures, and that everything he used produced absolutely negative results, except the arsenites, which injured both foliage and fruit. It would appear probable from these results that the sprays were applied too late to be effective against curl. Mr. L. B. Geiger, of Hoffman, Pa., writes[3] that he was formerly troubled with leaf curl in his orchard, but has had very little of late years. The reason of this, he thinks, is the fact that he has sprayed his peach trees with Bordeaux mixture several times each year since 1892. He states that at least 75 per cent of the crop of one variety was thus saved. Whether the spray work was done in the winter, or whether, owing to the number of applications made, the summer spray persisted in its action through the following winter, is not known.

It was in 1892 that Prof. L. R. Taft, of the Michigan Agricultural Experiment Station, first obtained the idea that peach leaf curl could be controlled by the application of winter sprays. This gentleman has supplied the leading facts respecting his work.[4] He says: "In 1892 I was making a series of experiments with Bordeaux mixture and solutions of copper sulphate to learn the strength that could be used upon various plants and trees without injury. These materials were applied at different times, the sprayings being at intervals of about four weeks, from April to July, and while some trees received but one application, others were sprayed two, three, and four times. It was noticed, the trees sprayed in April with either copper sulphate or Bordeaux mixture had no curled leaves, while unsprayed trees and those that were not sprayed until June or July were seriously injured by leaf curl.

"From the marked difference in the injury from the leaf curl to the sprayed and unsprayed trees, I felt very confident that the disease could be held in check to a large extent by the use of fungicides, and in writing Bulletin 92, in December, 1892 (published in March, 1893), I make the statement that 'it is quite certain that the disease can be, to some extent, held in check by their use,' in referring to the effect

[1] Letters dated Medford, Oreg., Dec. 14, 1894.
[2] Letter dated Ridgely, Md., Feb. 15, 1895.
[3] Letter dated Hoffman, Pa., Mar. 18, 1895.
[4] Letter dated Agricultural College, Mich., Aug. 31, 1899.

of fungicides in preventing the development of leaf curl on peach trees."

It would seem that the work in Australia, as well as that of the preceding ten years in California, had not come under the notice of Professor Taft at the time of his observations in 1892, and that the same was true at the close of the succeeding year's experiments. In his article on curl, published in the American Agriculturist for February, 1894, he says,[1] in speaking of the treatment of curl prior to his work in 1893: "Although there were some vague suggestions as to the possible value of some of the fungicides as remedies for this disease, nothing was really known until the past season."

May 20, 1893, while working on plant diseases at Yuba City, Cal., in company with Mr. R. C. Kells, then horticultural commissioner of Sutter County, that gentleman told the writer of a peach orchard in the vicinity where peach leaf curl had been controlled by the previous winter's sprays. The orchard was that of Mr. W. H. Campbell, of Yuba City, and was at once examined by the writer in company with Mr. Kells. The trees were of the Orange Cling variety, and had been sprayed with lime, sulphur, and salt up to the base of the smaller branches of the main limbs, for the purpose of killing the San José scale upon the older wood, the spraying of the tops of the trees not being necessary. The result of this treatment was to protect the lower half of the trees from the attack of curl, while the tops were left unprotected. Curl developed seriously in the Sacramento Valley that spring, and as a consequence these trees were badly diseased and stripped of foliage down to the line where the limbs had been sprayed for San José scale. The resulting appearance was most striking, and showed the advantages of spraying in a marked degree. The lower half of the trees was well supplied with normal green foliage, while the upper half was either bare or the leaves present were yellow and badly curled. Photographs of these trees were taken on May 21, 1893.

May 22, 1893, the writer visited the Riviera orchard, at Live Oak, Cal. This orchard is situated on the Feather River bottom and is under the management of Mr. A. D. Cutts, of Live Oak, one of the proprietors. In this orchard was found a most striking case of the prevention of curl by the use of winter sprays. In the winter of 1892–93 one block of trees was thoroughly sprayed for San José scale with lime, sulphur, and salt. After this work was completed the weather became unfavorable for further spraying. The soil was so wet from rains that a 40-acre block of Crawfords Late trees could not be sprayed, and it was so late in the winter before the work could be done that Mr. Cutts feared it might injure the fruit buds if he sprayed the trees entire. He therefore had the trees in this block examined, and rags were tied upon the limbs of those which appeared to most need a thorough

[1] The Curl of the Peach, American Agriculturist, Feb., 1894, pp. 71, 72.

spraying for scale. These marked trees were scattered, here and there one, throughout the entire 40-acre block. In February the marked trees were very thoroughly sprayed over all parts, as much as two gallons of spray being applied to each tree. After this work was completed the entire block, with the exception of the trees already treated, was sprayed as high as the forks of the main limbs, thus avoiding any injury to swelling buds. As before stated, curl developed seriously in the Sacramento Valley in the spring of 1893, and the result was that the unsprayed trees, as well as those sprayed only on the main limbs, were nearly denuded by the disease, while the scattered trees which had been sprayed throughout were in full and vigorous foliage and growth. In the writer's notes upon the examination of this orchard on May 22, 1893, it is stated that the trees fully treated in this block were loaded with fruit and in full leaf, while the trees sprayed only to the forks of the limbs were nearly bare and almost wholly destitute of fruit on the unsprayed parts. Such fruit as was found on the unsprayed branches was inferior in size and quality. It is further stated that the absence of fruit on the untreated branches as compared with the abundant yield of the treated branches gives such a striking contrast as to be almost beyond belief.[1]

Mr. William N. Runyon, of Courtland, Cal., treated a large acreage of peach trees with lime, sulphur, and salt in the winter of 1892–93. He states that the trees sprayed once while dormant were practically free from curl, while trees of the same variety not sprayed were badly affected.[2] He also gives an observation of interest in connection with the habits of the fungus, and one since indorsed by the writer, that is, that the disease "will not spread from an unsprayed to a sprayed tree." In letters from Mr. Runyon[3] relative to this work, he remarks that although he had heard that a mixture of lime, sulphur, and salt was beneficial in controlling curl, he had no idea that the result would be so nearly a complete prevention. He says that it was only when curl leaf had become quite prevalent on unsprayed trees that he noticed its almost total absence on those that had been sprayed. The most striking instance, he states, was where about 50 three year old nectarine trees stood in rows adjoining about a dozen full-grown trees of the same variety that had shown curl for years. The young trees, not having shown any scale, were left unsprayed, and were a mass of curl, while the old trees, which were given the regular treatment, were almost entirely free. In this orchard about 60 acres of peach trees were also sprayed, the work being done about the 1st of

[1] For further notes and tabulated records of some of this work of the spring of 1893 the reader is referred to Chapter VII under Notes on the Auxiliary Experiments in California.

[2] Answer to circular letter of Nov. 25, 1893.

[3] Letters dated Courtland, Cal., Jan. 31, and Mar. 8, 1894.

February, and 40 acres of young trees left unsprayed. In the Santa Clara Valley the sulphur sprays were in general use by the leading growers in 1893. Mr. A. B. Elder, of Santa Clara, writes, in reply to a circular letter of November 25 of that year, that this spray is giving good satisfaction for the control of curl and "is used by large growers of peaches." Mr. John Rock, of Niles, Alameda County, Cal., writes, under date of December 28, 1893, that a mixture of lime, sulphur, and salt is a preventive of curl if applied before the flower buds expand.

Bordeaux mixture was used in the winter of 1892–93, in the Carmel Valley, near Old Monterey, with the express purpose of controlling curl. Mr. Daniel Snively, of Gubserville, Cal., writes[1] that his brother used Bordeaux mixture for the control of this disease, and that its action is "so certain that any twig not touched is sure to curl." Mr. George Woolsey, of Ione, Amador County, Cal., sprayed his orchard with Bordeaux mixture in the winter of 1892–93, for the express purpose of controlling curl, and as a result of his experiments in the winter of 1891–92, to which reference has already been made. Relative to his work in the spring of 1893, Mr. Woolsey says[2] that he sprayed all of his apricot trees, but as time pressed he found that he would not be able to spray all of his peach trees, so he sprayed the most valuable portion, i. e., the young lower growth, and left the top unsprayed. He states that the season of 1893 was damp, and leaf curl very prevalent in his neighbors' orchards, but on his place all the trees and parts of trees sprayed were exempt, all the others being badly affected by curl and the crop on them almost a failure. A healthy growth on the lower sprayed part of the trees, and the branches denuded of foliage on the upper unsprayed part, formed "a most striking object lesson," and, Mr. Woolsey adds, has made him "an enthusiast on Bordeaux mixture." A few demonstrations such as he obtained in the season of 1893, he remarks, would convince the growers of the profitableness of the work.

Many peach orchards were sprayed in Oregon in the winter of 1892–93. A favorite spray was a combination of the sulphur spray with copper sulphate, although the former was used separately by some growers. The object of the combined spray was to unite, as far as possible, the insecticidal qualities of the sulphur spray with the fungicidal qualities of the copper salts.[3] The winter application of ammoniacal copper carbonate was tested in Oregon also, by Mr. M. O. Lownsdale, of Lafayette. In reply to the circular letter dated November 25, 1893, Mr. Lownsdale says he had fair success in preventing curl with lime, sulphur, and salt applied in the winter, followed

[1] Reply to circular letter of Nov. 25, 1893.

[2] Letter dated Ione, Cal., Mar. 26, 1894.

[3] See results of the tests of combined sprays made by the writer, pp. 84, 86, 117, 118.

by three applications of ammoniacal copper carbonate after the appearance of the foliage. He had better success, however, from ammoniacal copper carbonate applied in late winter, before the swelling of the buds, followed by three applications of a weaker solution upon the foliage. "This," he says, "was a complete success."

In Michigan the work in 1893 was very satisfactory. Mr. Charles Youngreen, of Whitehall, sprayed one row of peach trees before they leafed out in the spring. He states[1] that not one of the sprayed trees showed curl, while the unsprayed trees were all affected. The following year he sprayed the entire orchard and not a tree suffered from the disease. At Shelby, Oceana County, several growers sprayed with Bordeaux mixture with good success. Mr. R. Morrill, of Benton Harbor, stated at a meeting of the Michigan Horticultural Society held at Shelby, June 14 and 15, 1893, that he found there, in four or five cases, that men had sprayed peach trees with Bordeaux mixture, and the effect in decrease of leaf curl was plain to be seen.[2] Mr. Morrill fails to state, however, whether the first spraying was done while the trees were dormant. The effects of curl at Shelby at that time were marked, the same gentleman remarking that in one morning he had seen enough damage done by it to pay for spraying all the orchards within five miles.

Professor Taft reports his work in 1893 as follows:[3] "In order to secure definite knowledge upon the subject [treatment of curl], I arranged for a series of experiments, and in the fall of 1892 had a number of peach trees sprayed with a solution of copper sulphate (1 pound in 25 gallons), and in a similar experiment at South Haven Bordeaux mixture was used as soon as the leaves dropped in November, 1892. During the first half of April, 1893, the same trees were again sprayed with similar mixtures, and other trees were treated that had not been sprayed in the fall of 1892. The result was that where fully 50 per cent of the leaves and all of the fruit dropped from the unsprayed trees, there was little injury to the same varieties that were treated in both fall and spring or that were sprayed only once, in April; but where they were not sprayed until after the leaves had come out only a slight benefit was secured. The results were given in Bulletins 103 and 104 of the Station. On June 14, 1893, I gave the results, up to that time, at the meeting of the State Horticultural Society."

The orchards of the Michigan Agricultural Experiment Station at South Haven, in charge of Mr. T. T. Lyon, had suffered severely from curl in 1890, 1891, and 1892.[4] Mr. Lyon says, respecting the spray

[1] Letter dated Whitehall, Mich., Sept. 6, 1899.

[2] Rept. Mich. State Hort. Soc., 1893, p. 68.

[3] Letter dated Agricultural College, Mich., Aug. 30, 1899.

[4] See Repts. Mich. Hort. Soc., 1890, p. 144; 1891, p. 228; 1892, pp. 160, 161.

work done in the winter of 1892-93,[1] that as the apparent result of the fall and spring sprayings, there was almost a total absence of leaf curl, although it had usually been quite prevalent there in early spring, and was present in 1893 in neighboring orchards, causing many of the leaves and fruits to drop. He says[2] further, that to him "the effect of the spray upon leaf curl in particular was a revelation." The work of Professor Taft in this orchard in 1893 was reported on several occasions during 1893 and 1894.[3]

The work of the writer began in Michigan by the publication, in the fruit belt of that State, in the latter part of July, 1893, of notices of the work done in California,[4] and of requests for the names of peach growers who had sustained losses from this disease. In August, plans for experiments at Shelby and Ludington were in progress, and in November a circular letter, stating that leaf curl had been successfully prevented in California, was addressed to the peach growers of all the leading peach centers of the country. In this circular it was stated that "It is proposed to carry on during the coming season some work in different parts of the United States." The circular reached many of the leading peach growers of Michigan. During the winter, that of 1893–94, plans for the testing of winter sprays for the control of curl were undertaken by growers, at the request of this Department, at Whitehall, Albion, Ganges, Beulah, Riverside, Benton Harbor, St. Joseph, Kalamazoo, Covert, Hawkhead, South Haven, Ludington, Shelby, Douglas, Millgrove, Custer, Amber, Mears, Hart, Gobleville, Ortonville, Monterey, Fenville, Saugatuck, Allegan, Wayland, Bradley, Peach Belt, etc. During the winter of 1894–95 the above list was greatly extended. Within these two years over 400 Michigan peach growers were sent full instructions for controlling curl. Each grower was requested to make his tests according to an experiment sheet sent him, leaving unsprayed trees for comparison. In this way many striking object lessons were obtained, aiding materially in the early and widespread introduction of the methods of treatment recommended. Reports of a few of these experiments are given in a subsequent chapter.

The Department's tests in Ohio were instituted through a circular letter in November, 1893, announcing to a large number of peach growers in that State the successful treatment of curl in California, and stating that experiments would be undertaken in the East. As a result of replies to this circular, full instructions for controlling curl

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[1] Mich. Exp. Sta. Bull. No. 104, pub. Feb., 1894, pp. 64, 65.

[2] Letter dated South Haven, Mich., Dec. 16, 1897.

[3] Paper read at Shelby, June 14, 1893, Rept. Mich. Hort. Soc., 1893, pp. 66, 67, and 79; article in Allegan Gazette, July 1, 1893; Mich. Exp. Sta. Bull. No. 104, p. 64; pub. Feb., 1894; American Agriculturist, Feb., 1894, pp. 71, 72.

[4] Ludington (Mich.) Appeal, issue of July 20, 1893, quoted by Shelby Sentinel, etc.

were sent to a number of orchardists in the peach-growing centers of Ohio in the winter of 1893–94. During this and the succeeding winter over fifty orchardists, located in twenty-five different peach-growing centers of the State, received carefully prepared instructions for winter spraying for curl. The instructions for both winters were planned in the usual manner of experimental work, a number of unsprayed or control trees being left for comparison with the trees to be treated with each spray to be tested. The object in thus planning the work was the same as for that in Michigan and elsewhere—that is, to obtain such striking contrasts between sprayed and unsprayed trees that they would form long-remembered object lessons for all who should chance to see them.

The spray work of the Ohio Agricultural Experiment Station after 1890 was quite extensive; but the treatment of peach leaf curl is not mentioned in the bulletins on orchard spraying published by that station in December, 1891, and February, 1893,[1] although in the latter (Bul. No. 48, p. 12) the spraying of peach trees for other diseases is considered. In the spring of 1893, however, Prof. W. J. Green sprayed a considerable number of young peach trees, just planted, the object being "to determine the truthfulness of the statements that had been made concerning the effect of spraying upon peach trees." In relation to curl, Professor Green says that he "did not see any effect until the season of 1894," during which and in 1895 "there was some effect noticeable." He says further, in this connection: "I am aware that other work in this direction had been done before I commenced, because I received my suggestions from some other source, but I can not now recall the particular case." (Letter dated September 30, 1899.)

Upon these results obtained by Professor Green, and supported by the work of Benton in California and Taft in Michigan, were based the subsequent experiments of Prof. A. D. Selby in the orchard of William Miller, of Gypsum, Ohio.[2] These experiments were begun, according to Professor Selby, in April, 1895,[3] but no results with leaf curl were obtained until 1896,[4] as in 1895 there was no difference between sprayed and unsprayed trees in the amount of curl developing, it being so insignificant as to be without evident effect. The curl which developed in 1896 enabled Mr. Selby to obtain some contrasts between sprayed and unsprayed trees, but these contrasts were not as

[1] Green, W. J., The Spraying of Orchards, Ohio Agr. Exp. Sta. Bul. No. 9, Dec., 1891, Vol. IV, second series; Bul. No. 48, Feb., 1893, p. 12; and a letter from Professor Green, dated Wooster, Ohio, Sept. 30, 1899.

[2] Letter from Prof. A. D. Selby, dated Wooster, Ohio, Sept. 13, 1899.

[3] L. c.; also Ohio Agr. Exp. Sta. Bul. No. 92, March, 1898, pp. 237–245.

[4] Ohio Agr. Exp. Sta. Bul. No. 92, March, 1898 p. 245; also Thirtieth Ann. Rept. Ohio State Hort. Soc., pp. 87.

marked as they would have been had the disease developed seriously.[1] As it was light in 1895 and 1896, no gain in fruit was shown by sprayed over unsprayed trees these years. In 1897 the work was continued, and owing to the serious development of curl the desired contrasts in foliage were obtained. Unfortunately, however, the fruit buds had been killed by cold and no fruit records were obtainable. The first contrasts in fruit on sprayed and unsprayed trees in Mr. Miller's orchard were reported to Mr. Selby in 1898, and they are both valuable and conclusive.[2]

The announcement of the Department's work on leaf curl was sent to the growers of peaches in Illinois, Indiana, and Pennsylvania at the same time that it was sent into Ohio and other States of the East, viz, in November, 1893; and during the winters of 1893–94 and 1894–95, 135 peach growers in Pennsylvania, 81 in Indiana, and 36 in Illinois were requested to spray for the control of curl and report to the Department. A complete plan for these tests, control trees being provided for in every case, was sent to each of the growers. So far as reported, where instructions were followed, the results of this work were satisfactory in all cases where curl developed and where frost did not prevent the obtaining of results.

Winter spraying for the control of curl began in New York, so far as known to the writer, in the winter of 1893–94, during which and the following winter over seventy peach growers of the State received from the writer full instructions for the treatment. These instructions were sent out through personal correspondence with orchardists in over twenty of the peach-growing centers, and by means of carefully prepared circulars. Among others, Mr. W. T. Mann, of Barkers, undertook spray work for the Department in the winter of 1893–94. Carefully planned experiments were carried out by him in his young orchard, the spraying being done on April 9, and before growth started, and alternate rows being left untreated for comparison. Mr. Mann reported the results of this work as satisfactory, and they are elsewhere given in this bulletin. Mr. James A. Staples, of Marlboro, also conducted spray work for the Department in 1894, 1895, and 1896, and where the instructions were carried out respecting the time of first spraying his results were fully satisfactory. Prof. L. H. Bailey[3] reported the work of Mr. Henry Lutts, of Youngstown, for the spring of 1894; and Mr. A. D. Tripp, of North Ridgeway, reports excellent results from his work.

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[1]Ohio Agr. Exp. Sta. Bull. No. 92, pp. 246, 247.

[2]Ohio Agr. Exp. Sta. Bull. No. 104, March, 1899, p. 210; also Rept. Ohio State Hort. Soc., 1898, p. 13.

[3]Bailey, L. H., Impressions of the Peach Industry in Western New York, Cornell Agr. Exp. Sta. Bull. No. 74, Oct., 1894, pp. 382, 383.

A bulletin of the Cornell Agricultural Experiment Station, by George F. Atkinson,[1] which appeared in September, 1894, treats of leaf curl and plum pockets. Respecting the treatment of leaf curl, Mr. Atkinson says that some experiments had been made in various places by spraying the trees with Bordeaux mixture for the prevention of the disease. Some of the experimenters regard it as certain, he states, that the disease can to some extent be checked by this method, and adds: "It is quite likely that, in some cases at least, another disease is confused with leaf curl, and this fact might account in those instances for the results claimed." The doubts here expressed as to the results of the work in New York do not appear to have been supported by any field work of the station, and may have arisen from Mr. Atkinson's understanding of the perennial habits of the fungus causing the disease. There seems to have been no winter spraying for curl by the Cornell Station before the spring of 1898, and the results then obtained are in perfect accord with those obtained in 1894 by growers cooperating with the Department. In the spring of 1898 several experiments were instituted and carried out by B. M. Duggar and H. P. Gould. The results of this work are given in a bulletin by Mr. Duggar, published in February, 1899.[2]

The efforts to control peach leaf curl by winter sprays in Canada, so far as concerns the work of the Canadian Government, appear to have begun nearly simultaneously in Ontario and British Columbia.

At the experiment farm at Agassiz, British Columbia, the peach orchard had suffered severely from curl prior to the introduction of winter spraying. The superintendent, Mr. Thomas A. Sharpe, reported for 1892 that of the large number of peach varieties at that time on the farm—about 116—only 5 escaped leaf curl, and the attack was severe.[3] In the report for 1893 it is said that leaf curl was worse that year than ever before. Of about 129 varieties on the farm the Malta was the only variety on the level land that was entirely free.[4] In the spring of 1894 the trees were sprayed with strong Bordeaux mixture when the leaves were partly expanded, but no leaf curl developed that year, even the unsprayed orchards not being troubled by it.[5] It should be stated here, however, that the work done was too late to have given good results had curl developed, and that it did not properly constitute a preventive spraying. Whether this late spraying was owing to the nature of the season, or whether it was supposed that such treatment would control the disease, is not known to the writer.

[1] Atkinson, Geo. F., Leaf Curl and Plum Pockets, Cornell Agr. Exp. Sta. Bull. No. 73, Sept., 1894, pp. 324–326.

[2] Duggar, B. M., Peach Leaf Curl, etc., Cornell Agr. Exp. Sta. Bull. No. 164, Feb., 1899, pp. 377–384.

[3] Rept. Exp. Farms, 1892, p. 278.

[4] Rept. Exp. Farms, 1893, pp. 342, 343.

[5] Rept. Exp. Farms, 1894, p. 404.

In 1895 Mr. Sharpe reports that the peach trees at Agassiz were sprayed with Bordeaux mixture before leafing out, and again when the leaves were nearly full grown. He states that the sprayed trees had very little curl, and made a very strong and healthy growth, while on a few unsprayed trees of several varieties the leaves were nearly all destroyed by curl, and the trees themselves made a very feeble growth.[1]

This treatment, so far as known, is the first successful experiment for the control of curl by the Canadian Government. Leaving control trees for comparison added greatly to the value of the work, which was also strengthened by the results at Agassiz the following year, 1896.[2] The writer regrets to add, however, that unfavorable results attended the spray work at Agassiz in 1898.[3] The reasons for this failure are not apparent.

In Ontario the early results were not so satisfactory as at Agassiz, owing to the nondevelopment of the disease in Ontario. Mr. John Craig, horticulturist of the Central Experimental Farm, at Ottawa, planned the Ontario work. He states that the work on peaches in 1894 was planned to prevent the rotting of fruit and injury from insects, and that the first spraying was not given until May 1.[4] Mr. Craig's work on leaf curl began in 1895, by the application of winter sprays,[5] but owing to the absence of the disease that year no conclusive results were obtained. Later work, I am informed by Mr. Craig, has given more conclusive and satisfactory results.[6] The variable results reported in Bulletin No. 1, second series, leads the writer to wonder, however, if the early spray work was done with sufficient thoroughness. Mr. W. M. Orr, of Fruitland, Ontario, met with very convincing and satisfactory results from winter spraying in 1898.[7] The same is true for the experiments of Mr. A. H. Pettit, of Grimsby, Ontario, who carried on work in 1898 and 1899, the results of the latter year, when one row of trees was left untreated for comparison, being very striking.

The work of this Department in extending the use of sprays for the control of curl on the Pacific coast began in the spring of 1893. In the fall of that year a circular letter on the subject was addressed to many Pacific coast growers, and this was closely followed by requests that growers undertake preventive spray work in the winter of

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[1] Rept. Exp. Farms, 1895, p. 396.
[2] Rept. Exp. Farms, 1896, p. 449.
[3] Rept. Exp. Farms, 1898, p. 403.
[4] Rept. Exp. Farms, 1894, pp. 110, 111.
[5] Peach Culture in Canada, Bull. No. 1, second series, pp. 35–37; Central Exp. Farm, Dept. of Agr., Ottawa, Canada, Sept., 1898.
[6] Letter dated Ottawa, Oct. 7, 1897.
[7] Canadian Horticulturist, Jan., 1899, pp. 18–20.

1893–94. During the winters of 1893–94 and 1894–95 the writer sent full instructions for preventing curl by winter sprays to over two hundred and seventy California peach growers, and requests to carry on spraying experiments, with similar instructions, to more than one hundred growers in Oregon, and to many in Washington. In all of this work for the extension of spraying an effort was made to introduce it in as large a number of leading peach-growing centers as possible, especially in those sections of the coast where leaf curl had been most prevalent. The results of some of these experiments are given in Chapter VII, and the facts gathered and experiments conducted under the direct charge of the writer in 1893, 1894, and 1895 are detailed in full in other portions of this bulletin, and require no discussion here.

CHAPTER IV.

PLAN OF PREVENTIVE SPRAY WORK CONDUCTED BY THE DEPARTMENT.

PRELIMINARY PLANS FOR THE WORK.

The partial control of peach leaf curl in the spring of 1893, in a few orchards of the Sacramento Valley in which the trees had received a winter spraying for the control of the San José scale (*Aspidiotus perniciosus*), showed to the writer the importance of conducting careful experiments for the prevention of curl. As a foundation for experimental work a circular of inquiry was sent to some 1,500 peach growers of the United States in the fall of 1893. The facts thus obtained were of much value, but the general lack of accurate knowledge respecting both the nature and control of the disease, as well as the heavy losses reported from this cause in different sections of the country, strikingly emphasized the need for widespread and thorough preventive experiments.

After careful consideration it was concluded to inaugurate two series of experiments. The first, which had been planned before the sending out of the circular, was to be conducted in California under the direct supervision of the writer, and the second, planned somewhat similarly, though on a more limited scale, was to be carried out by the growers themselves in various peach-growing sections of the country. The personally conducted work is described here, while the results of the cooperative work are given farther on.

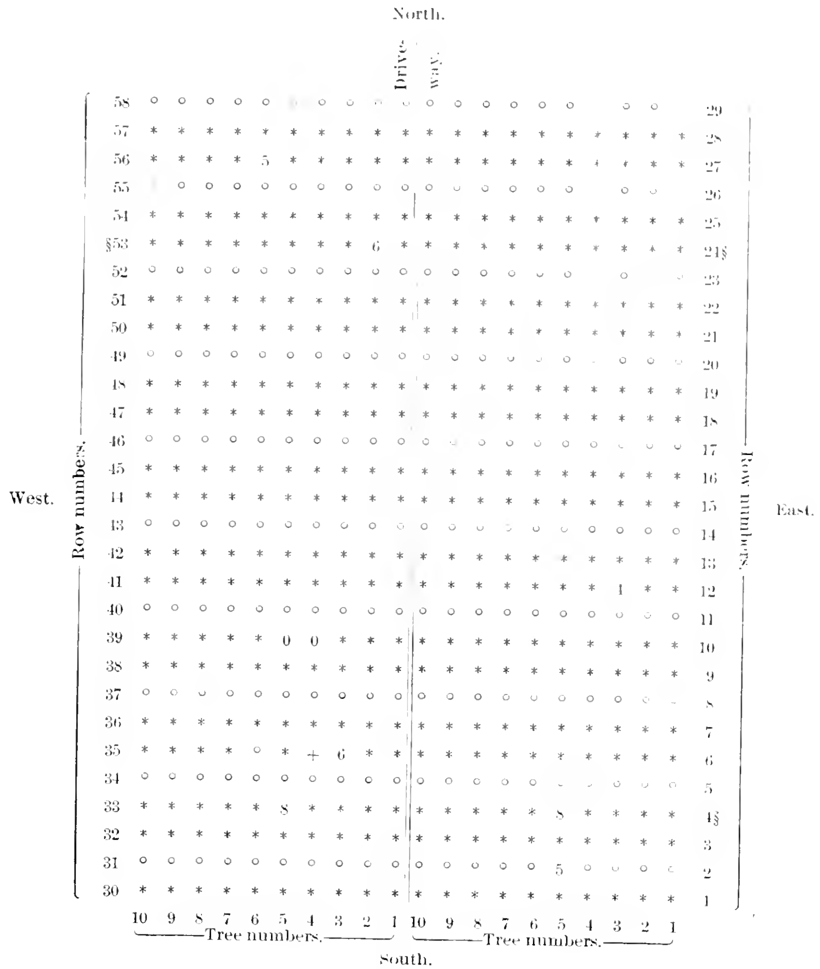
Observation and correspondence had already shown which sections of California were most subject to frequent and serious recurrences of the disease. Facts thus gathered led to the opening of correspondence with Mr. George F. Ditzler, the manager of the Rio Bonito orchard, situated in the Sacramento Valley, in the bottom lands of the Feather River, near Biggs, Cal. This orchard is the property of the Hatch & Rock Orchard Company, and comprises some 1,600 acres, several hundred of which have as fine peach trees as any in the State. Among the varieties of peaches in this orchard is a large acreage of Lovell trees. The Lovell, it was learned, while presenting as thrifty growth as any variety in the orchard during years when curl did not prevail, had been especially subject to it in seasons favorable to its development, the crop of this variety, which would amount to several thousand dollars, having been largely lost in 1893. After a brief correspondence Mr. Ditzler kindly offered to allow the Department to select from the orchards of Lovell peaches a block of several hundred trees of exceptionally uniform and vigorous growth and especially suited to the purposes of the experiments planned, and no finer or more uniform block of trees has ever been seen by the writer than that eventually selected and assigned to this experimental work. It consisted of nearly 600 trees at the southwest corner of a 40-acre block of Lovells, and was nearly level. The soil was sandy loam—deep, rich, and almost uniform in quality. The trees had been set in orchard less than five years, were 25 feet apart each way, and had grown so vigorously that before pruning the branches met between the rows in many cases, thus presenting tops of exceptional size for trees so young.

The experiments planned included a rectangular block of the orchard, 20 trees wide from east to west by 29 trees long from north to south. The tract selected was 500 feet east and west by 725 feet north and south, or nearly 8⅓ acres in extent. At the south of these Lovells is an almond orchard of the same age; at the west a young apple orchard.

Through the center of the experiment tract, extending from south to north, was planned a driveway, thus dividing the trees into two long rectangular blocks, each block being 10 trees wide from east to west, and 29 trees long from north to south. Each cross row of 10 trees was numbered. The south 10 trees, forming the south east-and-west row on the east side of the driveway, was designated 1; the second row from the south, 2; the third row, 3; etc., the north row on the east of the driveway being row 29. On the west of the driveway the south row was 30, the second row 31, etc., the north row being 58. This arrangement gave 580 trees, divided into 58 rows of 10 trees each, one-half of these, rows 1 to 29, being east of the driveway and the other half, rows 30 to 58, west of the same. This arrangement may be fixed more clearly in the mind by the diagram on page 69.

This diagram, in addition to showing the arrangement of the rows, as already described, is planned to represent and distinguish the rows which were to be treated with sprays from those which were to be left untreated as check or control trees in each experiment. The trees of the rows to be treated are represented by a star (*) and the trees to be left unsprayed are shown by a circle (°), with the exceptions to be noted. It may thus be seen that each row of 10 trees intended for treatment has at its side 10 untreated trees as a check or control row. With the exception of rows 29 and 58 each control row serves for comparison with two sprayed rows, one on either side. This method of contrasting each control row with a sprayed row on either side admitted of the planning of 38 experiments in the block of 58 rows, each experiment comprising 20 trees—10 sprayed and 10 unsprayed, in two immediately adjoining and parallel rows.

After locating and numbering each of the 38 experiments to be tested the block was carefully examined to determine if any of the trees were missing or so injured as not to represent entire trees. The results of this examination are also embodied in the plat. Where trees were missing the fact is shown by a cipher (0) in the place of the



* Sprayed in 1894 and 1895, except where noted.
○ Unsprayed in 1894 and 1895.
§ Sprayed in 1894 and left unsprayed in 1895.

tree, but it was found that only two trees, both from row 39, were wanting in the block. The cross (+) in row 35 represents a nectarine tree, omitted in results of work. In cases where main limbs had been broken off or the tree otherwise injured, the proportion of the tree remaining is expressed in numerals, i. e., 8 in the place of a tree indicates that the tree was eight-tenths perfect, 5 that it was five-tenths perfect, etc. As will be seen, however, there were very few imperfect trees.

In all the following calculations of fruit, etc., these few discrepancies in the number of trees are carefully taken into account in arriving at results intended for comparison with other rows. The amounts produced by the trees of each row are first divided by the number of trees actually in the row to obtain the average per tree, and this amount is multiplied by 10 to obtain the amount a full row would yield at the given average. By reference to the plat it may be seen that the trees and parts of trees missing amount to but 5.8 equivalent trees for the entire block, that 51 of the 58 rows have the whole complement of 10 perfect trees, and that the missing trees or parts of trees are divided among the remaining 7 rows.

SPRAY WORK CONDUCTED IN 1894.

The spray tests conducted in the Rio Bonito orchard in 1894 included the application of sprays prepared according to 38 different formulæ, making 38 distinct experiments. Each experiment included two adjoining rows of 10 trees each, one sprayed and the other unsprayed for comparison. Of these 38 experiments 11 involved two sprayings of the trees treated and 27 a single treatment. All treatments were made during the dormant period of the trees and varied in date from February 1 to March 6. The consideration of the preparation of sprays for this work will be discussed in a subsequent chapter devoted to that subject, as will also the methods of application, which will be given for use in both small and large orchards.

The table which follows is prepared to show as concisely as possible the arrangements adopted for the experiments of 1894. The rows of trees once treated and those twice treated are shown, the date or dates of treatment and the formula or formulæ used in each case.

TABLE 1.—*Showing the formulæ of the sprays applied in 1894, dates of application, and rows treated.*

Row No.	Date of spraying.	Formulæ for 45 gallons of spray.
1	Feb. 20	15 lbs. sulphur, 30 lbs. lime, 10 lbs. salt.
2		Control row.
3	Feb. 24	10 lbs. sulphur, 20 lbs. lime, 7 lbs. salt.
4	Feb. 16 Feb. 28	10 lbs. sulphur, 20 lbs. lime, 7 lbs. salt. 5 lbs. sulphur, 10 lbs. lime, 3 lbs. salt.
5		Control row.
6	Feb. 23	5 lbs. sulphur, 10 lbs. lime, 3 lbs. salt.
7	Feb. 24	15 lbs. sulphur, 30 lbs. lime.
8		Control row.
9	Feb. 23	10 lbs. sulphur, 20 lbs. lime.
10	Feb. 20 Mar. 3	10 lbs. sulphur, 20 lbs. lime. 5 lbs. sulphur, 10 lbs. lime.
11		Control row.
12	Feb. 24	5 lbs. sulphur, 10 lbs. lime.
13	Feb. 13	20 lbs. lime, 20 lbs. salt.
14		Control row.
15	Feb. 13	20 lbs. lime.
16	Feb. 26 Mar. 6	45 lbs. salt (hot). 45 lbs. salt (hot).

TABLE 1.—*Showing the formulæ of the sprays applied in 1894, dates of application, and rows treated*—Continued.

Row No.	Date of spraying.	Formulæ for 45 gallons of spray.
17		Control row.
18	Feb. 26	3 lbs. copper sulphate, 5 lbs. sulphur, 10 lbs. lime.
19	Feb. 27	2 lbs. copper sulphate, 5 lbs. sulphur, 10 lbs. lime.
20		Control row.
21	Feb. 16	5 lbs. copper sulphate, 5 lbs. lime.
	Feb. 20	5 lbs. copper sulphate, 5 lbs. lime.
22	Feb. 21	4 lbs. copper sulphate, 5 lbs. lime.
23		Control row.
24	Feb. 6	4 lbs. copper sulphate, 5 lbs. lime.
	Mar. 1	3 lbs. copper sulphate, 5 lbs. lime.
25	Feb. 23	3 lbs. copper sulphate, 5 lbs. lime.
26		Control row.
27	Feb. 6	3 lbs. copper sulphate, 2 lbs. lime.
	Mar. 1	2 lbs. copper sulphate, 5 lbs. lime.
28	Feb. 26	2 lbs. copper sulphate, 5 lbs. lime.
29		Control row.
30	Feb. 2	2 lbs. copper sulphate, 3 lbs. ammonia.
31		Control row.
32	Feb. 2	4 lbs. copper sulphate.
33	...do...	2 lbs. copper sulphate.
	Mar. 2	2 lbs. copper sulphate.
34		Control row.
35	Mar. 3	4 lbs. copper sulphate, 5 lbs. soda, 3 lbs. ammonia.
36	Feb. 27	3 lbs. copper sulphate, 10 lbs. sulphur, 10 lbs. lime.
37		Control row.
38	Feb. 26	5 oz. copper carbonate, 3 lbs. ammonia.
39	Feb. 1	5 oz. copper carbonate, 3 lbs. ammonia.
	Feb. 28	5 oz. copper carbonate, 3 lbs. ammonia.
40		Control row.
41	Feb. 23	5 lbs. copper sulphate, 10 lbs. lime.
42	Feb. 14	6 pints spray solution.
	Mar. 3	6 pints spray solution.
43		Control row.
44	Feb. 21	6 lbs. copper sulphate, 15 lbs. lime.
45	Feb. 27	3 lbs. copper sulphate, 15 lbs. lime.
46		Control row.
47	Feb. 14	8 pints spray solution.
	Mar. 3	8 pints spray solution.
48	Feb. 14	6 pints spray solution, 3 lbs. lime.
	Mar. 6	6 pints spray solution, 10 lbs. lime.
49		Control row.
50	Feb. 14	8 pints spray solution, 3 lbs. lime.
51	Mar. 3	5 lbs. sulphur, 5 lbs. lime.
52		Control row.
53	Feb. 14	10 lbs. spray solution, 1 lb. soap (hot).
	Mar. 6	8 pints spray solution, 1 lb. soap (hot).
54	Feb. 27	3 lbs. copper sulphate, 10 lbs. lime.
55		Control row.
56	Mar. 6	8 pints spray solution, 2 lbs. copper sulphate, 10 lbs. lime.
57	...do...	5 lbs. sulphur, 15 lbs. lime.
58		Control row.

The spray work outlined in the above table was fully completed before the opening of many of the peach blossoms in the spring. Following this work, plans were laid for the preservation of records of fruit thinned from the trees, etc., should peach leaf curl develop. As the spring advanced, however, it became evident that the disease would not appear to any serious extent in that portion of the State that season, it not being sufficiently severe to produce a contrast either in foliage or fruit between the sprayed and unsprayed trees, hence the action of the sprays applied could not be determined. While this failure to arrive at the results hoped for in 1894 was much regretted, the failure, nevertheless, led to the acquisition of certain facts at a later date which are of prime importance to the orchardist wishing to combat the disease with sprays. The treatment of the trees in 1894 made it possible when the work was resumed in 1895 to ascertain if the effects of one year's treatment extended to the crop or foliage of the second year.

While peach leaf curl did not develop seriously in the Sacramento Valley in 1894, it prevailed quite extensively in other portions of the United States. This resulted in acquiring facts bearing on the experiments for 1895 in the Rio Bonito orchard. The experiments planned by the Department and carried out by growers in the East and in the north Pacific States, where leaf curl developed, showed that one thorough spraying during the dormant period of the tree was sufficient. The experiments of 1895 were consequently modified from those of 1894 in respect to the number of applications made, as well as in other respects found to be advisable.

SPRAY WORK CONDUCTED IN 1895.

In the spray work in the Rio Bonito orchard during the winter and spring of 1895, the same block of Lovell peach trees was selected as that treated the previous year, and in each case the same unsprayed or control rows were left as in 1894. In 1895 the number of experiments made in this block was 38, as in the previous year, but three of the 38 rows were not sprayed, being left without treatment for the purpose of observing the action of sprays applied in 1894 upon the crop and foliage of 1895. These three rows were numbers 4, 24, and 53, each of which had received two treatments in 1894. The facts thus learned are considered farther on. The spray work of 1895 included but a single spraying of each row designed for treatment. As already indicated, each experiment included one treated and one untreated row, each row having 10 immediately adjoining trees. By treating one row on either side of each control row the latter served as a contrast row for both sprayed rows. By referring to the plat of the block, p. 69, this arrangement may be seen. Row 1 is sprayed; row 2, unsprayed; row 3, sprayed. These three rows make two experiments—rows 1 and 2 compared make the first experiment, while rows 3 and 2 compared make the second experiment. In like manner rows 4 and 5 and 5 and 6 make two experiments. These illustrations will be sufficient, as the entire block, with the exception of the three rows already noted, was treated according to the same general plan.

In considering the application of sprays in the experiments of 1895, the nature of the sprays used, the formulæ according to which they were prepared, the location of the rows treated, and the dates of application, as well as the location of the control rows for comparison, are set forth in the table which follows. That the reader may better grasp the nature of all treatments which each row had received the previous year, the formulæ for the sprays applied in 1894 are placed at the left of the treatment given the same rows in 1895.

Table 2.—*Showing formulæ of sprays used in 1894 and 1895, the rows treated, and dates of application.*

Row No.	Date of spraying.	Formulæ for 45 gallons of spray as used in 1894.	Date of spraying.	Formulæ for 45 gallons of spray as used in 1895.
1	Feb. 20	15 lbs. sulphur, 30 lbs. lime, 10 lbs. salt	Mar. 1-5	15 lbs. sulphur, 30 lbs. lime, 10 lbs. salt.
2		Control row		Control row.
3	Feb. 24	10 lbs. sulphur, 20 lbs. lime, 7 lbs. salt	Mar. 1-5	10 lbs. sulphur, 20 lbs. lime, 5 lbs. salt.
4	Feb. 16 Feb. 28	10 lbs. sulphur, 20 lbs. lime, 7 lbs. salt 5 lbs. sulphur, 10 lbs. lime, 3 lbs. salt		Unsprayed, to note action of 1894 spray.
5		Control row		Control row.
6	Feb. 23	5 lbs. sulphur, 10 lbs. lime, 3 lbs. salt	Feb. 26	5 lbs. sulphur, 10 lbs. lime, 3 lbs. salt.
7	Feb. 24	15 lbs. sulphur, 30 lbs. lime	...do...	15 lbs. sulphur, 30 lbs. lime.
8		Control row		Control row.
9	Feb. 23	10 lbs. sulphur, 20 lbs. lime	Feb. 26	10 lbs. sulphur, 20 lbs. lime.
10	Feb. 20 Mar. 3	10 lbs. sulphur, 20 lbs. lime 5 lbs. sulphur, 10 lbs. lime	...do...	10 lbs. sulphur, 8 lbs. lime.
11		Control row		Control row.
12	Feb. 24	5 lbs. sulphur, 10 lbs. lime	Feb. 26	5 lbs. sulphur, 10 lbs. lime.
13	Feb. 13	20 lbs. lime, 20 lbs. salt	Mar. 1-5	20 lbs. lime, 20 lbs. salt.
14		Control row		Control row.
15	Feb. 13	20 lbs. lime	Feb. 26	6 lbs. copper sulphate, 15 lbs. lime.
16	Feb. 26 Mar. 6	45 lbs. salt (hot) 45 lbs. salt (hot)	...do...	6 lbs. sulphur, 4 lbs. lime.
17		Control row		Control row.
18	Feb. 26	3 lbs. copper sulphate, 5 lbs. sulphur, 10 lbs. lime	Mar. 1-5	3 lbs. copper sulphate, 5 lbs. sulphur, 10 lbs. lime.
19	Feb. 27	2 lbs. copper sulphate, 5 lbs. sulphur, 10 lbs. lime	Feb. 27	2 lbs. copper sulphate, 5 lbs. sulphur, 10 lbs. lime.
20		Control row		Control row.
21	Feb. 16 Feb. 20	5 lbs. copper sulphate, 5 lbs. lime 5 lbs. copper sulphate, 5 lbs. lime	Mar. 1-5	5 lbs. copper sulphate, 5 lbs. lime
22	Feb. 21	4 lbs. copper sulphate, 5 lbs. lime	Feb. 27	4 lbs. copper sulphate, 5 lbs. lime
23		Control row		Control row.
24	Feb. 6 Mar. 1	4 lbs. copper sulphate, 5 lbs. lime 3 lbs. copper sulphate, 5 lbs. lime		Unsprayed, to note action of 1894 spray.
25	Feb. 23	3 lbs. copper sulphate, 5 lbs. lime	Mar. 1-5	3 lbs. copper sulphate, 5 lbs. lime.
26		Control row		Control row.
27	Feb. 6 Mar. 1	3 lbs. copper sulphate, 2 lbs. lime 2 lbs. copper sulphate, 5 lbs. lime	Mar. 1-5	4 lbs. copper sulphate, 3 lbs. ammonia.
28	Feb. 26	2 lbs. copper sulphate, 5 lbs. lime	...do...	2 lbs. copper sulphate, 5 lbs. lime.
29		Control row		Control row
30	Feb. 2	2 lbs. copper sulphate, 3 lbs. ammonia	Mar. 1-5	2 lbs. copper sulphate, 3 lbs. ammonia.
31		Control row		Control row.
32	Feb. 2	4 lbs. copper sulphate	Mar. 1-5	3 oz. copper carbonate, 2 lbs. ammonia.
33	...do... Mar. 2	2 lbs. copper sulphate 2 lbs. copper sulphate	...do...	3 lbs. copper sulphate, 15 lbs. lime
34		Control row		Control row.
35	Mar. 3	4 lbs. copper sulphate, 5 lbs. soda, 3 lbs. ammonia	Mar. 1-5	4 lbs. copper sulphate, 5 lbs. soda, 3 lbs. ammonia.
36	Feb. 27	3 lbs. copper sulphate, 10 lbs. sulphur, 10 lbs. lime	Feb. 27	3 lbs. copper sulphate, 10 lbs. sulphur, 20 lbs. lime
37		Control row		Control row.
38	Feb. 26	5 oz. copper carbonate, 3 lbs. ammonia	Feb. 27	5 oz. copper carbonate, 3 lbs. ammonia

TABLE 2.—*Showing formulæ of sprays used in 1894 and 1895, the rows treated, and dates of application*—Continued.

Row No.	Date of spraying.	Formulæ for 45 gallons of spray as used in 1894.	Date of spraying.	Formulæ for 45 gallons of spray as used in 1895.
39	Feb. 1 Feb. 28	5 oz. copper carbonate, 3 lbs. ammonia 5 oz. copper carbonate, 3 lbs. ammonia	Mar. 1–5	2 lbs. copper sulphate, 3 lbs. soda, 2 lbs. ammonia.
40		Control row		Control row.
41	Feb. 23	5 lbs. copper sulphate, 10 lbs. lime	Mar. 1–5	5 lbs. copper sulphate, 10 lbs. lime.
42	Feb. 14 Mar. 3	6 pints spray solution 6 pints spray solution	do	8 pints spray solution, 5 lbs. lime.
43		Control row		Control row.
44	Feb. 24	6 lbs. copper sulphate, 15 lbs. lime	Mar. 1–5	20 lbs. lime.
45	Feb. 27	3 lbs. copper sulphate, 15 lbs. lime	do	3 lbs. copper sulphate, 10 lbs. lime.
46		Control row		Control row.
47	Feb. 14 Mar. 3	8 pints spray solution 8 pints spray solution	Mar. 1–5	8 pints spray solution.
48	Feb. 14 Mar. 6	6 pints spray solution, 3 lbs. lime 6 pints spray solution, 10 lbs. lime	do	12 pints spray solution, 10 lbs. lime.
49		Control row		Control row.
50	Feb. 14	8 pints spray solution, 3 lbs. lime	Mar. 1–5	6 lbs. sulphate of iron, 10 lbs. lime.
51	Mar. 3	5 lbs. sulphur, 5 lbs. lime	do	5 lbs. sulphur, 5 lbs. lime.
52		Control row		Control row.
53	Feb. 14 Mar. 6	10 pints spray solution, 1 lb. soap (hot) 8 pints spray solution, 1 lb. soap (hot)		Unsprayed, to note action of 1894 spray.
54	Feb. 27	3 lbs. copper sulphate, 10 lbs. lime	Mar. 1–5	3 lbs. copper sulphate, 10 lbs. lime.
55		Control row		Control row.
56	Mar. 6	8 pints spray solution, 2 lbs. copper sulphate, 10 lbs. lime	Feb. 27	5 lbs. sulphate of iron, 5 lbs. sulphur, 10 lbs. lime.
57	do	5 lbs. sulphur, 15 lbs. lime	Mar. 1–5	5 lbs. sulphur, 15 lbs. lime.
58		Control row		Control row.

The methods of preparing and applying the sprays used in 1895 are considered in subsequent chapters. In each case an effort was made to do thorough work in applying the sprays, but, as is true with all such work in the field, more or less variable results could not be avoided owing to the weather conditions and other influences. The treatment was given the 35 rows during the ten days immediately preceding the general opening of the flowers, that is, at the close of the dormant period of the trees, or from February 26 to March 5. In a few of the more forward trees a small percentage of the flowers had opened before the completion of the work.

GENERAL CONSIDERATION OF SPRAYS APPLIED.

Several distinct types of sprays were tested in the preventive work on curl in 1895, and these were prepared in many forms and proportions. The two fungicidal bases, copper and sulphur, which are now recognized in all countries as most valuable for this class of work, enter into the composition of a large proportion of the sprays used, in one form or another.

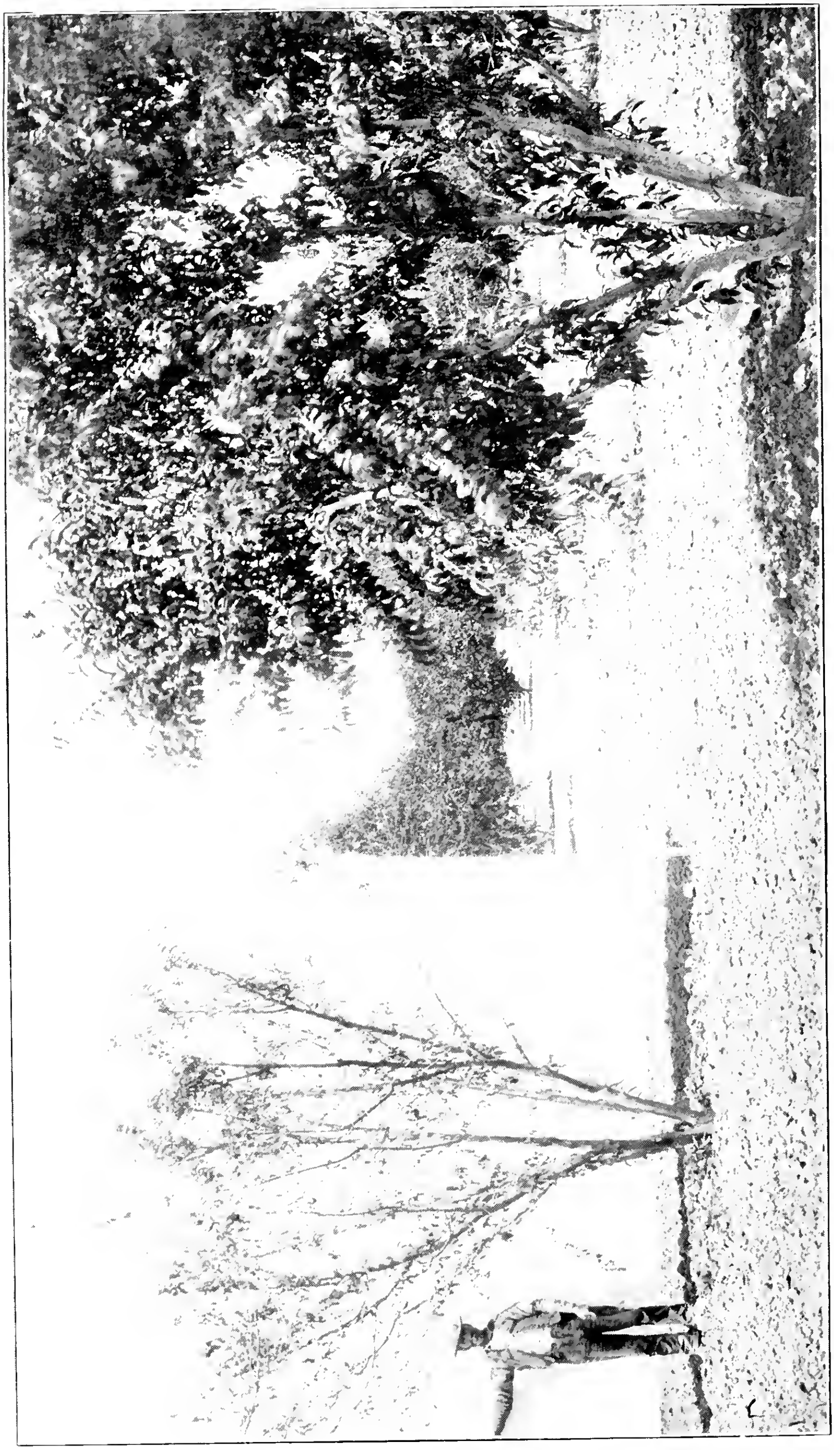
In testing sprays considerable weight was given to the fact that the peach tree is subject to the attacks of certain serious insect pests, prominent among which is the San José scale, and that a spray combining both fungicidal and insecticidal properties would often prove of greater value than one the action of which was solely fungicidal. Having these facts in mind, and knowing the demonstrated value of the sulphur, lime, and salt spray as an effective remedy for the San José scale, this spray, together with various modifications, was tested and compared (rows 1, 3, and 6). Besides quantitative modifications of the spray, tests of its constituents were made to acquire such facts respecting their value as were obtainable. The sulphur and lime united were tested in several proportions without salt (rows 7, 9, 10, 12, 16, 51, and 57). The lime and salt were tested together (row 13), and the lime was tested separately (row 44). The trial of a strong salt solution was made the previous year (row 16), but as it injured the foliage somewhat it was omitted in 1895. Other modifications of the sulphur spray were prepared by adding different fungicides, with the hope of increasing its fungicidal action without detracting from its effectiveness as an insecticide. Sulphate of copper was added in different proportions (rows 18, 19, and 36), and the addition of iron sulphate was also tried (row 56).

The copper sprays tested for leaf curl were numerous and were variously prepared and combined. As already said, copper sulphate was added to the sulphur sprays, but it was most extensively used in the preparation of the Bordeaux mixture, in which form it was applied in many experiments and of various strengths (rows 15, 21, 22, 25, 28, 33, 41, 45, and 54). Copper sulphate with ammonia (eau celeste) was tested (rows 27 and 30), as was the modified eau celeste, composed of copper sulphate, sal soda, and ammonia (rows 35 and 39). Two experiments were also conducted with ammoniacal copper carbonate (rows 32 and 38).

The action of sulphide of potassium was tested (row 47), as well as sulphide of potassium combined with milk of lime (rows 42 and 48).

Iron sulphate in connection with lime was applied in one experiment (row 50), and, as already stated, was also used in connection with sulphur and lime (row 56).

Of the three rows left unsprayed in 1895 (rows 4, 24, and 53), one (row 4) had received two applications of the sulphur, lime, and salt spray in 1894; another (row 24) had been twice sprayed in 1894 with Bordeaux mixture; and the third (row 53) had received two sprayings in 1894 with a hot saponified solution of sulphide of potassium.



TREATED AND UNTREATED CRAWFORDS LATE TREES, LIVE OAK, CAL.

Untreated tree at left shows the general denuding action of curl without hypertrophy of the branches; tree at right treated with lime, sulphur, and salt.

DESCRIPTION OF PLATE VII.

Sprayed and unsprayed Crawfords Late trees in the orchard of Mr. A. D. Cutts, Live Oak, Cal. The tree seen at the right was sprayed with lime, sulphur, and salt in February, 1893; that at the left was unsprayed and was denuded of foliage and fruit by curl. (See records of fruit of sprayed and unsprayed trees in this orchard, p. 141.) The trees were photographed in May, after most of the curled leaves had fallen from the unsprayed tree. (Compare with Pl. XX.)

CHAPTER V.

INFLUENCE OF SPRAYS ON THE VEGETATION OF THE TREES.

SAVING OF FOLIAGE FROM INJURY BY CURL.

(Pl. VII.)

The effectiveness of the winter sprays discussed in the previous chapter in saving the foliage of peach trees from injury by peach leaf curl has been carefully considered. The relative importance of this matter appears from the fact that it is the injury from the loss of foliage which is responsible for the ultimate loss of the fruit. The spray work already mentioned was completed, in 1895, about the close of the first week in March. From this time on the flowers opened rapidly, and they were soon followed by the pushing of the leaf buds and the complete resumption of the vegetative growth of the year. By the middle of April the trees were well in foliage, while peach leaf curl was nearing the height of its development. By the 22d of the month the contrast between healthy and diseased foliage on the sprayed and unsprayed trees had become so great that a careful estimate was made of the percentage of the diseased leaves upon every tree in the block.

The first estimate of the condition of the foliage was made to determine the amount and percentage of disease present on sprayed and unsprayed trees. The estimate of each tree was calculated upon the basis that the foliage present represented 100 per cent, and the amount of badly diseased leaves was taken as a certain per cent of the leaves present at that date. Badly diseased leaves were considered as those seeming to have sufficient curl present to cause their premature fall from the tree. The ultimate comparisons of sprayed with unsprayed rows are not based upon this first estimate of foliage as the disease was still progressing. The parasite was still in the vegetative state, few of the swollen leaves as yet showing the fruit of the fungus, and still fewer having fallen from the trees. The trees sprayed with the stronger sulphur preparations were injured somewhat by the sprays, many of the more tender twigs being killed. This delayed the leafing of these trees, and resulted in their showing rather a smaller percentage of diseased foliage at the time this estimate was made than would have been the case had the leaves pushed earlier. These discrepancies influence only a few of the sprayed rows. In other respects, it is believed the numerous influencing conditions would apply, so far as could be told, with equal force to all rows.

In taking the percentage estimates of disease shown in the following table, the trees were examined in north and south rows. This was done so as to work across the lines of the experiment rows rather than with them, and for the purpose of avoiding any influence which a knowledge of the sprays used on the trees estimated might be thought to exert.

TABLE 4.—*Estimated percentage of diseased leaves on trees April 22 and 23, 1895.*

Row No.	Percentage of diseased leaves estimated Apr. 22 and 23, 1895, on tree No.—										Average per cent of diseased leaves per tree in sprayed rows.	Average per cent of diseased leaves per tree in control rows.
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.		
1	10	15	15	10	10	10	15	15	20	15	13.5	....
2	90	90	90	85	85	90	90	85	85	85	....	87.5
3	30	35	35	40	35	30	30	30	25	20	31.0	....
4	70	80	80	80	85	85	80	80	85	80	[a]80.5	....
5	80	80	85	85	80	90	85	90	90	85	....	85.0
6	40	60	40	50	40	45	35	40	35	30	41.5	....
7	20	25	25	30	25	35	30	30	35	30	28.5	....
8	75	85	80	85	75	70	70	75	80	80	....	77.5
9	30	34	46	42	25	27	25	29	47	45	35.0	....
10	30	32	40	40	35	27	23	30	27	36	32.0	....
11	80	90	90	85	85	85	85	80	80	80	....	84.0
12	25	47	15	35	34	50	45	50	45	47	39.3	....
13	40	45	55	40	45	50	35	50	60	35	45.5	....
14	80	80	78	78	75	76	77	80	80	80	....	78.4
15	5	11	8	13	16	16	9	12	11	13	11.4	....
16	16	35	30	45	37	31	20	20	30	25	28.9	....
17	80	90	85	85	87	78	65	80	82	90	....	82.2
18	25	30	33	40	29	32	40	31	35	60	35.5	....
19	8	15	13	16	25	23	35	20	23	36	21.4	....
20	80	90	90	90	90	90	90	90	90	90	....	89.0
21	7	11	16	26	17	10	11	10	10	9	12.7	....
22	8	10	15	9	16	9	10	10	12	8	10.7	....
23	82	85	80	85	85	80	85	80	90	85	....	83.7
24	80	80	80	85	85	85	80	85	85	80	[a]82.5	....
25	8	12	12	18	27	15	9	11	15	10	13.7	....
26	80	80	85	90	90	85	85	85	90	85	....	85.5
27	17	20	17	21	21	15	24	26	23	17	20.1	....
28	20	21	21	30	26	24	30	31	15	19	23.7	....
29	85	90	90	90	90	87	87	90	88	90	....	88.7
30	8	5	15	15	10	15	15	15	20	15	13.3	....
31	85	80	85	85	90	85	80	85	80	85	....	84.0
32	25	35	30	35	30	30	30	35	35	30	31.5	....
33	10	10	10	10	5	10	10	10	10	5	9.0	....
34	90	90	85	90	90	85	90	90	90	85	....	88.5
35	20	15	15	20	12	10	8	15	12	10	13.7	....
36	25	15	10	10	15	10	15	20	12	10	14.2	....
37	75	75	70	75	75	75	65	60	65	65	....	70.0
38	50	45	40	35	25	19	17	25	24	10	29.0	....
39	27	35	18	....	....	15	20	15	15	18	20.3	....
40	78	85	80	80	82	80	75	80	85	78	....	80.3
41	9	14	12	13	20	18	18	23	13	17	15.7	....
42	50	45	50	55	55	65	55	60	55	60	55.0	....
43	85	80	80	85	88	85	87	85	85	85	....	81.5
44	13	27	16	30	30	35	31	28	30	25	26.5	....
45	14	12	12	12	10	11	18	12	12	13	12.6	....
46	85	85	90	90	80	90	85	80	85	85	....	85.5
47	70	70	60	50	65	70	70	75	75	75	68.0	....
48	30	40	40	38	37	38	30	40	28	42	36.3	....
49	90	87	85	85	85	80	87	85	85	85	....	85.4
50	35	40	40	50	45	42	45	43	35	33	40.8	....
51	30	26	28	25	32	30	35	22	35	28	29.1	....
52	85	80	80	80	80	85	80	85	85	80	....	82.0
53	85	80	80	80	85	85	85	85	80	85	[a]83.0	....
54	17	10	11	12	12	20	15	15	16	18	14.6	....
55	85	75	80	80	85	80	85	85	82	87	....	82.4
56	30	22	30	25	22	9	20	18	19	13	20.8	....
57	26	31	31	32	21	20	18	16	15	11	22.1	....
58	90	89	85	90	85	87	88	90	90	88	....	88.2

[a] Rows sprayed in 1894 but left unsprayed in 1895.

General consideration of the above table develops some striking contrasts. By adding the figures corresponding to the average percentage of diseased leaves on the trees of the control rows, and dividing this amount by the number of rows, we find that in the entire block, containing 200 control trees, 83.6 per cent of the leaves were badly diseased at the date of this estimate. In contrast to this, the total of the average percentages of disease shown by the trees of the sprayed rows, divided by the number of sprayed rows in the block, shows the average amount of disease in the sprayed rows to have been 26.2 per cent. Evidently this average is much above the percentage of disease shown at that date by many separate rows, as it included the rows treated with noneffective sprays as well as those giving the best results. Adding the averages of rows 4, 24, and 53 and dividing the amount by 3 gives 82 per cent of disease as the average of the three rows. As noted in the table, these rows were not sprayed in 1895, but were left in order to ascertain the effects of the sprays applied to them in 1894, and the average of disease is seen to be practically as great as upon rows never sprayed.

From the date of this first estimate the progress of the disease in the orchard was very marked. Within the next two weeks the fungus fruited quite generally upon the swollen leaves, and a large percentage of the worst diseased leaves had fallen from the trees. By May 9 the contrast between sprayed and unsprayed trees had quite generally reached its highest point, and any irregularities of special trees, etc., could no longer be considered. On May 9 a second careful estimate of the foliage was made. In this work, however, it was impossible to estimate the amount of disease on the trees as compared with the total amount of foliage present, as had first been done, for much of the diseased foliage had already fallen. To avoid this difficulty a new method of estimating was adopted. From the entire block of trees were selected two rows, Nos. 21 and 22, which showed only from 4 to 6 per cent of disease, and were in other respects in perfect foliage. A careful study of these rows was made to get a clear idea of the condition of a tree in full foliage at that date, and with these types in mind each tree of the entire block was carefully examined. An estimate was made for each tree, based on the twenty typical trees studied, to determine the per cent of perfect foliage upon it, taking the amount which should be upon the tree at that date, if no disease existed, as 100 per cent. The following table gives the results of this work. The percentages in the last column represent the gain in leaves of sprayed trees over the average of all control trees in the block. The manner of obtaining these percentages is discussed on page 85.

TABLE 5.—*Estimated percentage of healthy foliage on the sprayed and unsprayed trees May 9, 1895, as compared with the amount a healthy tree should have at that date.*

Row No.	Percentage of healthy foliage compared with the amount the tree should have, estimated May 9, 1895. Tree No.— 1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	Average per cent of healthy leaves per tree in sprayed rows.	Average per cent of healthy leaves per tree in control rows.	Gain in leaves of sprayed trees over average of all control trees, expressed in per cent.
1	92	93	93	92	94	95	92	92	93	87	92.3	....	607
2	9	10	12	9	15	10	8	13	10	5	....	10.1	....
3	90	85	80	82	85	85	85	80	90	85	84.7	....	549
4	15	8	15	10	15	20	18	20	12	15	*a* 14.8	....	13
5	10	12	12	10	18	15	15	25	10	18	....	14.5	....
6	85	65	87	80	85	60	83	78	80	65	76.8	....	488
7	95	85	90	85	83	84	87	85	90	70	85.4	....	554
8	10	1	13	9	12	10	12	25	20	20	....	14.1	....
9	88	75	87	80	90	80	88	80	85	78	83.1	....	536
10	90	80	88	83	90	82	87	85	89	80	85.4	....	554
11	9	8	10	20	11	20	10	10	12	18	....	12.8	....
12	92	80	88	85	80	80	78	72	80	75	81.0	....	520
13	87	87	75	85	65	86	85	80	70	75	79.5	....	509
14	8	10	15	11	20	12	20	20	12	15	....	14.3	....
15	95	89	95	90	90	88	92	88	93	80	90.0	....	589
16	92	65	80	83	83	87	85	85	85	75	82.0	....	528
17	20	11	12	10	8	15	10	22	10	12	....	12.8	....
18	92	85	90	85	88	86	88	80	85	68	84.7	....	549
19	90	85	90	91	85	85	77	84	75	70	83.2	....	537
20	10	9	9	8	9	10	10	10	20	12	....	10.7	....
21	97	95	97	89	92	99	96	98	98	98	95.9	....	634
22	96	96	96	90	90	98	95	96	90	98	94.5	....	624
23	8	10	14	10	8	10	8	20	9	25	....	12.2	*b* 39
24	8	9	11	9	9	9	10	7	8	14	*a* 9.4	....	....
25	89	90	92	85	88	87	96	92	85	94	89.8	....	588
26	10	10	9	8	10	12	11	8	9	35	....	12.2	....
27	91	92	97	87	92	91	89	85	98	90	91.2	....	598
28	87	88	96	88	85	92	84	86	95	92	89.3	....	584
29	9	10	12	10	8	13	9	8	8	10	....	9.7	....
30	96	95	92	91	90	96	90	95	82	95	92.2	....	606
31	11	18	20	20	15	22	21	23	23	20	....	19.3	....
32	65	50	55	60	65	45	45	45	45	50	52.5	....	302
33	92	92	94	94	90	90	85	95	92	95	91.9	....	604
34	9	9	16	20	16	14	15	15	10	18	....	14.2	....
35	86	90	88	92	92	90	98	95	93	94	91.8	....	603
36	65	80	85	90	75	80	50	90	75	92	78.2	....	499
37	10	13	10	12	15	15	12	12	12	17	....	12.8	....
38	65	45	68	70	70	75	80	75	70	85	70.3	....	438
39	73	82	93	(*c*)	(*c*)	92	85	86	78	78	83.4	....	539
40	15	10	10	12	10	12	15	11	10	18	....	12.5	....
41	93	92	95	85	85	80	90	78	87	85	87.0	....	566
42	45	25	45	28	45	50	45	45	48	40	41.6	....	219
43	10	12	15	10	15	18	10	18	22	15	....	14.5	....
44	78	75	80	55	65	55	40	65	40	35	58.8	....	350
45	89	89	80	90	90	95	75	87	75	87	85.7	....	556
46	11	16	13	15	25	20	8	18	15	18	....	15.9	....
47	40	40	40	45	28	45	50	45	30	25	38.8	....	197
48	70	75	55	70	65	50	45	50	50	50	58.0	....	344
49	9	10	20	18	20	15	10	12	15	12	....	14.1	....
50	70	65	50	60	40	50	45	65	65	60	57.0	....	336
51	80	70	75	70	70	65	55	70	65	65	68.5	....	424
52	9	10	10	10	18	12	18	10	18	15	....	13.0	....
53	20	15	18	8	15	15	10	10	15	22	*a* 14.8	....	13
54	85	87	90	70	82	85	85	80	88	70	82.2	....	529
55	9	14	10	9	15	15	10	9	10	12	....	11.3	....
56	85	80	70	75	65	90	60	75	68	90	75.8	....	480
57	70	83	65	60	75	87	80	70	70	88	74.8	....	473
58	8	10	11	10	12	12	11	8	10	10	....	10.2	....

a Trees sprayed in 1894, but unsprayed in 1895.
b Gain of control row over row sprayed in 1894.
c Tree missing.

The comparison of some of the general facts brought out in the estimates of foliage April 22 and 23 and May 9, 1895, shows the progress of the disease during that time.

TABLE 6.—*Comparative percentage of diseased foliage on sprayed and unsprayed trees April 22 and 23 and May 9, 1895.*

Trees examined.	April 22 and 23, 1895.	May 9, 1895.
Average per cent of disease on the trees of all control rows	83.6	86.9
Average per cent of disease on the trees of all sprayed rows	26.2	21.2
Average per cent of disease on the trees of the three rows sprayed in 1894, but left unsprayed in 1895	82.0	87.0

These comparisons show 3.3 per cent more diseased foliage on the control trees May 9 than April 22. The percentage of foliage of the sprayed trees showing disease had decreased, however, 5 per cent. Of the total foliage of the trees sprayed in 1894, but left unsprayed in 1895, 5 per cent more was diseased at the second date than at the first. These figures indicate that the divergence in the percentage of disease on sprayed and unsprayed trees was still increasing just prior to the second estimate. The second estimate may thus be considered as taken before any of the trees had begun to recover from the effects of the disease. The time of maximum contrast was the true time to make the estimates, and it is believed the date of this second estimate was certainly not too late to fully comply with this requirement. This belief was substantiated by a third partial estimate made a week later, which gave in general very similar results to those obtained May 9. It should also be said that the decrease in the percentage of disease on the sprayed trees between the dates of the first and second estimates did not indicate that the second estimate was made too late, or after the trees had begun to recover, but merely that the leaf buds had not fully pushed at the time of the first estimate. This is further shown by the fact that the percentage of disease was still increasing on unsprayed trees up to that time.

Before considering the action of individual sprays in saving the foliage from curl, the following comparisons are given of the action of the classes of sprays used:

TABLE 7.—*Percentage of healthy foliage on trees differently sprayed.*

Percentages of healthy foliage shown by trees sprayed with different classes of sprays. Estimated April 23 and May 9, 1895.	Percentage of healthy foliage Apr. 22 and 23, 1895.	Percentage of healthy foliage May 9, 1895.	Gain in percent of foliage from Apr. 23 to May 9, 1895.	Loss in percent of foliage from Apr. 23 to May 9, 1895.
Average of 30 trees sprayed with sulphur, lime, and salt	71.4	84.6	13.2	....
Average of 70 trees sprayed with sulphur and lime	69.3	80.0	10.7	....
Average of 100 trees sprayed with the two preceding sulphur sprays	70.3	82.3	12.0	....
Average of 90 trees sprayed with Bordeaux mixture	86.2	89.6	3.4	....
Average of 20 trees sprayed with eau celeste	83.3	91.7	8.4	....
Average of 20 trees sprayed with modified eau celeste	83.0	87.6	4.6	....
Average of 130 trees sprayed with the three preceding copper sprays	84.2	89.6	5.4	....
Average of 20 trees sprayed with ammoniacal copper carbonate	69.8	61.4	....	8.4

TABLE 7.—*Percentage of healthy foliage on trees differently sprayed*—Continued.

Percentages of healthy foliage shown by trees sprayed with different classes of sprays. Estimated April 23 and May 9, 1895.	Percentage of healthy foliage Apr. 22 and 23, 1895.	Percentage of healthy foliage May 9, 1895.	Gain in percent of foliage from Apr. 23 to May 9, 1895.	Loss in percent of foliage from Apr. 23 to May 9, 1895.
Average of 30 trees sprayed with copper sulphate, sulphur, and lime (*a*)	76.3	82.0	5.7	....
Average of 10 trees sprayed with iron sulphate and lime	59.2	57.0	....	2.2
Average of 10 trees sprayed with iron sulphate, sulphur, and lime	79.2	75.8	....	3.4
Average of 10 trees sprayed with sulphide of potassium	32.0	38.8	6.8	....
Average of 20 trees sprayed with sulphide of potassium and lime	54.3	49.8	....	4.5
Average of 10 trees sprayed with milk of lime	73.5	58.8	....	14.7
Average of 10 trees sprayed with milk of lime and salt	54.5	79.5	25.0	....

a Compare text.

The table shows the average of healthy foliage on the trees sprayed with the sulphur sprays (sulphur, lime, and salt, 30 trees; sulphur and lime, 70 trees) to have been 82.3 per cent May 9. The average on the trees sprayed with the leading copper sprays (Bordeaux mixture, 90 trees; eau celeste, 20 trees; modified eau celeste, 20 trees) was 89.6 per cent. The average amount of healthy foliage saved on trees sprayed with a combination of these two leading classes of sprays (Bordeaux mixture added to the sulphur and lime sprays, 30 trees) was no greater than the average saved by all sulphur and lime sprays alone, being 82 per cent as against 82.3 per cent for the sulphur sprays. This result was a surprise, but by carefully looking into the reason it would seem that the low average in the case of the combined sprays was due to the low average of the single row 36, while the high average of the sulphur sprays arose from including in the average the results of those sprays which contained much more sulphur than was used in the combined sprays. Notes on the spray applied to row 36 show that considerable sulphur was precipitated in cooking, probably through overheating, and for this reason it would be as well to omit this row in determining the average saving of the combined sprays. The two remaining rows, 18 and 19, sprayed with combined sprays, showed 84.7 and 83.2 per cent of healthy foliage, respectively—an average of 83.9 per cent. The formula for each of these experiments contained 5 pounds of sulphur. In the experiments with uncombined sulphur sprays there were four formulæ containing 5 pounds of sulphur each. The average per cent of saving of these four experiments was 75.3. These facts show that when the amount of sulphur was equal there was an average gain of 8.6 per cent in healthy foliage resulting from the addition of Bordeaux mixture to the sulphur sprays.

The average percentage of foliage saved by the use of the ammoniacal copper carbonate (20 trees) was, May 9, 61.4. As the ammoniacal copper carbonate sprays used contained much less basic copper carbonate than the other copper sprays applied, their comparatively low effectiveness against curl is fully accounted for, and for this reason they were not included when calculating the average action of the copper sprays in general. They were outclassed by the amount of copper used in the other sprays.

The foliage saved by the use of iron sulphate and lime (10 trees) was but 57 per cent May 9. This shows a much less satisfactory action than either the copper or the sulphur sprays. The iron sulphate combined with the sulphur and lime sprays showed a saving of foliage May 9 of 75.8 per cent. While this is a good showing, the beneficial action was evidently due to the sulphur of the spray and not to the iron, and the result was even below the average obtained by the sulphur sprays alone, or equal to those having the same amount of sulphur.

One experiment (10 trees) was made with sulphide of potassium, but the average percentage of foliage saved by this spray was, May 9, only 38.8. Sulphide of potassium combined with milk of lime (20 trees) showed a greater saving of leaves, being 49.8 per cent, but as the sulphide alone gave a saving 11 per cent lower, and as milk of lime saved as high as 58.8 per cent, it is questionable if the lime was not the more active agent in the combination. As already stated, the milk of lime applied as a spray (10 trees) showed a saving of 58.8 per cent of the leaves, which was quite satisfactory for a spray containing none of the standard fungicides. The spray prepared from lime and salt (10 trees) gave a high record, the healthy foliage May 9 being 79.5 per cent. While it is possible that the fungicidal action of this spray may be somewhat higher than that of milk of lime alone, it is perhaps more probable that the results noted arose from another influence. It was learned in the previous year's work that a solution of salt injured the new growth and tender leaves, and it is thought likely that in the present case the earliest growth and that which first showed disease was destroyed by the spray, and that the foliage estimated was a new and somewhat later growth, showing much less disease than the first foliage would have shown. It would be well, however, to repeat this test.

Some interesting facts are brought out by the preceding table in relation to the continued action of the fungicides used. By comparing the first column, the percentages of healthy foliage taken April 22 and 23, with the second column, the percentages taken May 9, it will be seen that the percentage of healthy foliage on all trees sprayed with the sulphur or copper sprays increased decidedly between the two dates of estimate, as shown in the third column. On the other hand, the action of the weaker sprays was overcome by the disease, and the percentage of healthy foliage May 9 was much less than April 23, as shown in the fourth column. These weaker sprays checked the action of the fungus at first, but were not sufficiently active or persistent to prevent its gradual increase upon the trees. An apparent exception to this in the case of the sulphide of potassium appears to arise from the fact that the disease was never greatly checked by this fungicide, the amount of healthy foliage being only 32 per cent April 23. Another and more marked exception is seen in the trees sprayed with lime and salt in solution. It is thought, however, that the true explanation of this exception is that given in the preceding paragraph.

What has been stated will be sufficient to indicate the comparative value of the main classes of sprays used in these experiments. It is shown that the highest degree of effectiveness in saving foliage is possessed by the copper sprays, that the sulphur sprays also possess a high degree of fungicidal activity, and that where Bordeaux mixture is added to the sulphur sprays the effectiveness of the latter is somewhat increased. It is also made clear that sulphide of potassium, sulphate of iron, and several other sprays, as tested, are of secondary value in this work. It should be noted that the average saving obtained from the use of the sulphur sprays is sufficiently high to well warrant the use of these sprays, either in combination with Bordeaux mixture or alone, in cases where it is desired to use a spray having both fungicidal and insecticidal qualities.

It will now be advantageous to briefly consider the leading individual sprays composing the classes of sprays already discussed, in respect to their action on peach foliage and peach leaf curl. The following table gives a compact presentation of the number and nature of these sprays, as well as their action in controlling curl:

TABLE 8.—*Nature and composition of sprays applied.*

Row No.	Classes and formulæ of sprays applied.	Average per cent of healthy foliage May 9, 1895.	Net gain per cent of healthy foliage over average per cent of all control trees.	Percentage of color, texture, and size of uninfected leaves.
	Sulphur, lime, and salt:			
1	15 lbs. sulphur, 30 lbs. lime, 10 lbs. salt	92.3	607	80
3	10 lbs. sulphur, 20 lbs. lime, 5 lbs. salt	84.7	549	60
6	5 lbs. sulphur, 10 lbs. lime, 3 lbs. salt	76.8	488	60
	Sulphur and lime:			
7	15 lbs. sulphur, 30 lbs. lime	85.4	554	60
9	10 lbs. sulphur, 20 lbs. lime	83.1	536	60
10	10 lbs. sulphur, 8 lbs. lime	85.4	554	60
16	6 lbs. sulphur, 4 lbs. lime	82.0	528	80
57	5 lbs. sulphur, 15 lbs. lime	74.8	473	60
12	5 lbs. sulphur, 10 lbs. lime	81.0	520	60
51	5 lbs. sulphur, 5 lbs. lime	68.5	424	60
	Bordeaux mixture and sulphur sprays combined:			
36	3 lbs. copper sulphate, 10 lbs. sulphur, 20 lbs. lime	78.2	499	70
18	3 lbs. copper sulphate, 5 lbs. sulphur, 10 lbs. lime	84.7	549	80
19	2 lbs. copper sulphate, 5 lbs. sulphur, 10 lbs. lime	83.2	537	80
	Bordeaux mixture:			
15	6 lbs. copper sulphate, 15 lbs. lime	90.0	589	100

TABLE 8.—*Nature and composition of sprays applied*—Continued.

Row No.	Classes and formulæ of sprays applied.	Average per cent of healthy foliage May 9, 1895.	Net gain per cent of healthy foliage over average per cent of all control trees.	Percentage of color, texture, and size of uninfected leaves.
33	3 lbs. copper sulphate, 15 lbs. lime	*91.9	*601	80
41	5 lbs. copper sulphate, 10 lbs. lime	87.0	566	100
45	3 lbs. copper sulphate, 10 lbs. lime	85.7	556	90
54	3 lbs. copper sulphate, 10 lbs. lime	82.2	529	80
21	5 lbs. copper sulphate, 5 lbs. lime	95.9	634	100
22	4 lbs. copper sulphate, 5 lbs. lime	94.5	624	100
25	3 lbs. copper sulphate, 5 lbs. lime	89.8	588	80
28	2 lbs. copper sulphate, 5 lbs. lime	89.3	584	80
	Eau celeste:			
27	4 lbs. copper sulphate, 3 pints ammonia	91.2	598	80
30	2 lbs. copper sulphate, 3 pints ammonia	†92.2	†606	†100
	Modified eau celeste:			
35	4 lbs. copper sulphate, 5 lbs. sal soda, 3 pints ammonia	91.8	603	80
39	2 lbs. copper sulphate, 3 lbs. sal soda, 2 pints ammonia	83.4	539	80
	Ammoniacal copper carbonate:			
38	5 ounces copper carbonate, 3 pints ammonia	70.3	438	80
32	3 ounces copper carbonate, 2 pints ammonia	52.5	302	60
	Iron sulphate and lime:			
50	6 lbs. iron sulphate, 10 lbs. lime	57.0	336	10
	Iron sulphate, sulphur, and lime:			
56	5 lbs. iron sulphate, 5 lbs. sulphur, 10 lbs. lime	75.8	480	10
	Potassium sulphide solution:			
47	8 pints potassium sulphide solution	38.8	197	40
	Potassium sulphide solution and lime:			
48	12 pints potassium sulphide solution, 10 lbs. lime	58.0	344	50
42	8 pints potassium sulphide solution, 5 lbs. lime	41.6	219	40
	Lime and salt:			
13	20 lbs. lime, 20 lbs. salt	79.5	509	60
	Lime:			
41	20 lbs. lime	58.8	350	50

* Exceptional, see p. 87. † Outside row, next to driveway.

The above table is planned to give for each experiment the following facts: (1) The number of the row to which the spray was applied: (2) the nature and amount of the ingredients used in each case: (3) the average per cent of healthy foliage shown by the trees of the row May 9, 1895; (4) net gain in healthy foliage above the average per cent of healthy foliage produced by all of the control trees of the block (200 unsprayed trees), and which is expressed in per cent; (5) thrift of uninfected leaves in color, texture, and size. The figures under the fourth head were obtained in the following manner: The average percentage of healthy foliage of all the trees of each control row was first ascertained. These amounts were added together and divided by the number of rows (20) to obtain the average percentage of healthy foliage of all control trees of the block. This average was 13.06. From the average percentage of each sprayed row was then subtracted the average of all control trees to obtain the gain in healthy foliage of each sprayed row. This net gain was then divided by the 13.06 per cent of the control trees to obtain the net gain per cent of each sprayed row. For example, take row 1: $92.3\% - 13.06\% = 79.24\%$ gain; $79.24\% \div 13.06\%$ shows the net gain to be $\frac{607}{100} = 607\%$ of the average amount of healthy foliage of the control trees. The fifth subject, thriftiness of leaves, is discussed in the next general head of this chapter.

In considering the saving of foliage induced through the use of the sulphur, lime, and salt sprays (rows 1, 3, and 6) in comparison with the average saving of sprays containing an equal amount of sulphur but no salt (rows 7, 9, 10, 16, 57, 12, and 51), there appears to be a slight gain in favor of the former sprays. The average saving from both classes, taken together or separately, is in proportion to the amount of sulphur contained in the spray. With 15 pounds of sulphur the average net gain in healthy foliage was 580 per cent; with 10 pounds, 547 per cent; with 6 pounds, 528 per cent; and with 5 pounds, 480 per cent.

In considering the combined sulphur and copper sprays (rows 18, 19, and 36), it is well to omit comparisons of row 36, on account of the injury caused to the effectiveness of the spray applied to it through the precipitation of a portion of the sulphur in boiling, as has already been noted. Rows 18 and 19, containing 3 pounds and 2 pounds of copper sulphate, respectively, and each containing 5 pounds of sulphur and 10 pounds of lime, show a gain in healthy foliage of 549 per cent and 537 per cent, or an average gain of 543 per cent. The average gain from the sulphur sprays, which contained the same amount of sulphur but no copper, was, as already stated, 480 per cent. This shows the advantage of adding the copper to the sulphur sprays.

In the table the experiments with the Bordeaux mixture are arranged according to the amount of copper and lime used in each. The results obtained in the 9 experiments bring out some valuable facts respecting the most desirable proportions of copper and lime to be used. Of the 9 experiments with Bordeaux mixture, 2 formulæ contained 15 pounds of lime each, 3 formulæ 10 pounds each, and 4 formulæ 5 pounds each.

By comparing rows 15 (6 pounds copper sulphate, 15 pounds lime), 41 (5 pounds copper sulphate, 10 pounds lime), and 21 (5 pounds copper sulphate, 5 pounds lime), it will be seen that there was a gain in healthy foliage of 589 per cent, 566 per cent, and 634 per cent, respectively. Dividing these gains by the number of pounds of copper in the respective formulæ, which may be fairly done, owing to the nearly equal amounts of copper contained in each, the following results will be obtained:

	Per cent.
Row 15 (6 pounds copper sulphate, 15 pounds lime = 1 pound copper to 2.5 pounds lime) shows a gain of foliage per pound of copper sulphate of........	98
Row 41 (5 pounds copper sulphate, 10 pounds lime = 1 pound copper to 2 pounds lime) shows a gain of foliage per pound of copper sulphate of........	113
Row 21 (5 pounds copper sulphate, 5 pounds lime = 1 pound copper to 1 pound lime) shows a gain of foliage per pound of copper sulphate of................	127

These comparisons indicate a decided increase in activity of the sprays as the percentage of lime is lessened—the total amount of copper remaining the same, at least to that point where the number of pounds of copper sulphate and lime are equal. The formulæ containing 3 pounds of copper sulphate can not all be compared as justly as the above formulæ have been, owing to a difference in the make of copper sulphate used on row 33. However, rows 45 and 54, each having been sprayed with a formula containing 3 pounds copper sulphate and 10 pounds lime, may be compared with row 25, which was treated with 3 pounds of copper sulphate and 5 pounds of lime. The average saving of foliage per pound of copper sulphate in the former two experiments (10 pounds lime) was 180 per cent. The saving per pound of copper sulphate in the latter experiment (5 pounds lime) was 196 per cent. These comparisons also show most gain in foliage per pound of copper sulphate where least lime was used.

That no misconception may be formed from the preceding comparisons, it is well to consider that the sprays were applied in these cases immediately before the opening of the buds, so that prompt action of the copper was of greater importance than the enduring qualities of the sprays. As will be elsewhere shown, however, the endurance of sprays upon the trees is largely increased with the increase of the amount of lime they contain. A large increase of lime above the absolute requirements for the Bordeaux mixture is not necessary when the spray is applied so near the date of the opening of the buds that its action can not be delayed without loss in effectiveness. On the other hand, if the spray is applied at an earlier date, so that it is required to withstand weathering for a longer period, a considerable increase in the amount of lime may be an advantage in increasing its enduring quality.

The amount of copper sulphate used in the preparation of the Bordeaux mixture varied from 2 to 6 pounds for 45 gallons of spray. Of the nine formulæ tested, that containing 5 pounds of copper sulphate and 5 pounds of lime (row 21) gave the highest gain in foliage over the average healthy foliage of the control trees, or 634 per cent. There was an actual average saving of 95.9 per cent of the spring foliage of the 10 trees sprayed, consequently the average loss of foliage in this experiment was only 4.1 per cent. The next best results were obtained with the spray containing 4 pounds copper sulphate and 5 pounds lime (row 22). This spray gave a gain in foliage above the average produced by the control rows of 624 per cent. The average amount of foliage saved on the 10 trees was 94.5 per cent, showing that all but 5.5 per cent of disease had been prevented. While row 33 shows the next highest saving in foliage, these results, as already indicated, are exceptional, as shown by comparison. The yield of fruit which this row produced also shows the foliage records to be exceptional, and they may properly be omitted in these comparisons.

The results obtained by the use of eau celeste and modified eau celeste were very satisfactory, but in no case was as high a percentage of foliage saved by them as in the better tests with Bordeaux mixture. The exceptionally high percentage of foliage saved on row 30 with but 2 pounds of copper sulphate may be in part due to the fact that the row was an exterior one of the block and next to a driveway, where the trees may have been better nourished than those of interior rows. By comparing the formula used on row 27 with that used on row 35 (each containing 4 pounds of copper sulphate) it will be seen that the saving of foliage was about equal with eau celeste and modified eau celeste. Comparison of these results with those shown by row 22, which was sprayed with Bordeaux mixture containing the same amount of copper, will show that the latter saved the highest percentage of foliage.

Ammoniacal copper carbonate gave less satisfactory results than the preceding sprays, probably owing to insufficient copper. The various results given by the other sprays tabulated require no special comment.

Another fact is made evident by the preceding table. Of two formulæ of the same class, as the Bordeaux mixtures, one containing more of the fungicide than the other, the percentage of foliage saved for each pound of fungicide will be the greater in the weaker spray. Each of the Bordeaux mixtures used in spraying rows 21, 22, 25, and 28 contained 5 pounds of lime, but the amounts of copper sulphate used were 5, 4, 3, and 2 pounds, respectively. The total net amount of foliage saved by these sprays and the net saving per pound of copper sulphate each contained may be thus shown.

Row 21: 5-pound formula, 634 per cent saved; per pound of copper sulphate, 127 per cent.

Row 22: 4-pound formula, 624 per cent saved; per pound of copper sulphate, 156 per cent.

Row 25: 3-pound formula, 588 per cent saved; per pound of copper sulphate, 196 per cent.

Row 28: 2-pound formula, 584 per cent saved; per pound of copper sulphate, 292 per cent.

These figures show a gradual decrease of the total per cent of foliage saved as the amount of the fungicide is decreased, but a decided increase in the percentage of foliage saved per pound of fungicide.

COMPARISONS OF WEIGHT AND COLOR OF FOLIAGE FROM SPRAYED AND UNSPRAYED TREES.

Besides the direct loss of leaves through infection by *Exoascus deformans*, there is an indirect loss through the retarding of growth of such foliage as has not been directly infected by the fungus. A limited examination of this matter was made May 17 and 18, 1895. Two typical trees were selected in adjoining rows, one of which had been

UNTREATED TREES IN LOVELL ORCHARD, BIGGS, CAL.

(Compare with Plate IX.)

DESCRIPTION OF PLATE VIII.

Experiments at Biggs, Cal. (Unsprayed.) Looking north through the Lovell trees from row 28 of the experiment block, showing the unsprayed trees on both sides as they appeared May 15, 1895, in the unsprayed orchard. These should be contrasted with the two sprayed rows, 21 and 22, shown in Pl. IX.

This row, No. 22, set 21,478 peaches; the adjoining unsprayed row set only 2,127.

TREATED TREES IN LOVELL ORCHARD.

(Compare with Plate VIII.)

This row, No. 21, set 22,163 peaches; the adjoining unsprayed row set only 1,911.

DESCRIPTION OF PLATE IX.

Experiments at Biggs, Cal. (Bordeaux mixture.) Looking east between rows 21 and 22, May 15, 1895. Row 21 was treated before blooming with 5 pounds copper sulphate, 5 pounds lime, and 45 gallons of water, and row 22 with 4 pounds copper sulphate, 5 pounds lime, and 45 gallons of water. Row 21 matured 4,443 pounds of fruit, and row 22, 4,421 pounds, while row 20, unsprayed, just south of row 21, matured only 648 pounds, and row 23, unsprayed, just north of row 22, matured only 712 pounds. Row 21 set 22,164 peaches, and row 22 set 21,478, while row 20 set only 1,911, and row 23 only 2,127; or, in other words, row 21 set eleven times as many peaches as row 20, and row 22 ten times as many as row 23 (p. 111). (Compare with Pl. VIII.)

sprayed and the other not. These were trees No. 10 of rows 20 and 21. Tree No. 10 of row 21 was sprayed the first week in March, 1895, with Bordeaux mixture (5 pounds copper sulphate, 5 pounds lime). Tree No. 10 of row 20 had not been sprayed. From each of these trees was gathered 2 pounds of healthy foliage. Careful measurements were made of the length of the branches of 1894 growth necessary to yield this weight of healthy leaves, and it was found that on the unsprayed tree it required 186 feet 2 inches, while on the sprayed tree it required only 49 feet 4 inches. The work was done as similarly as possible on both trees. The 2 pounds of foliage from the sprayed tree contained 2,428 leaves, and the 2 pounds from the unsprayed tree 2,546. In other words, 118 more healthy leaves were required from the unsprayed tree than from the sprayed tree to equal 2 pounds in weight, or 59 more leaves per pound. This result is due to the indirect rather than the direct action of the disease. The leaves from the unsprayed trees, being healthy, should average as great in weight as those from the sprayed trees, were it not for the retarding and impoverishing action of the disease upon the general growth of the tree. In comparing diseased with healthy leaves, however, this ratio would be reversed. The number of diseased leaves required for a given weight would be much less than the number of healthy leaves required. The diseased leaves are greatly curled and distorted through the irritation or stimulative action of the fungus present in the tissues, and in many instances they also become enormously increased in width, thickness, and weight.

The contrast observed in the color and general appearance of the leaves of the sprayed and unsprayed trees was very marked. The foliage of the trees treated with the stronger copper sprays, especially the Bordeaux mixtures, presented the finest appearance. On May 8, 1895, two months after the spray work was completed, and at the height of the disease, the foliage on trees thus sprayed presented the greatest perfection. It was so abundant and so dense as to throw very dark shadows beneath the trees, making it difficult to obtain good photographs among them. This dense foliage existed upon both the lower and the upper branches. The leaves were of a very dark and rich green color, long, soft, and beautiful. Upon the unsprayed trees comparatively few leaves presented the appearance of full health, and much of the diseased foliage had already fallen, leaving many trees nearly bare. The color of much of the remaining foliage was yellow and sickly. Many of the uncurled leaves were small and light colored on both the lower and the upper limbs. What growth these trees had made up to that date was largely terminal, very little healthy or comparatively healthy growth being apparent from lateral buds. (Compare Pls. VIII and IX.)

The influence of the various sprays on the thriftiness of the leaves was especially examined. This examination was confined to such foliage as was free from infection by the fungus, but was extended to sprayed and unsprayed trees alike, and to all rows of the block. In recording the comparative thrift of uninfected foliage, attention was given to the depth of the green color, to the softness of texture, and to the size of the leaves. These features of the foliage were considered collectively and recorded on the scale of 100; for instance, the most thrifty foliage was recorded at 100 per cent of thrift, and the less thrifty at a lower percentage. This method enables one to distinguish at a glance those sprays giving the best results in color, texture, and size of leaves—in other words, in functional ability. The records for each row and formula are given in the general table under the preceding head of this chapter, to which the reader is referred. It will there be seen that the trees of 5 rows produced foliage of the highest quality in spite of the presence of disease. These rows were all sprayed with the copper sprays, and all but one with Bordeaux mixture. Owing to the fact that row 30, showing first-quality foliage, was an outside row, it may be well to omit it in comparisons. The remaining 4 rows, Nos. 15, 41, 21, and 22, were all sprayed with Bordeaux mixture, containing 6 pounds, 5 pounds, 5 pounds, and 4 pounds of copper sulphate, respectively. Smaller amounts of copper sulphate did not give equally high results.

The average results shown by the different classes of sprays are as follows:

	Per cent.
Sulphur, lime, and salt (3 rows)	67
Sulphur and lime (7 rows)	63
Bordeaux, sulphur, and lime combined (3 rows)	77
Bordeaux (9 rows)	90
Bordeaux, 4, 5, and 6 pound formulæ (4 rows)	100
Eau celeste (2 rows)	90
Modified eau celeste (2 rows)	80
Ammoniacal copper carbonate (2 rows)	70
Iron sulphate and lime (1 row)	40
Iron sulphate, sulphur, and lime (1 row)	40
Potassium sulphide (1 row)	40
Potassium sulphide and lime (2 rows)	45
Lime and salt (1 row)	60[1]
Lime (1 row)	50
Trees sprayed in 1894, but not in 1895 (3 rows)	20
Control trees (19 rows)	20[2]

The Bordeaux mixture is here shown to give the best average results as to thrift of foliage. The excellence of texture, color, and size of the leaves on rows sprayed with the stronger Bordeaux mixtures would be hard to surpass.

[1] First leaves probably injured by spray.

[2] One exceptional row, showing 40 per cent, omitted; perhaps benefited by wind-borne spray.

GROWTH OF BRANCHES AND LEAF BUDS ON SPRAYED AND UNSPRAYED TREES.

Besides knowing the action of the disease and of the sprays upon foliage, it is desirable to ascertain their action on leaf buds and the growth of branches. Two months after growth started from May 10–14, 1895—a study was made of the growth of 20 trees in the experiment block, 10 sprayed and 10 unsprayed. The rows selected for this work were Nos. 20 (unsprayed) and 21 (sprayed). These rows were types of the injurious action of the disease and of the beneficial action of the spray applied, which was 5 pounds of copper sulphate and 5 pounds of lime. Much time was given to making measurements of the new growth and recording the results, the time being equally divided between the 10 sprayed and the 10 unsprayed trees. Typical limbs were measured upon both the lower and upper portions of the trees, and the length and comparative health of the new growth was recorded. The length of 1894 growth and that which was older was first ascertained, and was followed by careful measurements of all spring growth of 1895 arising from wood of 1894 or from that which was older. The results of this work are shown in the following table:

TABLE 9.—*Records of measurements of healthy and diseased wood on unsprayed and sprayed trees, taken May 10–14, 1895.*

Tree No.	Row 20, unsprayed trees.					Row 21, sprayed trees.				
	Length of wood of 1894.	Length of spring growth of 1895—				Length of wood of 1894.	Length of spring growth of 1895—			
		On wood of 1894.		On wood more than 1 year old.			On wood of 1894.		On wood more than 1 year old.	
		Healthy.	Diseased.	Healthy.	Diseased.		Healthy.	Diseased.	Healthy.	Diseased.
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
1	1,422	492	249	76	91	674	1,189	11	194	2
2	1,614	570	229	219	134	664	908	6	494	14
3	1,364	301	251	83	22	592	768	4	46	....
4	1,304	557	304	234	29	666	1,580	6	330	....
5	1,576	499	326	85	41	702	1,100	3	45	....
6	1,886	298	257	182	41	976	1,259	4	325	1
7	1,366	527	230	18	32	998	1,348	4	183	....
8	1,758	686	516	53	2	1,068	2,751	2	195	....
9	1,986	977	550	120	8	938	2,100	....	84	....
10	1,912	670	582	56	2	982	1,869	....	220	....
Total	16,188	5,577	3,494	1,126	402	8,260	14,872	40	2,116	17

From the footings in the preceding table it appears that the total length of 1894 wood measured upon the unsprayed trees was nearly twice as great as that measured on the sprayed trees. This arose from the scarcity of new growth on this unsprayed wood, hence an equal time given to taking measurements upon each tree included more old wood upon unsprayed than upon sprayed trees.

On the unsprayed trees, prior to the middle of May, the total amount of new growth on 16,188 inches of 1894 wood, including the older wood from which this arose, was 10,599 inches. On the sprayed trees the new growth amounted to 17,045 inches during the same time (two months) on 8,260 inches of 1894 growth, including the older growth from which the latter arose. This was a net gain of 215 per cent, length of old wood considered, over the growth produced by the unsprayed trees. Otherwise stated, the unsprayed trees had averaged a new spring growth of 7.85 inches per running foot of 1894 wood and older, while the sprayed trees had produced a growth of 24.75 inches per foot of 1894 wood and older during the same time. This shows a gain in growth on the sprayed trees during these two months of 16.90 inches per foot of old wood. The importance of this matter will appear to all growers who have peach orchards situated where the spring growth represents the major part of that of the season, as is true in many peach-growing regions. In such orchards this would frequently represent a reduction of 25 per cent in the annual growth. In the peach, the growing wood of one year is the bearing wood of the next, hence the amount of wood produced would have added significance.

Considering the total growth of the spring of 1895 from wood grown prior to 1894—the pushing of dormant or quiescent buds—an analysis of the table shows a net gain by the old wood of sprayed trees of 173 per cent above the growth produced from like wood of unsprayed trees. This action of spray enables the grower to renew bearing wood on the lower portions of his trees, which is an advantage where trees are old or close set and tending to grow upward, or where curl or other causes have tended to denude the lower limbs of young and productive wood. This tendency of Bordeaux mixture to aid in the forcing and active growth of dormant buds was especially well marked in the case of a tree sprayed very thoroughly on one side (6 pounds copper sulphate, 4 pounds quicklime, 45 gallons of water) and left unsprayed on the other. From the base of the main limbs on the sprayed side there arose 13 shoots from dormant buds during the first two months of spring growth, while the unsprayed limbs produced practically none. The 13 shoots on the sprayed side had made the following growth to May 17, growth beginning about the close of the first week in March:

Shoots.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	Total.
Length in inches............	36	44	29	37	46	21	36	36	36	46	22	21	23	36 feet 1 inch.

As shown by the table, the growth coming from 13 dormant buds at the base of the main limbs of the sprayed side of the tree during the first two months of spring growth amounts to 36 feet and 1 inch, or an average of over 33 inches for the 13 shoots. That this astonishing pushing of new basal buds was not due to injury of the top by the spray was shown by the immense amount of dark green foliage the sprayed half of the tree produced and from the amount and perfection of the fruit it bore. It was evidently an aided or stimulated basal growth. In table 9 is shown the comparative health or disease of the spring wood measured. Where shoots had suffered from disease to such an extent that they were enlarged, crooked, or otherwise distorted or injured by the disease, they were classed as diseased; when not so injured, they were classed as healthy. In respect to this classification the table gives the following facts: On the unsprayed trees the new shoots measured on growth of 1894 or older amounted to 10,599 inches, of which 6,703 inches was of healthy wood and 3,896 inches of diseased wood, or, in other words, 63 per cent of the wood was healthy and 37 per cent diseased. On the sprayed trees the total length of new shoots measured on 1894 growth or older was 17,045 inches; of this, 16,988 inches was of healthy wood and only 47 inches of diseased wood, or $99\frac{2}{3}$ per cent was healthy and $\frac{1}{3}$ per cent diseased.[1]

Many peach orchards are cultivated under conditions of moisture and nourishment that enable the trees to grow throughout the entire summer. In such situations trees badly diseased in the spring are apt to so far recover before frost that there is little apparent difference between them and the trees saved from curl by the use of sprays. That this recovery is not entire, however, is shown by actual comparisons. In the Riviera orchard, Live Oak, Cal., were obtained the following records, in February, 1894, from 10 sprayed and 10 unsprayed Crawfords Late peach trees. The trees are fully described under the following heading of this

[1] These comparative records of the length of healthy and diseased branches upon sprayed and unsprayed trees fully serve the purpose of comparison for which they are here intended. There is another phase of the matter, however, which should not be overlooked or misunderstood at this time. A branch classed as diseased does not mean that it was diseased or swollen throughout its entire length, but that external signs of a diseased or injured condition were noted at some point in its course. If it be supposed that one-third of the injuries noted were dead ends or other imperfections not due to the infecting of the branch by the fungus, but indirect injuries arising from the loss of foliage, there remain two-thirds of the injuries which may be properly assumed to be due to the infection of branches by means of mycelium coming from diseased leaves. There would then appear to be 25 per cent of the cases which might be classed as diseased from mycelium infection. As already indicated, however, this does not mean that these branches are infected throughout their entire length, but show one or more points of infection at the buds. It is thought by the writer that not more than 1 bud in 10 is actually infected in these diseased branches. If this estimate is approximately correct, the number of infected buds on the unsprayed trees would be represented by one-tenth of 25 per cent, or 2.5 per cent of the buds on the tree. In brief, it is believed that it is rare for more than 3 per cent of the buds of a badly diseased tree to become infected by the mycelium from diseased leaves—in other words, that rarely more than this percentage of buds of one year carry a perennial mycelium to the next spring.

chapter, and it will here be sufficient to state that the growth on the sprayed and unsprayed trees could be fairly compared. The sprayed trees were treated with the sulphur, lime, and salt spray in the winter of 1892-93. Leaf curl developed seriously in the orchard in the spring of 1893. The sprayed trees saved their foliage and bore a full crop of fruit in 1893, while the unsprayed trees, everywhere surrounding those that were sprayed, lost the spring foliage and most of the fruit. All trees stood upon moist, deep, rich river bottom land, where growth could continue throughout the season. In the fall of 1893 the unsprayed trees had apparently largely overtaken the sprayed trees in growth, as the former had carried little crop, while those that were sprayed had matured a full crop. That the unsprayed trees were not, however, fully abreast of the sprayed trees when growth ceased in 1893, is shown by the measurements recorded in February, 1894 (table 11). These measurements were made on various sides of each tree, and on lower and upper limbs, and as a week was devoted to the work, the measurements are believed to be sufficiently extensive to give reliable results.

TABLE 10.—*Gain in number of lateral shoots and spurs from old wood on sprayed trees.*

Records.	Trees.	
	Sprayed.	Unsprayed.
Length of old wood, measured in inches, on sprayed and unsprayed trees....	8,255	7,363
Number of lateral shoots and spurs that pushed from old wood in 1893.......	2,922	2,300
Number of lateral shoots and spurs per inch of old wood........................	0.3539	0.3124
Gain in favor of sprayed trees....................................per cent..	13	....

The above table shows that 13 per cent more buds had pushed into shoots and spurs on the sprayed trees, in the summer of 1893, than on the unsprayed trees. All represented new growth from old wood.

The following table shows that the length of the new growth for the entire season of 1893 on the sprayed trees was 6.4 per cent more than that produced on the unsprayed trees. This was in spite of the facts that the unsprayed trees were so situated that growth could continue until frost and that they had not carried a crop of fruit as had the sprayed trees:

TABLE 11.—*Gain in length of new growth in favor of sprayed trees.*

Records.	Trees.	
	Sprayed.	Unsprayed.
Length of old wood, measured in inches, on sprayed and unsprayed trees....	8,255	7,363
Length of new branches..	18,174	16,390
Length of spurs, estimated at 2 inches per spur................................	2,692	1,100
Total length of new growth in inches	20,866	17,490
Inches of new growth per inch of old wood	2.527	2.375
Gain in new growth in favor of sprayed trees........................per cent..	6.4	....

The number of leaf buds produced on the sprayed and unsprayed trees per lineal inch or foot of old wood did not greatly differ. There was, however, a gain of 1 per cent in favor of the sprayed trees, as shown below:

TABLE 12.—*Gain in number of leaf buds in favor of sprayed trees.*

Records.	Trees.	
	Sprayed.	Unsprayed.
Length of old wood, measured in inches, on sprayed and unsprayed trees	8,255	7,363
Number of leaf buds	5,403	4,763
Average number of leaf buds to inch of wood	0.651	0.647
Gain in favor of sprayed trees ... per cent	1	....

The tendency of the new growth to send out lateral branches and spurs was much more marked upon the sprayed than upon the unsprayed trees, the gain in this case being 109 per cent. This is a decided advantage, for the tree is thus enabled to bear a heavier and more equally distributed crop than where such laterals are few.

TABLE 13.—*Gain in number of lateral shoots and spurs from new wood on sprayed trees.*

Records.	Trees.	
	Sprayed.	Unsprayed.
Length of new wood, measured in inches, on sprayed and unsprayed trees	18,171	16,390
Number of lateral shoots and spurs from new wood	640	276
Number of lateral shoots and spurs per inch of new wood	0.0352	0.0168
Gain in favor of sprayed trees ... per cent	109	....

A complete tabular presentation of the data from which the four preceding tables have been drawn will be found under the following heading.

THE DEVELOPMENT OF NEW FRUIT BUDS AND FRUIT SPURS FOR THE YEAR FOLLOWING AN ATTACK OF CURL.

In February, 1894, while the action of the sulphur sprays was being considered in the Riviera orchard, the question arose as to the relative ability of sprayed and unsprayed trees to produce fruit buds and fruit spurs for the year following a severe attack of curl. Many trees in this orchard had been sprayed with the sulphur sprays in the winter of 1892–93 for the destruction of the San José scale (*Aspidiotus perniciosus*). The manner in which this work was done furnished an excellent opportunity to ascertain the facts desired respecting the development of fruit buds. It was noted during the early part of the winter that individual trees, scattered through a 40-acre block of 4-year-old Crawfords Late, had become infested with San José scale. A careful examination of this part of the orchard was then made, and each tree found to be infested with the scale was marked for spraying.

Later in the winter Mr. A. D. Cutts, one of the proprietors and the superintendent of the orchard, had these marked trees thoroughly sprayed with sulphur, lime, and salt, the formula used being as follows: Sulphur 15 pounds, lime 30 pounds, salt 10 pounds, water 60 gallons.

While this spray was known to be effective against San José scale, it also proved very effective against curl, which developed seriously in the orchard in the spring of 1893. The result of the spraying was to produce a most striking effect. When the disease developed, the unsprayed trees, which represented the major portion of this 40-acre orchard, were almost wholly denuded of foliage and largely of fruit, while the sprayed trees, scattered through the block, were in full foliage and fruit. This orchard was selected as a very suitable place in which to study the relative thrift and number of fruit buds and spurs produced on sprayed and unsprayed trees for the year following, and for this purpose 20 trees were selected from this block in February, 1894. Ten of these trees had been sprayed in the winter of 1892–93, and had thus escaped serious injury from curl in the spring of 1893, while 10 of them had not been sprayed and had suffered considerably from the disease. These 20 trees were all Crawfords Late, 5 years old in the winter of 1893–94, and similar in other respects, the soil, situation, etc., being the same.

The work of counting and grading buds upon these sprayed and unsprayed trees was begun about the middle of February, 1894, and continued for a week, an equal amount of time being given to each tree. To make all records as representative as possible of all portions of the trees studied, the limbs were measured and the buds counted and classified upon different sides of each tree and upon both lower and upper limbs. In the selection and measurement of limbs, as well as in the counting and classification of the buds, an effort was made to correctly represent the conditions existing in all parts of each tree, and of all trees alike. After the selection of a limb for study, all wood grown prior to 1893 was measured and the length recorded. Following this all the shoots and spurs of 1893 growth, and arising from the old wood measured, were counted and the number set down. All these new shoots, with the exception of fruit spurs 4 inches or less in length, were then measured. Records were kept of the length of the new shoots, the number of well-developed fruit buds, the number of poorly developed fruit buds, and the number of leaf buds they bore. A record of the number of lateral shoots and fruit spurs from the growth of 1893 was also preserved. The results of this work are brought together in the two tables which follow:

TABLE 14.—*Records of fruit buds and leaf buds produced on given lengths of branches on 10 sprayed trees (Crawfords Late) after a severe attack of leaf curl in the spring of 1893.*

Tree No.	New wood.												New growth from old wood.					
	Lower limbs.						Upper limbs.						Lower limbs.			Upper limbs.		
	Number of spurs.	Laterals, number of shoots.	New wood (length in inches).	Fruit buds.		Number of leaf buds.	Number of spurs.	Laterals, number of shoots.	New wood (length in inches).	Fruit buds.		Number of leaf buds.	Number of spurs.	Number of shoots.	Old wood (length in inches).	Number of spurs.	Number of shoots.	Old wood (length in inches).
				Well developed.	Poorly developed.					Well developed.	Poorly developed.							
1	3	21	673	397	333	220	21	22	824	454	273	192	126	45	297	79	79	339
2		3	597	501	202	192	2	13	998	804	375	215	27	53	288	44	151	573
3	2	3	810	448	358	276	12	22	922	603	426	304	77	67	483	69	116	490
4	5	10	664	407	346	264	19	54	1,112	590	528	385	68	63	347	86	96	483
5	2	3	731	581	273	238	23	34	938	689	405	221	24	72	426	28	80	304
6			517	456	198	151	7	25	1,157	744	489	281	78	74	409	76	103	516
7	4	6	822	458	389	198	14	108	1,507	802	692	511	28	113	428	29	68	295
8	1	5	693	600	259	218	16	41	1,189	688	449	275	90	80	535	49	111	341
9		4	820	641	295	253	25	60	1,181	819	510	411	66	87	554	36	63	265
10	7	8	883	619	390	177	8	27	1,136	745	592	421	59	112	440	36	114	442
Total	24	63	7,210	5,111	3,043	2,187	147	406	10,964	6,938	4,749	3,216	643	766	4,207	532	981	4,048

TABLE 15.—*Records of fruit buds and leaf buds produced on given lengths of branches on 10 unsprayed trees (Crawfords Late) after a severe attack of leaf curl in the spring of 1893.*

Tree No.	New wood.												New growth from old wood.					
	Lower limbs.						Upper limbs.						Lower limbs.			Upper limbs.		
				Fruit buds.						Fruit buds.								
	Number of spurs.	Laterals, number of shoots.	New wood (length in inches).	Well developed.	Poorly developed.	Number of leaf buds.	Number of spurs.	Laterals, number of shoots.	New wood (length in inches).	Well developed.	Poorly developed.	Number of leaf buds.	Number of spurs.	Number of shoots.	Old wood (length in inches).	Number of spurs.	Number of shoots.	Old wood (length in inches).
1	1	4	475	155	266	123	1	12	589	240	389	214	6	30	151	17	60	236
2	1	1	479	281	245	95	12	12	787	538	375	230	34	50	202	20	66	305
3	......	6	597	308	274	176	3	13	1,002	558	488	381	27	67	253	15	97	454
4	......	......	715	221	436	197	5	6	934	483	620	267	34	62	250	18	121	513
5	2	19	983	374	582	275	10	23	1,166	485	714	421	13	49	206	2	94	319
6	1	3	498	397	247	117	4	8	746	737	303	210	34	71	291	44	114	491
7	......	......	646	405	390	157	19	31	1,188	616	648	408	12	122	348	8	116	425
8	2	26	806	416	479	168	5	12	1,260	572	858	393	60	111	408	23	130	576
9	3	3	719	402	372	193	3	4	937	636	545	262	19	82	319	49	161	727
10	......	5	702	459	348	166	......	16	1,161	644	621	310	24	100	380	19	116	506
Total	10	67	6,620	3,418	3,639	1,667	62	137	9,770	5,509	5,561	3,096	263	747	2,808	215	1,075	4,555

In the preceding tables, the number of shoots and spurs of 1893, which arose from wood of 1892 or earlier (old wood), as well as the length of the old wood itself, are classed under the general head of new growth from old wood. The measurements of the growth of 1893, and the number of lateral shoots and fruit spurs, as well as the number of fruit and leaf buds the new growth produced, are classed under the head of new wood. The buds were counted in a uniform manner upon all growth measured, except the buds borne by fruit spurs, which are estimated at 3 buds per spur in the tabulated calculations which follow. The fruit buds have been divided into two classes—well developed and poorly developed.

In considering the information given in the preceding tables, only those facts having a direct bearing on the fruit buds of the sprayed and unsprayed trees will be taken up under this heading. Those relating to length of new growth, number of new shoots, and number of leaf buds have already been considered under the preceding heading of this chapter.

The following digest from the general tables shows that 23,879 fruit buds of all kinds were produced by the new growth arising from 8,255 linear inches of old wood on 10 sprayed trees in 1893—an average of 2.892 buds per inch of old wood. The average number of buds per inch of old wood on the 10 unsprayed trees, obtained in a similar manner, was 2.686. These figures show that the sprayed trees produced $7\frac{2}{3}$ per cent more fruit buds of all kinds in the summer of 1893 than were produced by the unsprayed trees. These were fruit buds for the crop of 1894, and upon trees bearing a full crop in 1893, while the contrasted unsprayed trees bore very little.

TABLE 16.—*Gain in total number of fruit buds on sprayed trees.*

Records.	Trees.	
	Sprayed.	Unsprayed.
Length of old wood, measured in inches, on sprayed and unsprayed trees	8,255	7,363
Total number of fruit buds of all kinds	23,879	19,777
Average number of same to inch	2.892	2.686
Gain in favor of sprayed trees ......per cent..	$7\frac{2}{3}$	....

The percentage of gain in the gross number of fruit buds shown by the sprayed trees is considerable, but it represents only partially the advantages derived from the spray. Examinations of the unsprayed trees showed that a large percentage of the fruit buds they had produced in 1893 were imperfect, many of them being so poorly developed that fruit could not be expected from them. The following table shows the average number of imperfectly developed fruit buds on the sprayed trees to be 0.944 per linear inch of old wood, while on the unsprayed trees the average per inch of old wood was 1.249. This shows 32 per cent more imperfect fruit buds on the unsprayed than upon the sprayed trees at the close of the growing season of 1893.

TABLE 17.—*Excess of imperfectly developed fruit buds on unsprayed trees.*

Records.	Trees.	
	Sprayed.	Unsprayed.
Length of old wood, measured in inches, on sprayed and unsprayed trees	8,255	7,363
Number of imperfectly developed fruit buds	7,792	9,200
Average number of imperfectly developed fruit buds to inch of wood	0.944	1.249
In favor of unsprayed trees .... per cent	....	32

In comparing the number of well-developed fruit buds which were produced in 1893 by the sprayed and unsprayed trees, independent of the number of spur buds, it was learned that the number upon the sprayed trees was 20 per cent greater, as shown in the following table, than the number produced by the unsprayed trees.

TABLE 18.—*Gain in well-developed fruit buds, exclusive of spurs, on sprayed over unsprayed trees.*

Records.	Trees.	
	Sprayed.	Unsprayed.
Length of old wood, measured in inches, on sprayed and unsprayed trees	8,255	7,363
Number of well-developed fruit buds, exclusive of spur buds	12,049	8,927
Average number of well-developed fruit buds to inch of wood	1.459	1.212
Gain in favor of sprayed trees .... per cent	20	....

Taking the aggregate of all well-developed fruit buds, including the spurs, at an average of 3 buds each, the sprayed trees make a still better showing when contrasted with the unsprayed. The average number of all well-developed buds on the sprayed trees was 1.949 per linear inch of old wood, and on the unsprayed trees 1.437 per inch of old wood. This shows a gain of 35 per cent in well-developed fruit buds in favor of the sprayed trees. These facts are shown in tabular form as follows:

TABLE 19.—*Gain in spur buds and other well-developed fruit buds on sprayed over unsprayed trees.*

Records.	Trees.	
	Sprayed.	Unsprayed.
Length of old wood, measured in inches, on sprayed and unsprayed trees	8,255	7,363
Aggregate of spur buds and of other well-developed fruit buds	16,087	10,577
Average number of same to inch	1.949	1.437
Gain in favor of sprayed trees .... per cent	35	....

One of the most striking contrasts shown by the data obtained in these field studies is that existing between the number of fruit spurs and spur buds produced by the sprayed and unsprayed trees in 1893. There was a net gain in the number of fruit spurs and spur buds on the sprayed trees of 118 per cent above the number produced by the unsprayed trees, a fact that should certainly appeal directly to the business faculties of every grower of peaches. It should also be remembered that these sprayed trees had carried a crop while producing these fruit spurs for the following year, while the unsprayed trees had borne but few peaches. The facts here discussed are shown in the table that follows.

TABLE 20.—*Gain in number of spur buds on sprayed over unsprayed trees.*

Records.	Trees.	
	Sprayed.	Unsprayed.
Length of old wood, measured in inches, on sprayed and unsprayed trees	8,255	7,363
Total number of spurs	1,346	550
Number of spur buds, estimated at 3 buds per spur	4,038	1,650
Average number of spurs per inch	0.163	0.075
Average number of spur buds per inch	0.489	0.224
Gain in favor of sprayed trees ....per cent..	118	....

Besides comparing the number of fruit buds produced in 1893 by the sprayed and unsprayed trees, it is desirable to contrast the bud-producing abilities of the upper and lower portions of these trees. It is generally conceded as desirable that the crop of a peach tree should be borne as largely as possible upon the lower limbs, and anything tending to this result may prove of value. Peach leaf curl, being due to a fungous parasite, has a tendency to do more injury to the lower than to the upper portions of the trees affected. The atmospheric conditions are more favorable for the germination of spores and to fungous growth in the lower and more shaded portions of the tree, and the lower branches accumulate greater numbers of fungous spores than the upper branches. In the following table it is shown that the total number of fruit buds produced by the lower limbs of the sprayed trees was 7 per cent greater than the number produced by the upper limbs, comparing equal lengths of new wood in each case. On the unsprayed trees, however, the upper limbs produced 5 per cent more fruit buds per linear unit of new wood than the lower limbs. This shows a difference of 12 per cent in favor of the sprayed trees. The tabulated figures are as follows:

TABLE 21.—*Gain in total number of fruit buds on lower limbs of sprayed trees over those of unsprayed trees, as compared with upper limbs of each, respectively.*

Records.	Trees.	
	Sprayed.	Unsprayed.
Length of new wood, measured in inches, on upper limbs	10,964	9,770
Length of spurs, estimated at 2 inches per spur	1,358	554
Total length of new wood on upper limbs	12,322	10,324
Length of new wood, measured in inches, on lower limbs	7,210	6,620
Length of spurs, estimated at 2 inches per spur	1,334	546
Total length of new wood on lower limbs	8,544	7,166
Total number of fruit buds on upper limbs	13,724	11,901
Total number of fruit buds on lower limbs	10,155	7,876
Average number of fruit buds per inch on upper limbs	1.114	1.153
Average number of fruit buds per inch on lower limbs	1.189	1.099
Gain in favor of lower limbs on sprayed trees ....per cent..	7	....
Gain in favor of upper limbs on unsprayed trees ....do....	....	5
Difference in favor of sprayed trees ....do....	12	....

By contrasting only the well-developed and spur fruit buds it is learned that there was 14 per cent in the number of buds in favor of the lower limbs on the sprayed trees and 4 per cent in favor of the upper limbs on the unsprayed trees. This showed a difference of 18 per cent in favor of the lower limbs of the sprayed trees. The entire comparison is given in the table which follows:

TABLE 22.—*Gain in number of well-developed and spur fruit buds on the lower limbs of sprayed over unsprayed trees, as compared with upper limbs of each, respectively.*

Records.	Trees.	
	Sprayed.	Unsprayed.
Length of new wood, measured in inches, on upper limbs	10,964	9,770
Length of spurs, estimated at 2 inches per spur	1,358	554
Total length of new wood on upper limbs	12,322	10,324
Length of new wood, measured in inches, on lower limbs	7,210	6,620
Length of spurs, estimated at 2 inches per spur	1,334	546
Total length of new wood on lower limbs	8,544	7,166
Number of well-developed and spur fruit buds on upper limbs	8,975	6,340
Number of same on lower limbs	7,112	4,237
Average number of same per inch on upper limbs	0.728	0.614
Average number of same per inch on lower limbs	0.832	0.591
Gain in favor of lower limbs on sprayed trees ... per cent	14	
Gain in favor of upper limbs on unsprayed trees ... do		4
Difference in favor of sprayed trees ... do	18	

CHAPTER VI.

INFLUENCE OF SPRAYS ON THE FRUITING OF THE TREES.

THINNING THE FRUIT OF SPRAYED TREES.

The general discussion of the spray work conducted in the Rio Bonito orchard will be found in Chapter IV, and it is therefore not necessary to review these matters here. As soon as growth was well started in this orchard in the spring of 1895, it became evident that the fruit would have to be thinned on a portion of the Lovell trees comprising the experiment block. The peaches were setting thickly on both sprayed and unsprayed trees, but as leaf curl developed, the young fruit upon the control trees began to fall, while that upon the sprayed trees remained firmly attached and grew rapidly.

When the young peaches had reached the size of hickory nuts, and the pits were forming, the danger of dropping from curl had passed, and the thinning of fruit on overloaded trees was then undertaken. To enable the writer to make just comparisons of the merits of the various sprays in saving fruit, it became necessary to carefully record the amount and number of peaches thinned from all trees in the experiment block. Thinning fruit is an equalizing process, and to equalize the crop upon sprayed and unsprayed trees or upon trees treated with different sprays, would be to destroy the contrast in the amount of fruit arising from the use of different formulæ. This would result in the loss of the very facts which it was hoped to obtain from the experiments, unless records of the fruit thinned off were preserved. For the preservation of such records the following plan was adopted: Canvas sheets of large size, commonly used in the harvest of the almond crop in the same orchard, were spread beneath the trees to be thinned. The young peaches were allowed to fall upon the canvas as picked, and the canvas was moved as necessary. The fruit thus thinned was poured from the canvas into picking boxes beneath the tree from which it was thinned. By this plan the fruit thinned from each tree was kept by itself. After an experiment row of 10 trees had been thinned, the fruit picked from each tree was separately weighed and the weight recorded. From 3 trees of the row sufficient fruit was now taken to amount to 25 pounds. The peaches in this 25 pounds were then counted, the number entered with the other records of the row, and on this basis the average number of small peaches per pound for the row was determined. By multiplying the number of pounds of young peaches thinned from each tree by the average number of peaches per pound, as above obtained, the writer was able to determine quite accurately the number of peaches thinned from each tree of the row.

When the work on one experiment row was completed, the fruit from a second row of 10 trees was gathered, weighed, and counted in like manner, and this process was followed for each row of the block which required thinning.

From the field records thus gathered two tables have been carefully compiled, the first showing the actual weight of young peaches picked from each tree thinned in the block, and the second the computed number of peaches which these weights represent, as determined by the above-described method.

TABLE 23.—*Weight of peaches thinned from the sprayed Lovell peach trees in the experiment block of the Rio Bonito orchard in the spring of 1895.* (*a*)

Row No.	Actual weight in pounds of thinned peaches from trees Nos.—										Total weight of peaches in row.	Number of peaches in 25 pounds.	Average number of peaches per pound.	Total number of peaches per row.
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	*Pounds.*			
1	15	16½	18	33	20¼	22½	27	45	50	35	282¼	482	19.28	5,442
2														
3	27	22	15	20	22½	21	30½	16½	29	16	219½	550	22.00	4,829
4														
5														
6	18	2	15	6	15	3	21½	5	19	16½	121	486	19.44	2,352
7	17	25	11	7½	12	9½	15	6	5½	8½	117	484	19.36	2,265
8														
9	36	21	15	13½	18½	25	36	6½	6	7½	185	522	20.88	3,863
10	30	30½	24	10	17	25	40	19½	17	20½	233½	466	18.64	4,352
11														
12	31	13	3	10	6	16½	1½	19½	10½	22½	133½	511	20.44	2,729
13	23½	14½	2	2½	18	13½	7½	2½	3½	5½	93	495	19.80	1,841
14														
15	82	44	27	31	24	40	45	23	29½	22	367½	528	21.12	7,762
16	20½	6	15	3½	9½	5	17	17½	14	13	121	496	19.84	2,401
17														
18	32	17	26	16	17	8	10	6	14	4	150	504	20.16	3,024
19	24	35	29	16	25	14	13	11	7	12	186	486	19.44	3,616
20														
21	68	48	26	28	48½	49	58	21	29½	61½	437½	484	19.36	8,470
22	33	51	35	21	35	58	41	22	29	60	385	472	18.88	7,269
23														
24														
25	42	20	22	18	28	21	37	38	43	51	320	449	17.96	5,747
26														
27	34	34	35	11	14	35	30	22	21	23	259	495	19.80	5,128
28	18	21	32	29	31	33	34	30	63	50	341	421	16.84	5,742
29														
30	55	49	42	43	60	43	41	35	70	86	524	487	19.48	10,208
31														
32	31	15	18	20	22	18	27	8	....	....	159	514	20.56	3,269
33	47	51	34	40	22	39	33	29	39	47	381	483	19.32	7,361
34														
35	62	63	23	....	57	42	46	57	54	62	466	522	20.88	9,730
36	23	35	14	10	11	31	26	31	28	46	255	480	19.20	4,896
37														
38	15	6	6	8	10	22	26	17	15	25	150	553	22.12	3,318
39	40	26	39	....	....	37	34	29	34	27	266	547	21.88	5,820
40														
41	54	52	27	24	26	12	27	8	35	28	293	508	20.32	5,953
42														
43														
44	6	8	11	5	6	....	....	....	....	....	36	537	21.48	773
45	25	23	21	11	22	17	20	16	27	14	196	504	20.16	3,951
46														
47														
48	7	6	3	5	....	....	....	....	8	4	33	511	20.44	675
49														
50														
51	15	22	8	12	11	12	12	13	18	17	140	533	21.32	2,985
52														
53														
54	30	34	44	18	17	27	30	21	36	17	274	508	20.32	5,568
55														
56	22	40	44	18	17	27	30	21	36	17	272	520	20.80	5,658
57	21	35	16	20	11	19	20	29	32	37	240	547	21.88	5,251
58														

a For plat of orchard see p. 69; for sprays applied see p. 73.

By referring to the above table it will be seen that only those rows which were sprayed in the spring of 1895 were thinned, and that a portion of these required but little thinning. The reasons for this lie in the severe action of the disease upon the unsprayed rows and those sprayed with weak or unsatisfactory sprays, in which cases the fruit fell from disease. The table shows the weight of thinned peaches per tree, the total weight of peaches thinned from the row, the number of peaches contained in 25 pounds, the average number of peaches per pound, and the total number of peaches thinned from the row.

In the table which follows the pounds have been reduced to show the number of peaches, the reduction being made according to the method already described. Comparison of the total number of peaches thinned from the separate rows, as given in the two tables, will show slight variations in the units column in several cases. These variations arise from the gain or loss in fractions resulting from the use of the different methods which it was necessary to employ in obtaining the figures shown in the two tables.

TABLE 24.—*Number of peaches thinned from the sprayed Lovell peach trees in the experiment block of the Rio Bonito orchard in the spring of 1895.* (*a*)

Row No.	Number of peaches thinned from sprayed trees Nos.—										Total.
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	
1	289	318	347	636	390	434	521	868	964	675	5,442
2											
3	594	484	330	440	495	462	671	363	638	352	4,829
4											
5											
6	350	39	292	117	292	58	418	97	369	321	2,353
7	329	484	213	145	232	184	290	116	106	165	2,264
8											
9	752	438	313	282	386	522	752	136	125	157	3,863
10	559	569	447	186	317	466	746	363	317	382	4,352
11											
12	634	266	61	204	123	337	31	399	215	460	2,730
13	465	287	40	50	356	267	148	50	69	109	1,842
14											
15	1,732	929	570	655	507	845	950	486	623	465	7,762
16	407	119	298	69	188	99	337	347	278	258	2,400
17											
18	645	343	524	323	343	161	202	121	282	81	3,025
19	467	680	564	311	486	272	253	214	136	233	3,616
20											
21	1,316	929	503	542	939	949	1,123	407	571	1,191	8,470
22	623	963	661	396	661	1,095	774	415	548	1,133	7,269
23											
24											
25	754	359	395	323	503	377	665	682	772	916	5,746
26											
27	673	673	693	218	277	693	594	436	416	455	5,128
28	303	354	539	488	522	556	573	505	1,061	842	5,743
29											
30	1,071	955	818	838	1,169	838	799	682	1,364	1,675	10,209
31											
32	637	308	370	411	452	370	555	164	....	....	3,267
33	908	985	657	773	425	753	638	560	753	908	7,360
34											
35	1,295	1,315	480	....	1,190	877	960	1,190	1,128	1,295	9,730
36	442	672	269	192	211	595	499	595	538	883	4,896
37											
38	332	133	133	177	221	487	575	376	332	553	3,319
39	875	569	853	....	....	810	744	635	744	591	5,821
40											
41	1,097	1,057	549	488	528	244	549	163	711	569	5,955
42											

a For plat of orchard see p. 69; for sprays applied see p. 73.

TABLE 24.—*Number of peaches thinned from the sprayed Lovell peach trees in the experiment block of the Rio Bonito orchard in the spring of 1895*—Continued.

Row No.	Number of peaches thinned from sprayed trees Nos.—										Total.
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	
43											
44	129	172	236	107	129						773
45	504	464	423	222	444	343	403	323	544	282	3,952
46											
47											
48	143	123	61	102					164	82	675
49											
50											
51	320	469	171	256	235	256	256	277	384	362	2,986
52											
53											
54	610	691	894	366	345	549	610	427	732	345	5,569
55											
56	458	832	915	374	354	562	624	437	749	354	5,659
57	459	766	350	438	241	416	438	635	700	810	5,253
58											

GATHERING FRUIT OF SPRAYED AND UNSPRAYED TREES.

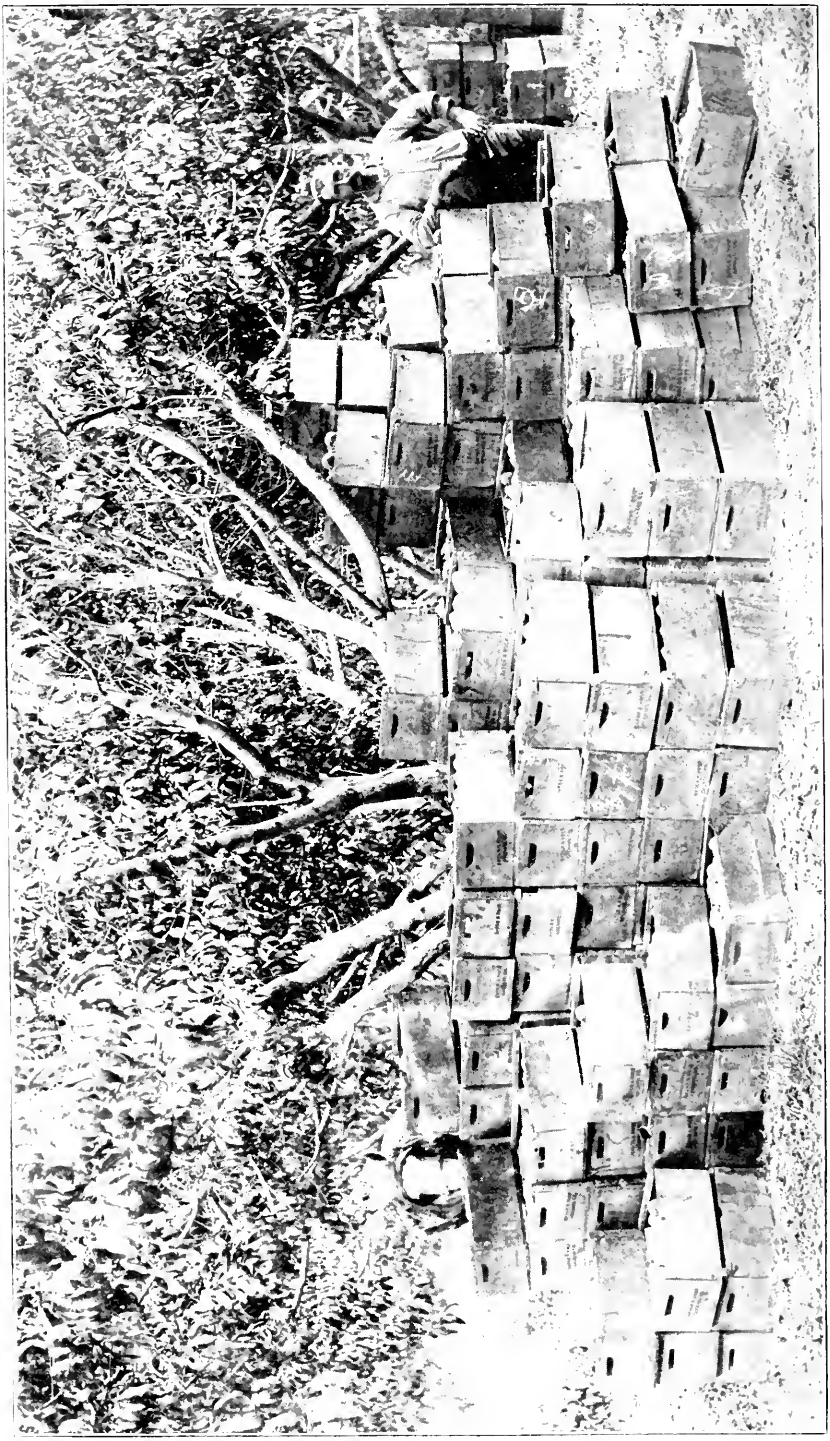
The fruit of the Lovell variety ripened rapidly in the Sacramento Valley after the middle of August, 1895. On the experiment trees a large portion of the crop was sufficiently matured for shipment to the canneries by the 20th of that month. By that date the plans had been made for the gathering of the crop, which work was completed before the 1st of September. The fruit was gathered at two pickings, the second picking beginning shortly after the close of the first. The crop was marketed in three ways:

(1) All perfect peaches above a standard size adopted by the canneries, and sufficiently firm to bear shipment by rail from Biggs to Oakland, Cal., a distance of about 140 miles, were sold to a firm at the latter point at $30.80 per ton, f. o. b. cars at Biggs. This fruit comprised about 54 per cent of the yield of the experiment block.

(2) All perfect peaches of canning size which were too mature to bear the delay and long shipment by rail to Oakland were shipped to a cannery at Chico, Cal., a distance of about 30 miles. This fruit brought $30 per ton, f. o. b. cars at Biggs. It comprised about 30 per cent of the yield of the experiment block.

(3) Such fruit as was below cannery size, overmature, or imperfect in any respect was sent to the drying ground to be dried. In the calculations of the present work this fruit is valued at three-fourths of a cent per pound in the green state. This is less than the equivalent of dried fruit was worth at the time of curing after allowing for the cost of drying. The fruit sent to the drying ground represented about 16 per cent of the yield of the experiment block.

The work of gathering, weighing, and grading the crop of the experiment rows was carefully systematized. As before shown, the experiment block was 20 trees wide from east to west, and through the center from north to south a driveway was made, so that the rows



FRUIT PRODUCED BY TREATED TREES OF ROW 15, EXPERIMENT BLOCK, BIGGS, CAL.

The fruit produced by the trees of the adjoining unsprayed row (14) is shown in the boxes in the background at the extreme right.

DESCRIPTION OF PLATE X.

Experiments at Biggs, Cal. (Bordeaux mixture.) Fruit gathered from row 15 of the experiment block of the Rio Bonito orchard in the summer of 1895. The formula for the spray used on this row was 6 pounds copper sulphate, 15 pounds quicklime, 45 gallons of water. The 10 trees of the row matured 4,351 pounds of fine peaches, which are shown in the picking boxes. The trees of the adjoining unsprayed row, No. 14, bore only 928 pounds. The value of the fruit matured on row 15 was $60.02; on row 14 it was $13.24, a net gain from spraying 10 trees of $46 after allowing for the cost of spraying. This gain resulted after more than one-third of the peaches had been thinned from the sprayed row, while none had been thinned from row 14. The total number of peaches set by the trees of row 15 was 21,272, by those of row 14 it was 2,855. The comparative average net gain shown by the spray used on row 15 was 619 per cent.

on either side were 10 trees long from east to west. One picker was assigned to each tree of the row across the block, thus making ten pickers on each side of the drive, or twenty in all, and an extra man was assigned as superintendent of the twenty pickers, to see that all instructions were carefully carried out. Every man was instructed to leave all fruit he picked beneath the tree from which it was gathered, picking boxes having been previously distributed for this purpose.

The work of picking began at the south end of the experiment block. When the fruit which was sufficiently matured had been gathered and placed in the boxes beneath a tree, the picker proceeded to the next tree north, thus following the same north-and-south row until he had passed entirely through the block, and when each man had thus completed his north-and-south row the entire block had been picked over, the fruit being beneath the trees from which it came. The first and second pickings were conducted in this manner, but the second was not begun until after the first was completed and the gathered fruit had been removed from beneath the trees.

The process of collecting the fruit of the first picking began as soon as the pickers had completed an east-and-west row and had proceeded to the next row toward the north. Four men were employed to collect and weigh the peaches—two to collect the fruit in the orchard and two to weigh, count, and keep the records. The fruit was brought from the east and from the west to the central driveway on a low platform wagon drawn by one horse. The boxes of fruit gathered from the 10 trees of each experiment row were piled at the side of the driveway, close to the last tree of the row. The boxes of fruit from each tree were also distinguished by means of cards bearing the number of the tree from under which the boxes were taken (Pl. X).

The weighing began as soon as the fruit from the 10 trees of an experiment row had been piled at the side of the central drive. Platform scales were placed on a level base close to the fruit boxes, and the fruit from each tree of the row was weighed separately. The gross weight was recorded for each tree, as well as the number of picking boxes. The average weight of the picking boxes used was afterwards carefully determined, and from these data the net weight of fruit was ascertained and tabulated for each tree of each row of the block. After the weight of fruit for each tree of an experiment row was thus learned, 100 pounds of peaches were weighed out from typical boxes of several trees of the row. The number of peaches in this 100 pounds of fruit was then ascertained by counting, the number being recorded with the other data for the row. The fruit of all the experiment rows was weighed and the average size of the peaches determined by counting, as here indicated.

Following close after the weighers came five or six sorters. These men graded the fruit, according to the requirements already outlined, into three classes—one for an Oakland cannery, one for a Chico cannery, and a third class for drying. These three classes constituted really but two qualities of fruit—a first quality for canning, and a second quality for drying. After the fruit of a row was graded a careful count of the number of picking boxes of each class of fruit was made, and the numbers recorded. From these figures were determined the proportions of the total yield of the row which belonged to the different classes of fruit. The same process of picking, collecting, weighing, counting, grading, and recording was followed for the second picking as for the first.

In the following table are shown the net weights of fruit gathered at the first picking from each tree of the entire block of 58 experiment rows, with the total weight for each row.

TABLE 25.—*Weight of peaches of first picking from the Lovell trees of the experiment block of the Rio Bonito orchard, gathered in the fall of 1895.*

Row No.	Weight of fruit, in pounds, gathered at first picking from trees Nos.—										Total net weight of fruit in row.	Number of trees in row.	Average weight per tree.
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.			
											Pounds.		*Pounds.*
1	75	109	142	207	147	118	262	190	180	140	1,570	10	157
2	51	89	122	137	54	111	90	140	165	48	1,007	9.5	106
3	164	121	140	147	157	179	289	241	200	49	1,687	10	168.7
4	69	71	129	31	57	120	87	74	69	34	741	9.8	75.6
5	42	74	36	56	73	140	159	100	64	66	810	10	81
6	190	75	193	175	228	97	212	212	237	204	1,813	10	181.3
7	88	267	139	169	181	183	180	222	169	110	1,708	10	170.8
8	93	29	22	11	39	151	115	39	53	16	568	10	56.8
9	259	271	162	202	218	248	233	234	153	121	2,101	10	210.1
10	216	275	332	89	219	240	249	297	467	169	2,553	10	255.3
11	65	71	30	86	83	107	114	41	166	70	833	10	83.3
12	229	166	111	191	304	154	247	168	240	147	1,957	9.4	208.2
13	232	192	200	70	161	203	209	187	145	77	1,676	10	167.6
14	121	55	114	109	47	114	91	114	47	32	844	10	84.4
15	492	357	538	253	471	474	573	340	453	273	4,227	10	422.7
16	157	112	303	87	298	216	451	235	291	198	2,348	10	234.8
17	133	56	55	52	88	119	58	89	44	21	715	10	71.5
18	383	241	322	242	341	233	296	144	288	119	2,609	10	260.9
19	251	324	365	144	331	364	245	201	189	180	2,594	10	259.4
20	61	99	110	109	32	27	32	22	23	59	574	10	57.4
21	426	438	470	405	498	431	617	252	343	427	4,307	10	430.7
22	384	524	539	257	544	556	469	324	332	346	4,275	10	427.5
23	22	80	88	54	62	95	75	38	105	53	672	10	67.2
24	65	50	65	48	43	52	48	56	24	96	547	10	54.7
25	280	236	386	180	426	424	565	459	285	430	3,771	10	377.1
26	70	121	71	16	19	62	109	96	49	45	658	10	65.8
27	345	400	438	116	166	425	513	290	206	217	3,116	10	311.6
28	313	385	573	298	400	489	489	379	421	379	4,126	10	412.6
29	29	36	98	64	60	90	33	95	25	46	576	10	57.6
30	188	198	237	258	323	219	296	318	236	342	2,615	10	261.5
31	71	152	127	134	149	179	111	199	215	215	1,552	10	155.2
32	177	139	132	252	315	218	209	298	299	243	2,282	10	228.2
33	283	271	159	401	250	373	428	429	387	208	3,189	9.8	325.4
34	87	128	94	53	107	148	79	133	127	146	1,102	10	110.2
35	393	291	237	.....	563	491	597	590	424	448	4,034	8.6	469
36	298	213	129	144	188	354	365	365	315	310	2,681	10	268.1
37	80	96	69	27	198	84	127	163	138	143	1,125	10	112.5
38	246	91	140	166	273	234	284	341	274	403	2,452	10	245.2
39	283	154	330	.....	.....	384	439	461	339	414	2,804	8	350.5
40	135	123	65	59	69	49	53	47	114	222	936	10	93.6
41	412	268	274	451	430	200	410	305	314	400	3,464	10	346.4
42	287	176	128	157	179	145	223	119	299	211	1,924	10	192.4
43	92	85	108	32	32	45	97	28	52	84	655	10	65.5
44	171	150	246	163	70	164	139	231	182	226	1,742	10	174.2
45	328	220	296	222	510	324	413	363	326	286	3,288	10	328.8
46	52	87	64	107	90	56	42	73	103	53	727	10	72.7
47	130	149	139	118	228	116	105	169	190	228	1,572	10	157.2
48	97	155	137	106	117	79	182	142	151	181	1,347	10	134.7
49	77	91	61	95	78	60	86	41	74	32	695	10	69.5
50	250	284	214	147	107	120	118	229	295	350	2,114	10	211.4
51	264	330	277	263	247	207	251	193	299	310	2,641	10	264.1
52	162	99	126	135	147	84	25	63	94	132	1,067	10	106.7
53	140	68	62	105	54	63	44	73	90	54	753	9.6	78.4
54	337	457	449	443	311	421	392	408	294	285	3,797	10	379.7
55	93	166	97	80	45	153	137	67	92	94	1,024	10	102.4
56	336	361	314	415	294	181	241	381	268	504	3,298	9.5	347.1
57	330	400	277	359	254	282	313	399	327	471	3,412	10	341.2
58	91	64	99	92	86	195	83	46	51	52	859	10	85.9

At the side of the total column in the preceding table is given a column showing the number of trees in each row. The total amount of fruit gathered at the first picking from each row has been divided by the number of trees in the row, giving the average amount of fruit picked per tree for each row of the block. This average is shown in the right-hand column.

In the table which follows is given the net weight of fruit gathered at the second picking from each tree of the block not picked clean at the first picking.

TABLE 26.—*Weight of peaches of second picking from the Lovell trees of the experiment block of the Rio Bonito orchard, gathered in the fall of 1895.*

Row No.	Weight of fruit, in pounds, gathered at second picking from trees Nos.—										Total net weight of fruit in row.	Number of trees in row.	Average weight per tree.
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.			
											Pounds.		*Pounds.*
1	54	121	41	133	112	127	132	112	242	168	1,242	10	121.2
2	25	6	12	99	.....	.....	25	41	67	68	343	9.5	36.1
3	79	124	33	151	151	88	26	162	108	187	1,109	10	110.9
4	12	.....	41	39	.....	45	4	26	34	51	255	9.8	26
5	.....	.....	13	90	61	12	.....	.....	23	37	236	10	23.6
6	19	8	60	32	83	20	109	10	38	43	452	10	45.2
7	60	9	99	28	120	.....	31	.....	30	140	517	10	51.7
8	11	10	8	.....	.....	.....	27	13	18	20	107	10	10.7
9	31	16	26	14	96	.....	82	.....	26	66	357	10	35.7
10	29	10	25	16	19	87	76	.....	63	90	415	10	41.5
11	7	5	5	11	.....	.....	31	28	18	31	136	10	36.6
12	11	12	.....	.....	.....	13	41	.....	15	54	146	9.4	15.5
13	23	13	21	.....	23	.....	35	.....	14	55	184	10	18.4
14	19	6	.....	8	.....	.....	8	13	12	18	84	10	8.4
15	33	6	18	.....	.....	.....	7	.....	22	38	124	10	12.4
16	20	11	18	.....	.....	.....	11	28	6	58	152	10	15.2
17	11	.....	11	.....	.....	.....	5	.....	7	9	43	10	4.3
18	23	10	.....	14	.....	.....	.....	.....	14	30	91	10	9.1
19	10	6	16	.....	31	.....	14	11	13	17	118	10	11.8
20	7	3	15	.....	22	.....	4	.....	5	18	74	10	7.4
21	12	8	13	5	.....	.....	12	.....	53	33	136	10	13.6
22	11	28	19	.....	.....	.....	.....	.....	8	80	146	10	14.6
23	6	.....	.....	13	.....	.....	7	.....	2	12	40	10	4
24	6	6	.....	.....	.....	.....	5	18	4	13	52	10	5.2
25	23	11	28	.....	32	.....	24	29	.....	70	217	10	21.7
26	5	.....	.....	.....	.....	.....	6	.....	3	.....	14	10	1.4
27	.....	9	8	.....	.....	.....	.....	16	16	51	100	10	10
28	.....	19	.....	.....	17	.....	.....	.....	39	62	137	10	13.7
29	.....	3	1	.....	5	12	.....	.....	.....	5	26	10	2.6
30	270	191	295	267	201	199	138	141	439	385	2,526	10	252.6
31	40	107	33	85	27	103	27	23	193	148	786	10	78.6
32	200	145	150	81	10	113	107	30	90	210	1,136	10	113.6
33	113	192	212	126	3	104	14	19	81	218	1,082	9.8	110.4
34	8	62	62	.....	.....	.....	13	6	14	57	222	10	22.2
35	89	251	63	.....	30	52	35	94	146	80	840	8.6	97.6
36	6	75	119	42	11	15	.....	72	.....	53	393	10	39.3
37	12	31	.....	55	44	27	8	24	.....	44	245	10	24.5
38	23	62	80	77	63	27	24	.....	31	37	424	10	42.4
39	26	142	108	.....	.....	67	23	14	30	29	439	8	54.8
40	15	32	30	48	.....	25	.....	.....	.....	23	173	10	17.3
41	47	103	149	48	.....	62	15	21	21	100	566	10	56.6
42	21	73	23	.....	.....	38	13	5	.....	25	198	10	19.8
43	7	.....	9	14	.....	13	7	12	.....	22	84	10	8.4
44	16	18	60	43	.....	41	15	9	31	32	265	10	26.5
45	19	16	18	.....	24	17	17	26	33	33	203	10	20.3
46	3	12	.....	.....	.....	7	2	9	.....	14	47	10	4.7
47	10	11	9	.....	.....	32	6	9	25	.....	102	10	10.2
48	11	.....	18	30	.....	15	.....	12	6	.....	92	10	9.2
49	5	.....	17	10	.....	13	9	2	5	.....	61	10	6.1
50	4	.....	.....	14	.....	10	.....	10	11	6	55	10	5.5
51	12	.....	11	25	.....	13	.....	10	15	5	91	10	9.1
52	.....	.....	9	6	.....	12	18	3	6	10	64	10	6.4
53	7	.....	10	9	.....	12	.....	9	.....	.....	47	9.6	4.9
54	19	21	92	17	.....	55	10	18	34	.....	266	10	26.6
55	.....	4	11	16	.....	18	.....	26	.....	.....	75	10	7.5
56	3	.....	32	27	.....	17	.....	.....	13	.....	92	9.5	9.7
57	1	18	.....	.....	.....	30	.....	26	.....	16	91	10	9.1
58	.....	.....	.....	.....	.....	.....	26	6	11	.....	43	10	4.3

The total yield of the trees and rows of the experiment block is shown in the following table, which was compiled from the preceding records of fruit gathered at the first and second pickings.

TABLE 27.—*Total weight of peaches of first and second pickings gathered from the Lovell trees of the experiment block of the Rio Bonito orchard in the fall of 1895.* (*a*)

Row No.	Total weight in pounds of fruit gathered at first and second pickings from trees Nos.—										
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	Total.
1	129	230	183	340	259	245	394	302	422	308	2,812
2	76	95	134	236	54	111	115	181	232	116	1,350
3	243	245	173	298	308	267	315	403	308	236	2,796
4	81	71	173	70	57	165	91	100	103	85	996
5	42	74	49	146	134	152	159	100	87	103	1,046
6	239	83	253	197	311	117	321	222	275	247	2,265
7	148	276	238	197	301	183	211	222	199	250	2,225
8	104	39	30	11	39	151	142	52	71	36	675
9	290	287	188	216	314	248	315	234	179	187	2,458
10	245	285	357	105	238	327	325	297	530	259	2,968
11	72	76	35	97	83	107	145	69	184	101	969
12	240	178	111	191	304	167	288	168	255	201	2,103
13	255	205	221	70	184	203	244	187	159	132	1,860
14	140	61	114	117	47	114	99	127	59	50	928
15	525	363	556	253	474	474	580	340	475	311	4,351
16	177	123	321	87	298	216	462	263	297	256	2,500
17	144	56	66	52	88	119	63	89	51	30	758
18	406	251	322	256	341	233	296	144	302	149	2,700
19	261	330	381	144	362	364	259	212	202	197	2,712
20	68	102	125	109	54	27	36	22	28	77	648
21	438	446	483	410	498	431	629	252	396	460	4,443
22	395	552	558	257	544	556	469	324	340	426	4,421
23	28	80	88	67	62	95	82	38	107	65	712
24	71	56	65	48	43	52	53	74	28	109	599
25	403	247	414	180	458	424	589	488	285	500	3,988
26	75	121	71	16	19	62	115	96	52	45	672
27	345	409	416	116	166	425	513	306	222	268	3,216
28	313	404	573	298	417	489	489	379	460	441	4,263
29	29	39	99	64	65	102	33	95	25	51	602
30	458	389	532	525	524	418	434	459	675	727	5,141
31	111	259	160	219	176	282	138	222	408	363	2,338
32	377	284	282	333	325	331	316	328	389	453	3,418
33	396	463	371	527	253	477	442	448	468	426	4,271
34	95	190	156	53	107	148	92	139	141	203	1,324
35	482	542	300	....	593	543	632	684	570	528	4,874
36	304	288	248	186	199	369	365	437	315	363	3,074
37	92	127	69	82	242	111	135	187	138	187	1,370
38	269	153	220	243	336	261	308	341	305	440	2,876
39	309	296	438	....	....	451	462	475	369	443	3,243
40	150	155	95	107	69	74	53	47	114	245	1,109
41	459	371	423	499	430	262	425	326	335	500	4,030
42	308	249	151	157	179	183	236	124	299	236	2,122
43	99	85	117	46	32	58	104	40	52	106	739
44	187	168	306	206	70	205	154	240	213	258	2,007
45	347	236	314	222	534	341	430	389	359	319	3,491
46	55	99	64	107	90	63	44	82	103	67	774
47	140	160	148	118	228	148	111	178	215	228	1,674
48	108	155	155	136	117	94	182	154	157	181	1,439
49	82	91	78	105	78	73	95	43	79	32	756
50	254	284	214	161	107	130	118	239	306	356	2,169
51	276	330	288	288	247	220	251	203	314	315	2,732
52	162	99	135	141	147	96	43	66	100	142	1,131
53	147	68	72	114	54	75	44	82	90	54	800
54	356	478	541	460	311	476	402	426	328	285	4,063
55	93	170	108	96	45	171	137	93	92	94	1,099
56	339	361	346	442	294	198	244	381	281	504	3,390
57	331	418	277	359	254	312	313	425	327	487	3,503
58	91	64	99	92	86	195	109	52	62	52	902

a For plat of orchard see p. 69; for sprays applied see p. 73.

As already said, after the weight of fruit for each tree of a row had been ascertained and recorded, the number of peaches in 100 pounds of this fruit was determined by counting. From several picking boxes of fruit, coming from different trees of the row, was weighed out 100 pounds of peaches fairly representing the fruit of the row. The peaches of this 100 pounds were then carefully counted and the number recorded. This was done both for the first and second pickings and for the sprayed and unsprayed rows. Where less than 100 pounds of fruit was gathered the number of peaches per 100 pounds was determined by counting a less weight of fruit, usually 50 pounds. The following table gives the results of this work for both first and second pickings:

TABLE 28.—*Number of peaches per 100 pounds; weight of fruit gathered; and number of peaches thinned, gathered, and set by the trees of each row in the experiment block of the Rio Bonito orchard in 1895.* (*a*)

Row No.	Number of peaches in 100 pounds.		Pounds of fruit—		Number of peaches gathered at—		Number of peaches—		Total number of peaches set by trees of row.	Number of trees in row.	Average number of peaches set per tree.	
	First picking.	Second picking.	First picking.	Second picking.	First picking.	Second picking.	Matured by trees of row.	Thinned from trees of row.			Sprayed.	Unsprayed.
1......	259	288	1,570	1,242	4,066	3,577	7,613	5,472	13,085	10	1,308	......
2......	295	317	1,007	313	2,971	1,087	4,058	....	4,058	9.5	....	427
3......	285	310	1,687	1,109	4,808	3,138	8,216	4,859	13,075	10	1,307	......
4......	300	335	741	255	2,223	854	3,077	....	3,077	9.8	....	314
5......	303	323	810	236	2,454	762	3,216	....	3,216	10	....	322
6......	278	324	1,813	152	5,040	1,464	6,504	2,352	8,856	10	886	......
7......	280	326	1,708	517	4,782	1,685	6,467	2,265	8,732	10	873	......
8......	282	322	568	107	1,602	345	1,917	....	1,917	10	....	195
9......	288	323	2,101	357	6,051	1,153	7,201	3,863	11,067	10	1,107	......
10......	282	313	2,553	115	7,199	1,299	8,498	4,352	12,850	10	1,285	......
11......	292	316	833	136	2,432	430	2,862	....	2,862	10	....	286
12......	283	321	1,957	146	5,538	469	6,007	2,730	8,737	9.4	929	......
13......	293	312	1,676	184	4,911	574	5,485	1,841	7,326	10	733	......
14......	306	*b* 324	844	84	2,583	272	2,855	....	2,855	10	....	285
15......	309	362	4,227	124	13,061	449	13,510	7,762	21,272	10	2,127	......
16......	294	317	2,348	152	6,903	482	7,385	2,401	9,786	10	979	......
17......	296	*b* 327	715	43	2,116	140	2,256	....	2,256	10	....	226
18......	300	*b* 339	2,609	91	7,827	308	8,135	3,024	11,159	10	1,116	......
19......	289	*b* 340	2,594	118	7,496	401	7,897	3,616	11,513	10	1,151	......
20......	290	*b* 332	574	74	1,665	246	1,911	....	1,911	10	....	191
21......	308	*b* 314	4,307	136	13,266	427	13,693	8,470	22,163	10	2,216	......
22......	320	*b* 362	4,275	146	13,680	529	14,209	7,269	21,478	10	2,148	......
23......	296	*b* 344	672	40	1,989	138	2,127	....	2,127	10	....	213
24......	292	*b* 356	547	52	1,597	185	1,782	....	1,782	10	....	178
25......	284	*b* 368	3,771	217	10,710	799	11,509	5,747	17,256	10	1,726	......
26......	280	*b* 354	658	14	1,842	50	1,892	....	1,892	10	....	189
27......	276	*b* 360	3,116	100	8,600	360	8,960	5,128	14,088	10	1,409	......
28......	291	*b* 370	4,126	137	12,006	507	12,513	5,742	18,255	10	1,825	......
29......	277	*b* 360	576	26	1,596	94	1,690	....	1,690	10	....	169
30......	292	313	2,615	2,526	7,636	7,906	15,542	10,208	25,750	10	2,575	......
31......	304	326	1,552	786	4,718	2,562	7,280	....	7,280	10	....	728
32......	294	311	2,282	1,136	6,709	3,533	10,242	3,269	13,511	10	1,351	......
33......	291	335	3,189	1,082	9,280	3,625	12,905	7,360	20,265	9.8	2,068	......
34......	290	330	1,102	222	3,196	733	3,929	....	3,929	10	....	393
35......	325	345	4,034	840	13,111	2,898	16,009	9,730	25,739	8.6	2,993	......
36......	285	332	2,681	393	7,641	1,305	8,946	4,896	13,842	10	1,384	......
37......	282	330	1,125	245	3,173	809	3,982	....	3,982	10	....	398
38......	282	330	2,452	424	6,915	1,399	8,314	3,318	11,632	10	1,163	......
39......	289	328	2,804	439	8,104	1,440	9,544	5,821	15,365	8	1,921	......
40......	300	312	936	173	2,808	540	3,348	....	3,348	10	....	334
41......	284	339	3,464	566	9,838	1,919	11,757	5,953	17,710	10	1,771	......
42......	303	335	1,924	198	5,830	663	6,493	....	6,493	10	649	......
43......	293	*b* 304	655	84	1,919	255	2,174	....	2,174	10	....	217
44......	309	337	1,742	265	5,383	893	6,276	773	7,049	10	705	......
45......	309	346	3,288	203	10,160	702	10,862	3,951	14,813	10	1,481	......
46......	303	*b* 330	727	47	2,203	155	2,358	....	2,358	10	....	236
47......	289	356	1,572	102	4,543	363	4,906	....	4,906	10	491	......
48......	308	*b* 324	1,347	92	4,149	298	4,447	675	5,122	10	512	......
49......	292	*b* 312	695	61	2,029	190	2,219	....	2,219	10	....	222
50......	287	*b* 366	2,114	55	6,067	201	6,268	....	6,268	10	627	......
51......	299	*b* 356	2,641	91	7,897	324	8,221	2,985	11,206	10	1,120	......
52......	303	*b* 336	1,067	64	3,233	215	3,448	....	3,448	10	....	345
53......	300	*b* 325	753	47	2,259	153	2,412	....	2,412	9.6	....	251
54......	306	*b* 352	3,797	266	11,619	936	12,555	5,568	18,123	10	1,812	......
55......	295	*b* 334	1,024	75	3,021	250	3,271	....	3,271	10	....	327
56......	293	*b* 384	3,298	92	9,663	353	10,016	5,659	15,675	9.5	1,650	......
57......	298	*b* 370	3,412	91	10,168	337	10,505	5,251	15,756	10	1,576	......
58......	282	*b* 360	859	43	2,422	155	2,577	....	2,577	10	....	258

a For plat of orchard see p. 69; for sprays applied see p. 73.
b Number calculated from a less weight than 100 pounds, usually from 50 pounds

Following the figures in the above table which show the number of peaches in 100 pounds of fruit are those giving the number of pounds of fruit gathered at the first and second pickings. From these four columns of figures has been calculated the number of peaches gathered from the trees of each row of the block for both the first and second pickings. By adding these numbers the total number of peaches matured by the trees of each row was quite accurately determined. To this amount is now added the number of peaches thinned from the trees, where thinning was required, the grand total representing the number of peaches firmly set by the trees of each row. By dividing this grand total by the number of trees in a row it has been possible to show the average number of peaches set per tree on both sprayed and unsprayed trees, and for every row in the experiment block.

COMPARATIVE QUANTITY, QUALITY, AND CASH VALUE OF FRUIT FROM SPRAYED AND UNSPRAYED TREES.

(Pls. XI and XII.)

The actual yield in pounds of peaches, the quality, and the cash value of the fruit produced by the sprayed and unsprayed trees of the experiment rows of the Rio Bonito orchard in the season of 1895 are fully and accurately shown in the table which follows. This table gives a full record of the yield as it was taken in the orchard, and the results are of the greatest value from a practical standpoint, conveying an accurate idea of the cash gain resulting from this spray work. If the reader will compare the average value of the fruit produced by the sprayed trees of row 21, for example, with that of the fruit produced by the unsprayed trees of row 20, some conception of the possible gains resulting from thorough spraying may be obtained. In studying this table, it should be remembered that the results shown were obtained from the use of 35 different formulæ and sprays. Some of the sprays were of little value, others of medium value, etc., hence the gains shown for the entire block are far below what they would have been had the trees of each of the rows been sprayed with such sprays as those used upon rows 21, 22, or others of the better-yielding rows of the block.

DESCRIPTION OF PLATE XI.

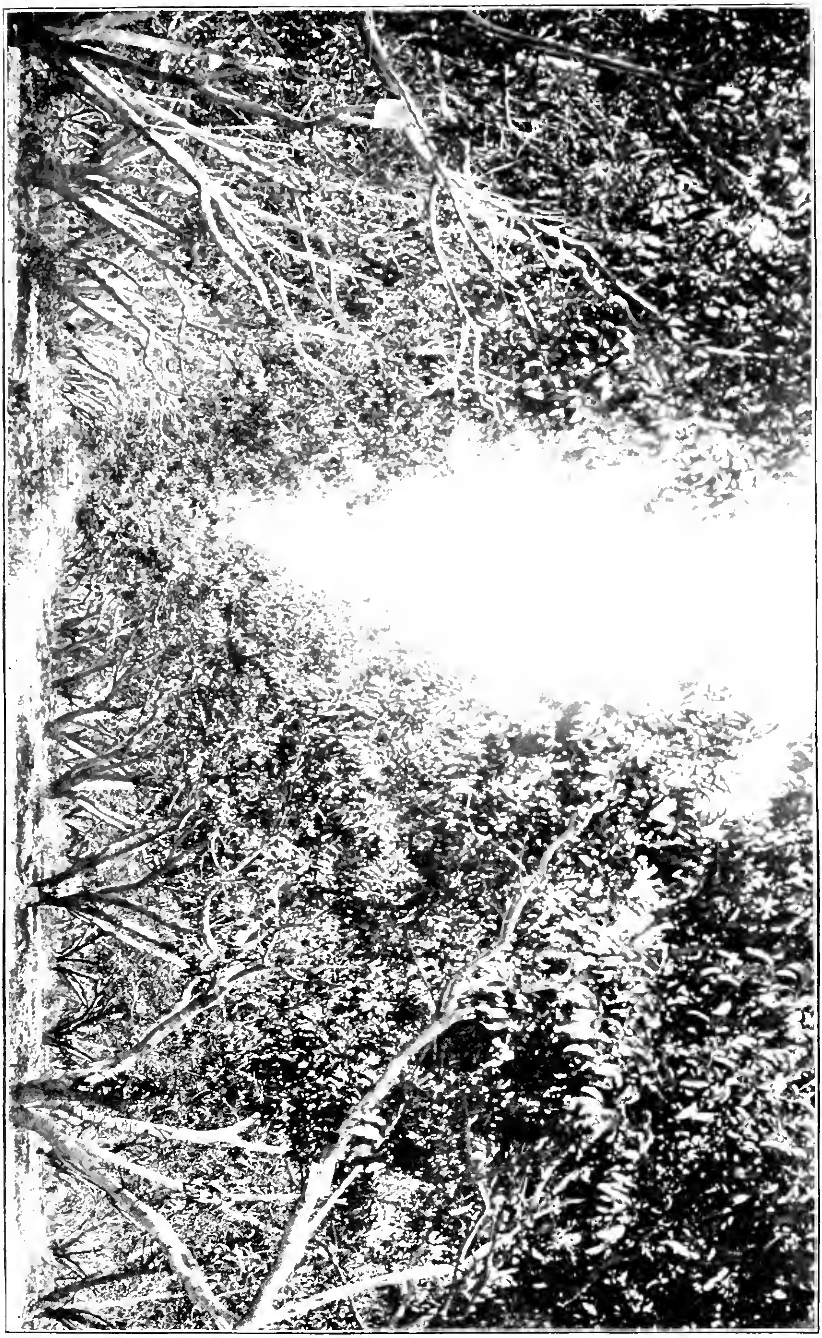
Experiments at Biggs, Cal. (Sulphur, lime, and salt.) Looking west between rows 2 and 3, May 14, 1895. Row 2 was unsprayed, row 3 was sprayed before blooming with 15 pounds sulphur, 20 pounds lime, 5 pounds salt, and 45 gallons of water. The average value of fruit matured per tree in row 2 was $1.96 and in row 3 $3.90. The spray used showed a net gain from the treatment, as determined by the comparative value of the peaches set by the trees of both rows, of 216 per cent (p. 117).

Rows 2 and 3, Experiment Block, Biggs, Cal.

Row 2, at left, unsprayed; row 3, at right, sprayed with sulphur, lime, and salt.

DESCRIPTION OF PLATE XII.

Experiments at Biggs, Cal. (Sulphur and lime.) Looking west between rows 9 and 10, May 14, 1895. Both rows were sprayed before blooming. Row 9 was treated with 10 pounds sulphur, 20 pounds lime, and 45 gallons of water, and row 10 with 10 pounds sulphur, 8 pounds lime, and 45 gallons of water. Row 8, adjoining row 9 at the south, and row 11, adjoining row 10 at the north, were untreated. The average value of fruit matured per tree on row 9 was $3.35, and on row 8 only 91 cents. The average value of fruit matured per tree on row 10 was $3.90, and on row 11, $1.35. As determined by the comparative value of the peaches set by the trees, the spray used on row 9 showed a net gain over row 8 of 457 per cent, and that used on row 10 showed a net gain over row 11 of 337 per cent (p. 117). It may be seen that the lower limbs are not as thickly covered with foliage where the sulphur sprays are used as where the copper sprays are used. This is especially true where the former is applied too late or too strong. (See Pl. XI.)



ROWS 9 AND 10, EXPERIMENT BLOCK, BIGGS, CAL.

TABLE 29.—*Quantity, quality, and cash value of fruit produced by the sprayed and unsprayed Lovell peach trees of the experiment block of the Rio Bonito orchard in the fall of 1895.* (*a*)

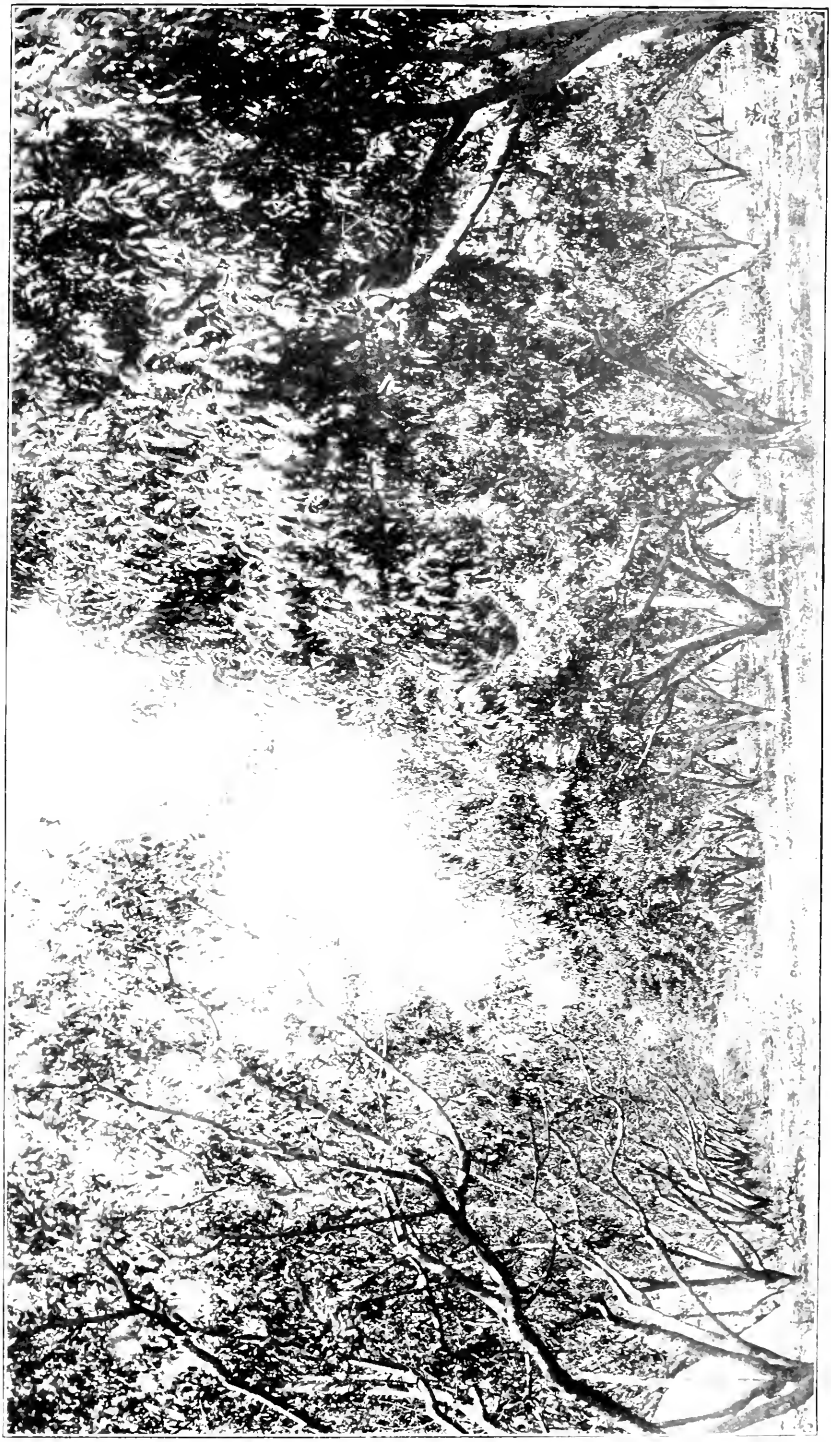
Row No.	Pounds of fruit—		Total pounds of fruit.		Number of trees in row.	Average pounds of fruit per tree.		Yield of fruit in pounds per row.	Classified yield.			Value of fruit for drying, at three-fourths cent per pound.	Value of fruit for Chico cannery, at 1½ cents per pound.	Value of fruit for Oakland cannery, at 1¼ cents per pound.	Total value of fruit.	Number of trees in row.	Average value of fruit per tree.	
	First picking.	Second picking.	Sprayed trees.	Unsprayed trees.		Sprayed trees.	Unsprayed trees.		Fruit for drying.	Fruit for Chico cannery.	Fruit for Oakland cannery.						Sprayed trees.	Unsprayed trees.
									Lbs.	*Lbs.*	*Lbs.*	$	$	$	$		$	$
1	1,570	1,242	2,812	....	10	281.2	....	2,812	621	544	1,647	4.65	8.16	24.70	37.51	10	3.75	....
2	1,007	343	....	1,350	9.5	....	142.1	1,350	214	379	757	1.60	5.68	11.35	18.63	9.5	....	1.96
3	1,687	1,109	2,796	....	10	279.6	....	2,796	385	837	1,574	2.88	12.55	23.61	39.04	10	3.90	....
4	741	255	....	996	9.8	....	101.6	996	177	109	709	1.32	1.63	10.63	13.58	9.8	....	1.38
5	810	236	....	1,046	10	....	101.6	1,046	155	127	761	1.15	1.90	11.46	14.51	10	....	1.45
6	1,813	452	2,265	....	10	226.5	....	2,265	371	280	1,614	2.77	4.20	24.21	31.18	10	3.11	....
7	1,708	517	2,225	....	10	222.5	....	2,225	400	160	1,665	3.00	2.40	24.97	30.37	10	3.03	....
8	568	107	....	675	10	....	67.5	675	130	24	591	.97	.36	7.81	9.14	10	....	.91
9	2,101	357	2,458	....	10	245.8	....	2,458	146	356	1,656	3.34	5.34	24.84	33.52	10	3.35	....
10	2,553	415	2,968	....	10	296.8	....	2,968	727	686	1,555	5.44	10.29	23.32	39.05	10	3.90	....
11	833	136	....	969	10	....	96.9	969	134	299	536	1.00	4.48	8.04	13.52	10	....	1.35
12	1,957	146	2,103	....	9.4	223.7	....	2,103	287	599	1,217	2.15	8.98	18.25	29.38	9.4	3.12	....
13	1,676	184	1,860	....	10	186	....	1,860	326	486	1,048	2.44	7.29	15.72	25.45	10	2.54	....
14	844	84	....	928	10	....	92.8	928	90	362	476	.67	5.43	7.14	13.24	10	....	1.32
15	4,227	124	4,351	....	10	435.1	....	4,351	699	1,270	2,382	5.24	19.05	35.73	60.02	10	6.00	....
16	2,348	152	2,500	....	10	250	....	2,500	449	769	1,282	3.36	11.53	19.23	34.12	10	3.41	....
17	715	43	....	758	10	....	75.8	758	96	303	359	.72	4.54	5.38	10.64	10	....	1.06
18	2,609	91	2,700	....	10	270	....	2,700	486	979	1,235	3.64	14.68	18.52	36.84	10	3.68	....
19	2,594	118	2,712	....	10	271.2	....	2,712	642	909	1,161	4.84	13.63	17.41	35.85	10	3.58	....
20	574	74	....	648	10	....	64.8	648	95	291	262	.71	4.36	3.93	9.00	10	....	.90
21	4,307	136	4,443	....	10	444.3	....	4,443	624	1,684	2,135	4.68	25.26	32.02	61.96	10	6.19	....
22	4,275	146	4,421	....	10	442.1	....	4,421	651	1,466	2,304	4.88	21.99	34.56	61.43	10	6.14	....
23	672	40	....	712	10	....	71.2	712	175	298	239	1.31	4.47	3.58	9.36	10	....	.93
24	547	52	....	599	10	....	59.9	599	119	266	214	.88	3.99	3.21	8.08	10	....	.80
25	3,771	217	3,988	....	10	398.8	....	3,988	765	1,478	1,745	5.73	22.17	26.17	54.07	10	5.40	....
26	658	14	....	672	10	....	67.2	672	136	315	221	1.02	4.72	3.31	9.05	10	....	.90
27	3,116	100	3,216	....	10	321.6	....	3,216	664	1,145	1,407	4.98	17.17	21.10	43.25	10	4.32	....
28	4,126	137	4,263	....	10	426.3	....	4,263	901	1,325	2,037	6.75	19.87	30.55	57.17	10	5.71	....
29	576	26	....	602	10	....	60.2	602	112	297	193	.84	4.45	2.89	8.18	10	....	.82

a For plat of orchard see p. 69; for sprays applied see p. 73.

TABLE 29.—*Quantity, quality, and cash value of fruit produced by the sprayed and unsprayed Lovell peach trees of the experiment block of the Rio Bonito orchard in the fall of 1895*—Continued. (*a*)

Row No.	Pounds of fruit—		Total pounds of fruit-		Number of trees in row.	Average pounds of fruit per tree.		Yield of fruit in pounds per row.	Classified yield.			Value of fruit for drying, at three-fourths cent per pound.	Value of fruit for Chico cannery, at 1½ cents per pound.	Value of fruit for Oakland cannery, at 1¼ cents per pound.	Total value of fruit.	Number of trees in row.	Average value of fruit per tree.	
	First picking.	Second picking.	Sprayed trees.	Unsprayed trees.		Sprayed trees.	Unsprayed trees.		Fruit for drying.	Fruit for Chico cannery.	Fruit for Oakland cannery.						Sprayed trees.	Unsprayed trees.
									Lbs.	Lbs.	Lbs.	$	$	$	$		$	$
30	2,615	2,526	5,141	....	10	514.1	....	5,141	851	980	3,310	6.37	14.70	49.65	70.72	10	7.07	....
31	1,552	786	....	2,338	10	....	233.8	2,338	354	833	1,151	2.66	12.49	17.26	32.41	10	....	3.24
32	2,282	1,136	3,418	....	10	341.8	....	3,418	401	999	2,018	3.01	14.98	30.27	48.26	10	4.83	....
33	3,189	1,082	4,271	....	9.8	435.8	....	4,271	661	967	2,643	4.96	14.50	39.64	59.10	9.8	6.03	....
34	1,102	222	....	1,324	10	....	132.4	1,324	185	554	585	1.39	8.31	8.78	18.48	10	....	1.85
35	4,034	840	4,874	....	8.6	566.7	....	4,874	517	1,761	2,596	3.87	26.41	38.94	69.22	8.6	8.05	....
36	2,681	393	3,074	....	10	307.4	....	3,074	302	671	2,101	2.27	10.06	31.51	43.84	10	4.38	....
37	1,125	245	....	1,370	10	....	137.0	1,370	200	553	617	1.50	8.30	9.25	19.05	10	....	1.90
38	2,452	424	2,876	....	10	287.6	....	2,876	269	951	1,656	2.02	14.26	24.84	41.12	10	4.11	....
39	2,804	439	3,243	....	8	405.4	....	3,243	335	1,172	1,736	2.51	17.58	26.04	46.13	8	5.77	....
40	936	173	....	1,109	10	....	110.9	1,109	146	263	700	1.10	3.94	10.50	15.54	10	....	1.55
41	3,464	566	4,030	....	10	403.0	....	4,030	570	559	2,901	4.28	8.38	43.51	56.17	10	5.62	....
42	1,924	198	2,122	....	10	212.2	....	2,122	398	663	1,061	2.99	9.94	15.91	28.84	10	2.88	....
43	655	84	....	739	10	....	73.9	739	142	283	314	1.07	4.24	4.71	10.02	10	....	1.00
44	1,742	265	2,007	....	10	200.7	....	2,007	385	647	975	2.89	9.70	14.62	27.21	10	2.72	....
45	3,288	203	3,491	....	10	349.1	....	3,491	726	468	2,297	5.45	7.02	34.45	46.92	10	4.69	....
46	727	47	....	774	10	....	77.4	774	117	307	350	.88	4.60	5.25	10.73	10	....	1.07
47	1,572	102	1,674	....	10	167.4	....	1,674	211	861	602	1.58	12.91	9.03	23.52	10	2.35	....
48	1,347	92	1,439	....	10	143.9	....	1,439	260	237	942	1.95	3.55	14.13	19.63	10	1.96	....
49	695	61	....	756	10	....	75.6	756	142	379	235	1.07	5.68	3.52	10.27	10	....	1.03
50	2,114	55	2,169	....	10	216.9	....	2,169	446	470	1,253	3.35	7.05	18.79	29.19	10	2.92	....
51	2,641	91	2,732	....	10	273.2	....	2,732	479	1,855	398	3.59	27.82	5.97	37.38	10	3.74	....
52	1,067	64	....	1,131	10	....	113.1	1,131	230	281	620	1.73	4.21	9.30	15.24	10	....	1.52
53	753	47	....	800	9.6	....	83.3	800	160	215	425	1.20	3.22	6.37	10.79	9.6	....	1.12
54	3,797	266	4,063	....	10	406.3	....	4,063	776	760	2,527	5.82	11.40	37.90	55.12	10	5.51	....
55	1,024	75	....	1,099	10	....	109.9	1,099	259	349	491	1.94	5.24	7.36	14.54	10	....	1.45
56	3,298	92	3,390	....	9.5	356.8	....	3,390	440	1,130	1,820	3.30	16.95	27.30	47.55	9.5	5.00	....
57	3,412	91	3,503	....	10	350.3	....	3,503	465	1,519	1,519	3.49	22.78	22.78	49.05	10	4.90	....
58	859	43	....	902	10	....	90.2	902	194	378	330	1.45	5.67	4.95	12.07	10	....	1.21

a For plat of orchard see p. 69; for sprays applied see p. 73.



ROWS 20 AND 21, EXPERIMENT BLOCK, BIGGS, CAL.

Row 20, at left, untreated; row 21, at right, treated with Bordeaux mixture. The net gain of row 21 over row 20 in fruit set was 1,025 per cent.

DESCRIPTION OF PLATE XIII.

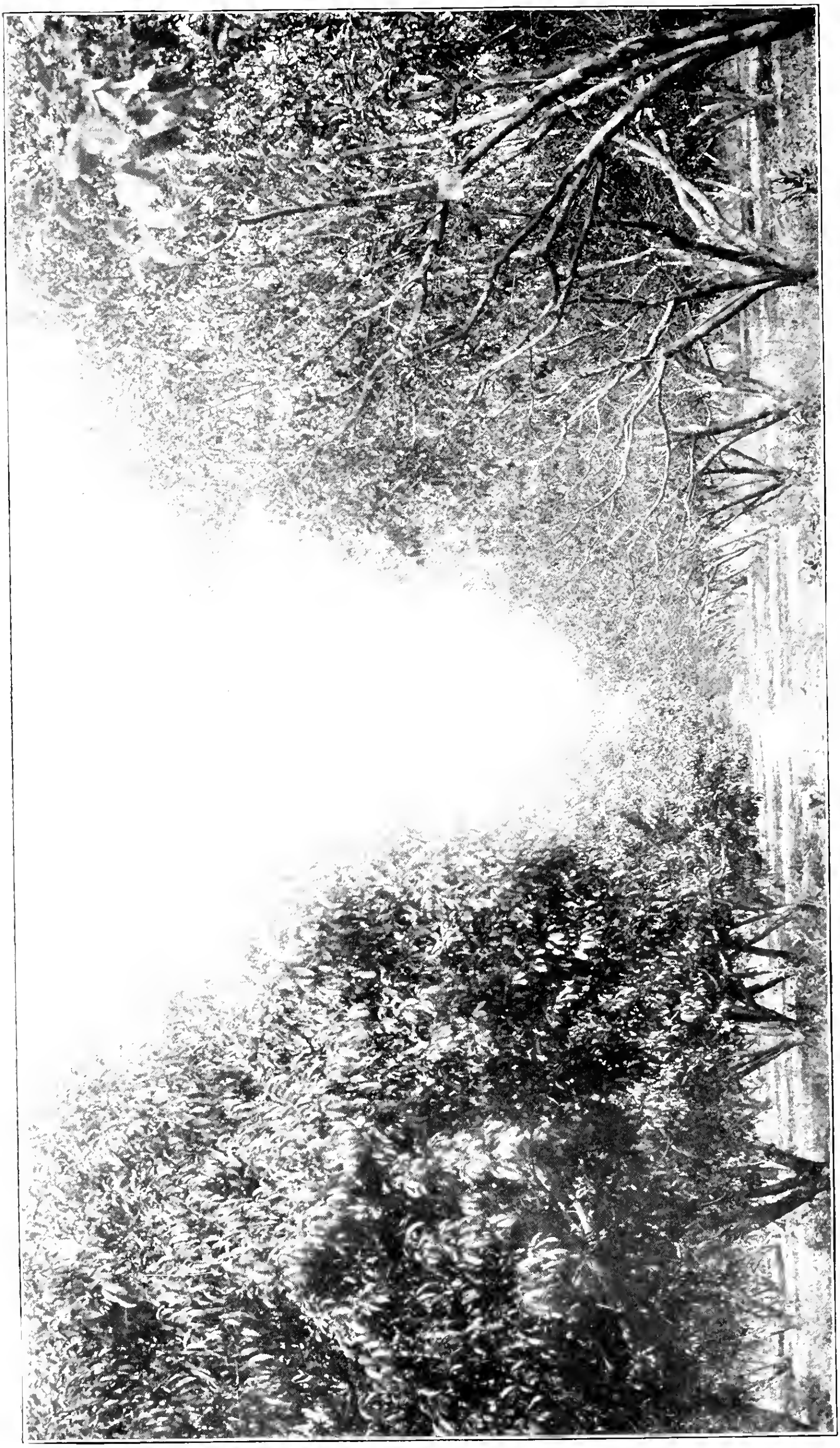
Experiments at Biggs, Cal. (Bordeaux mixture.) Looking west between rows 20 and 21, May 11, 1895. Row 20 was unsprayed; row 21 was sprayed before blooming with 5 pounds copper sulphate, 5 pounds lime, and 45 gallons of water. The average value of fruit matured per tree in row 20 was 90 cents; in row 21, $6.19. The spray used on row 21 showed a net gain over row 20, as determined by the comparative value of the peaches set by the trees of both rows, of 1,028 per cent (p. 117).

ROWS 26 AND 27, EXPERIMENT BLOCK, DIGGS, CAL.

Row 26, at left, untreated; row 27, at right, treated with eau celeste. Row 26 matured fruit worth $9.05; row 27 matured fruit worth $13.25.

DESCRIPTION OF PLATE XIV.

Experiments at Biggs, Cal. (Eau celeste.) Looking west between rows 26 and 27, May 11, 1895. Row 26 unsprayed; row 27 sprayed before blooming with 4 pounds copper sulphate, 3 pints ammonia, and 45 gallons of water. Average value of fruit matured per tree in row 26 was 90 cents; in row 27, $4.32. The spray used on row 27 showed a net gain over row 26, as determined by the comparative value of the peaches set by the trees of both rows, of 662 per cent (p. 117).



ROWS 34 AND 35, EXPERIMENT BLOCK, BIGGS, CAL.

Row 35, at left, treated with modified eau celeste; row 34, at right, untreated.

DESCRIPTION OF PLATE XV.

Experiments at Biggs, Cal. (Modified eau celeste.) Looking east between rows 34 and 35, May 14, 1895. Row 34 unsprayed; row 35 sprayed before blooming with 4 pounds copper sulphate, 5 pounds sal soda, 3 pints ammonia, and 45 gallons of water. The average value of fruit matured per tree in row 34 was $1.84; in row 35, $8.05. The spray used on row 35 showed a net gain over row 34, as determined by the comparative value of the peaches set by the trees of both rows, of 608 per cent (p. 118).

COMPARATIVE VALUE OF SPRAYS IN RELATION TO FRUIT.

(Pls. XIII, XIV, and XV.)

A review of the preceding table will show that no account has been taken there of the peaches thinned from the trees, and for this reason the results given in dollars and cents for the different rows can not be taken as representing the full comparative value of the sprays used. The value of a spray in controlling curl, so far as quantity of fruit is concerned, should be based upon its power to prevent the fall or loss of fruit from the disease. A spray may enable a tree to set more fruit than it can carry to maturity in a favorable season, but the value of the spray should not be decided from the amount of the crop after thinning. This will be evident from a consideration of the fact that in many years the trees may not set more peaches than can be properly matured without thinning. In such cases it would be the spray that enabled the trees to set and hold the greatest number of peaches in the presence of curl which would prove of the highest value to the grower. A less effective spray would not enable the trees to set and hold a full crop. It is thus seen that the comparative value of several sprays rests in their power to prevent the fall of the greatest number of peaches from disease, this being, of course, where other influences of the sprays are equal. Thinning is necessary only when the trees can not carry all the fruit set, or when it is desired to improve the size and quality of the fruit, and it bears no direct relation to the value of a spray in preventing curl.

In view of the preceding facts, a table has been prepared embodying those features of the fruit records by which the comparative value of all the sprays used may be determined.

To show the full comparative value of all influences of each spray upon the fruit, it has also been necessary to consider the quality as well as the number of peaches and weight of same. To obtain the ultimate comparative value of the sprays the writer has been obliged to treat the thinned peaches as if matured, assigning them the same value, in proportion to number, as the matured fruit. There is also one other calculation in the table which requires explanation. A considerable percentage of the better quality of fruit was picked while still immature. This fruit is tabulated as that for the Oakland cannery. It was necessary to gather this fruit while still hard so that it would arrive at the Oakland cannery in good condition. By weighing a large number of matured peaches and an equal number of peaches as picked for the Oakland cannery it was learned that the Oakland fruit should be increased by 11 per cent to make it equal in weight to mature fruit. This has been done, so that the quantity, quality, and full comparative value of all fruit considered could be accurately determined.

It has been possible in the manner just outlined to calculate the total comparative value of all fruit set by the trees of each row, as determined by the actual cash value of fruit of equal quality when matured. By dividing this sum by the number of trees in the row the average comparative value per tree of all fruit set is shown, both for sprayed and unsprayed rows. While these average values do not represent the money actually obtained, as in the case of the preceding table, they accurately show the average values for comparison of all fruit set by the trees, as determined by the market price of that fruit which the trees were able to bring to maturity. For these reasons the figures for the different rows may be rightly compared, and they fairly determine the comparative values of the 35 sprays tested in the block, so far as those values relate to the quantity and quality of the fruit.

To further facilitate the comparison of the values of the sprays in increasing the quantity and quality of fruit, as determined by the cash value of such fruit when matured, the results have been reduced to average net gain per cent of the sprayed trees of each treated row over those of the adjoining unsprayed row. For illustration, it may be seen that in row 30, sprayed, the average calculated value of all fruit set per tree would have been when matured $12.62; in row 31, unsprayed, $3.43. Deducting the calculated average value of the fruit set on the trees of row 31 from that set on the trees of row 30, there is shown an excess of $9.19 in favor of the trees of the sprayed row, and by dividing this excess by $3.43, the calculated average value of fruit set by the trees of the unsprayed row, there is shown to be a net gain of 268 per cent resulting from the use of the spray applied to the trees of row 30. The gain per cent has in this manner been calculated for every spray tested in the block, and it may be seen that on row 21 the spray gave a net gain of 1,028 per cent.

TABLE 30.—*The comparative value of the 35 sprays tested in the experiment block of the Rio Bonito orchard in 1895. The net gain per cent is based upon the value of all fruit set by the sprayed and unsprayed trees, as determined by the cash value of all fruit brought to maturity by the trees, both quantity and quality considered.* (a)

Row No.	Number of peaches— Thinned from trees of row.	Matured by trees of row.	Total number of peaches set by trees of row.	Classified yield of fruit for— Drying.	Chico cannery.	Oakland cannery when gathered.	11 per cent weight added to Oakland fruit.	Total estimated weight of Oakland fruit when matured.	Value of— Drying fruit at ¾ cent per pound.	Chico fruit at 1½ cents per pound.	Estimated value of Oakland fruit when matured.	Total value of drying and cannery fruit when matured.	Estimated value of thinned fruit at same rate as that matured.	Total estimated value of all fruit set by trees of row.	Number of trees in rows.	Average value of fruit per tree— Sprayed.	Unsprayed.	Average net gain per cent of sprayed trees over unsprayed trees.
				Lbs.	*Lbs.*	*Lbs.*			$	$	$	$	$	$		$	$	
1	5,442	7,643	13,085	621	514	1,647	181	1,828	4.65	8.16	27.42	40.23	28.64	68.87	10	6.89		229
2		4,058	4,058	214	379	757	83	840	1.60	5.68	12.60	19.88		19.88	9.5		2.09	
3	4,829	8,246	13,075	385	837	1,574	173	1,747	2.88	12.55	26.20	41.63	24.38	66.01	10	6.60		216
4		3,077	3,077	177	109	709	78	787	1.32	1.63	11.80	14.75		14.75	9.8		1.50	
5		3,216	3,216	155	127	761	84	848	1.15	1.90	12.72	15.77		15.77	10		1.58	5
6	2,352	6,505	8,857	371	280	1,614	177	1,791	2.77	4.20	26.86	33.83	12.23	46.06	10	4.61		192
7	2,265	6,467	8,732	400	160	1,665	183	1,848	3.00	2.40	27.72	33.12	11.60	44.72	10	4.47		347
8		1,947	1,947	130	24	521	57	578	.97	.36	8.67	10.00		10.00	10		1.00	
9	3,863	7,204	11,067	446	356	1,656	182	1,838	3.34	5.34	27.57	36.25	19.44	55.69	10	5.57		457
10	4,352	8,498	12,850	727	686	1,555	171	1,726	5.44	10.29	25.89	41.62	21.32	62.94	10	6.29		337
11		2,862	2,862	134	299	536	59	595	1.00	4.48	8.92	14.40		14.40	10		1.44	
12	2,730	6,007	8,737	287	599	1,217	134	1,351	2.15	8.98	20.26	31.39	14.27	45.66	9.4	4.86		237
13	1,841	5,485	7,326	326	486	1,048	115	1,163	2.44	7.29	17.44	27.17	9.10	36.27	10	3.63		159
14		2,855	2,855	90	362	476	52	528	.67	5.43	7.92	14.02		14.02	10		1.40	
15	7,762	13,510	21,272	699	1,270	2,382	262	2,644	5.24	19.05	39.66	63.95	36.74	100.69	10	10.07		619
16	2,401	7,385	9,786	449	769	1,282	141	1,423	3.36	11.53	21.34	36.23	11.78	48.01	10	4.80		329
17		2,256	2,256	96	303	359	39	398	.72	4.54	5.97	11.23		11.23	10		1.12	
18	3,024	8,135	11,159	486	979	1,235	136	1,371	3.64	14.68	20.56	38.88	14.44	53.32	10	5.33		376
19	3,616	7,897	11,513	642	909	1,161	128	1,289	4.81	13.63	19.33	37.77	17.29	55.06	10	5.51		486
20		1,911	1,911	95	291	262	29	291	.71	4.36	4.36	9.43		9.43	10		.94	
21	8,470	13,693	22,164	624	1,684	2,135	235	2,370	4.68	25.26	35.55	65.49	40.51	106.00	10	10.60		1,028
22	7,269	14,209	21,478	651	1,466	2,304	253	2,557	4.88	21.99	38.35	65.22	33.37	98.59	10	9.86		917
23		2,127	2,127	175	298	239	26	265	1.31	4.47	3.97	9.75		9.75	10		.97	15
24		1,782	1,782	119	266	214	24	238	.88	3.99	3.57	8.44		8.44	10		.84	
25	5,747	11,509	17,256	765	1,478	1,745	192	1,937	5.73	22.17	29.05	56.95	28.44	85.39	10	8.54		809
26		1,892	1,892	136	315	221	24	245	1.02	4.72	3.67	9.41		9.41	10		.94	
27	5,128	8,960	14,088	664	1,145	1,407	155	1,562	4.98	17.17	23.43	45.58	26.08	71.66	10	7.17		662
28	5,742	12,513	18,255	901	1,325	2,037	224	2,261	6.75	19.87	33.91	60.53	27.78	88.31	10	8.83		938
29		1,690	1,690	112	297	193	21	214	.84	4.45	3.21	8.50		8.50	10		.85	
30	10,208	15,542	25,750	851	980	3,310	361	3,674	6.37	14.70	55.11	76.18	50.04	126.22	10	12.62		268

a For plat of experiment block see p. 69; for sprays applied see p. 73.

TABLE 30.—*The comparative value of the 35 sprays tested in the experiment block of the Rio Bonito orchard in 1895, etc.*—Continued. (*a*)

Row No.	Number of peaches— Thinned from trees of row.	Number of peaches— Matured by trees of row.	Total number of peaches set by trees of row.	Classified yield of fruit for— Drying.	Classified yield of fruit for— Chico cannery.	Classified yield of fruit for— Oakland cannery when gathered.	11 per cent weight added to Oakland fruit.	Total estimated weight of Oakland fruit when matured.	Value of— Drying fruit at ¾ cent per pound.	Value of— Chico fruit at 1½ cents per pound.	Estimated value of Oakland fruit when matured.	Total value of drying and cannery fruit when matured.	Estimated value of thinned fruit at same rate as that matured.	Total estimated value of all fruit set by trees of row.	Number of trees in rows.	Average value of fruit per tree— Sprayed.	Average value of fruit per tree— Unsprayed.	Average net gain per cent of sprayed trees over unsprayed trees.
				Lbs.	*Lbs.*	*Lbs.*			$	$	$	$	$	$		$	$	
31	....	7,280	7,280	354	833	1,151	127	1,278	2.66	12.49	19.17	34.32	....	34.32	10	....	3.43	....
32	3,269	10,242	13,511	401	999	2,018	222	2,240	3.01	14.98	33.60	51.59	16.47	68.06	10	6.81	....	98
33	7,360	12,905	20,265	661	967	2,643	291	2,934	4.96	14.50	44.01	63.47	36.19	99.66	9.8	10.17	....	424
34	....	3,929	3,929	185	554	585	64	649	1.39	8.31	9.73	19.43	....	19.43	10	....	1.94	....
35	9,730	16,009	25,739	517	1,761	2,596	286	2,882	3.87	26.41	43.23	73.51	44.67	118.18	8.6	13.74	....	608
36	4,896	8,946	13,842	302	671	2,101	231	2,332	2.27	10.06	34.98	47.31	25.89	73.20	10	7.32	....	264
37	....	3,982	3,982	200	553	617	68	685	1.50	8.30	10.27	20.07	....	20.07	10	....	2.01	....
38	3,318	8,314	11,632	269	951	1,656	182	1,838	2.02	14.26	27.57	43.85	17.49	61.34	10	6.13	....	205
39	5,821	9,544	15,365	335	1,172	1,736	191	1,927	2.51	17.58	28.90	48.99	29.89	78.88	8	9.86	....	490
40	....	3,348	3,348	146	263	700	77	777	1.10	3.94	11.65	16.69	....	16.69	10	....	1.67	....
41	5,953	11,757	17,710	570	559	2,901	319	3,220	4.28	8.38	48.30	60.96	30.87	91.83	10	9.18	....	450
42	....	6,493	6,493	398	663	1,061	117	1,178	2.99	9.94	17.67	30.60	....	30.60	10	3.06	....	191
43	....	2,174	2,174	142	283	314	35	349	1.07	4.24	5.23	10.54	....	10.54	10	....	1.05	....
44	773	6,276	7,049	385	647	975	107	1,082	2.89	9.70	16.23	28.82	3.55	32.37	10	3.24	....	208
45	3,951	10,862	14,813	726	468	2,297	252	2,549	5.45	7.02	38.23	50.70	18.44	69.14	10	6.91	....	512
46	....	2,358	2,358	117	307	350	38	388	.88	4.60	5.87	11.35	....	11.35	10	....	1.13	....
47	....	4,906	4,906	211	861	602	66	668	1.58	12.94	10.02	24.54	....	24.54	10	2.45	....	117
48	675	4,447	5,122	260	237	942	104	1,046	1.95	3.55	15.69	21.19	3.22	24.41	10	2.44	....	128
49	....	2,219	2,219	142	379	235	26	261	1.07	5.68	3.91	10.66	....	10.66	10	....	1.07	....
50	....	6,268	6,268	446	470	1,253	138	1,391	3.35	7.05	20.86	31.26	....	31.26	10	3.13	....	193
51	2,985	8,221	11,206	479	1,855	398	44	442	3.59	27.82	6.63	38.04	13.81	51.85	10	5.18	....	218
52	....	3,448	3,448	230	281	620	68	688	1.73	4.21	10.32	16.26	....	16.26	10	....	1.63	36
53	....	2,412	2,412	160	215	425	47	472	1.20	3.22	7.08	11.50	....	11.50	9.6	....	1.20	....
54	5,568	12,555	18,123	776	760	2,527	278	2,805	5.82	11.40	42.07	59.29	26.29	85.58	10	8.56	....	459
55	....	3,271	3,271	259	349	491	54	545	1.94	5.24	8.17	15.35	....	15.35	10	....	1.53	....
56	5,659	10,016	15,675	440	1,130	1,820	200	2,020	3.30	16.95	30.30	50.55	28.56	79.11	9.5	8.32	....	443
57	5,251	10,505	15,756	465	1,519	1,519	167	1,686	3.49	22.78	25.29	51.56	25.77	77.33	10	7.73	....	513
58	....	2,577	2,577	194	378	330	36	366	1.45	5.67	5.49	12.61	....	12.61	10	....	1.26	....

a For plat of experiment block see p. 69; for sprays applied see p. 73.

COMPARATIVE SIZE OF FRUIT ON SPRAYED AND UNSPRAYED TREES.

Owing to the fullness of the records obtained relative to the weight and number of peaches gathered from the sprayed and unsprayed trees in the present experiments, it is possible to learn the comparative average weight of the fruit produced on treated and untreated trees. It might seem that the unsprayed trees, having to mature on an average 291.3 peaches per tree, would yield larger fruit than the sprayed trees, which had to mature 949.2 peaches per tree; in other words, that the increased number of peaches upon sprayed over unsprayed trees would, to a considerable extent, be counterbalanced by an increase in the size of the fruit on the lightly loaded unsprayed trees. It has been found, however, that where the conditions for vigorous growth of a tree are present, and where the fruit upon a tree is so thinned that the tree is not overloaded, the peaches of the full-bearing tree are practically as large when mature as are those of the tree which has lost much of the crop from curl. The following table has been compiled from the facts in hand upon this matter. It is shown in this table that the fruit from the sprayed trees averaged for the whole block (345.3 trees) 299.0344 peaches per 100 pounds, and the fruit from the unsprayed trees averaged for the whole block (228.9 trees) 299.0312 peaches per 100 pounds. This shows that the gain in size of peaches on unsprayed trees over those on sprayed trees, as determined by the average number of peaches to 100 pounds, is $\frac{106}{100000}$ per cent, or only about $\frac{1}{1000}$ of 1 per cent. This amounts to nothing from a practical standpoint.

TABLE 31.—*Size of fruit on sprayed and unsprayed trees as determined by the average number of peaches per 100 pounds.*

	Number of trees in block	Fruit produced by all trees of block.		Average production per tree.		Average number of peaches— Per 100 pounds.		Average number of peaches— Per tree.		Proportionate percentage yield of trees.		Average number of peaches per 100 pounds per tree.	Average percentage of gain in size of fruit on unsprayed trees over that of sprayed trees.
		First picking.	Second picking.	First picking.	Second picking.	First picking.	Second picking.	First picking.	Second picking.	First picking.	Second picking.		
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*								
Sprayed	345.3	95,094	14,504	275.4	42	293.2	337.4	807.5	141.7	86.8	13.2	299.0344	$\frac{106}{100000}$ per cent, or about
Unsprayed....	228.9	19,035	3,257	83.2	14.2	293.6	330.8	244.3	47	85.4	14.6	299.0312	$\frac{1}{1000}$ of 1 per cent.

It should not be understood by the above that a crop of 950 peaches draws no more heavily upon a tree than a crop of 300 peaches when other conditions are equal. All observation tends to show that such is not the case. A tree too heavily loaded will often produce much smaller fruit than a properly thinned tree, even upon exceedingly rich soil. The facts given in both the preceding text and table show clearly, however, that the severe attack of curl in the spring of 1895 drew upon the vitality of the unsprayed trees as heavily as did the excess of 650 peaches each on the sprayed trees. Otherwise stated, the trees averaging 300 peaches were drawn upon as heavily by the attack of curl, combined with the maturing of 300 peaches, as were the sprayed trees in maturing 950 peaches. If this had not been the case, the unsprayed trees would have better nourished their crop, and would have produced larger and heavier fruit than those which were sprayed. These facts should receive the attention of all thoughtful growers, as no one can afford to have his trees drawn upon to the extent of two-thirds of a crop of peaches without return, even when frost or other causes would not have allowed him a crop on sprayed trees. To permit trees thus to suffer from curl even in such a year would be equivalent to draining them of much vitality, even though they failed to show this drain in the reduction of wood or fruit buds for the ensuing year. But it has already been shown that a marked reduction in the number and quality of fruit buds is a result of a spring attack of curl. The soil is also certain to sustain an unnecessary drain upon its resources.

Another phase of this subject is made clearer by the above table. There are very many varieties of peaches so resistant to leaf curl that the fruit does not drop, even when a large percentage of the leaves are lost. Many growers leave such varieties unsprayed, thinking that the saving of the fruit is the all-important point, and that the loss of the spring foliage alone does not warrant the spraying of such varieties. The above facts will show the error of such deductions. When the loss of the foliage upon the Lovell is equal to the drain upon the tree brought about in maturing two-thirds of a crop, the loss of the foliage upon a semiresistant variety must be approximately the same. This drain will be apt to show also in the size and weight of the fruit, if not in the number of peaches. Certainly no grower is warranted in leaving any variety unsprayed simply because that variety holds its fruit in spite of the loss of foliage. The trees have suffered in such a case, and the orchardist can scarcely avoid feeling the loss in the reduced vigor of his trees, the reduced weight and size of his fruit, and the added drain upon his soil.

COLOR OF SPRAYED AND UNSPRAYED FRUIT.

The Lovell peach is normally a fruit of fine color, but under the action of certain of the sprays used its color was greatly heightened. In observing this action of the sprays no color scale was used, but the marked brightening on certain sprayed rows was too distinct to be mistaken by the most careless observer. This heightening of color was not due to excess or lack of crop, for it was distinct on both heavily and lightly loaded trees; where the fruit was of medium size and where it was exceptionally large, but was due to the use of the copper sprays, especially of the stronger Bordeaux mixtures applied. Here is another advantage in the use of the copper salts. This increase in color would certainly mean dollars to the grower where the fruit was placed on the market in competition with unsprayed fruit, even of the same variety. The writer regrets that a color scale could not have been used in this connection, so that the true heightening of color could be stated, but the contrast between sprayed and unsprayed fruit, where the spraying was done with the Bordeaux mixture, was observed and discussed by many who had this fruit to handle.

METHOD OF THINNING AND COST OF PICKING PEACHES.

THINNING BY HAND AND BY CURL.

An argument advanced by certain peach growers and requiring consideration is that a moderate spraying under ordinary conditions is sufficient. By avoiding too thorough work enough curl is allowed to develop to cause the dropping of one-fourth to one-half of the peaches being set by the tree. If soil conditions are favorable it is thought the trees will still retain a sufficient crop, and the expense of thinning will be avoided.

At first thought the plan here suggested might seem the easiest and cheapest way of thinning fruit. A consideration of all points involved will show, however, the faults of this method. To do effective preventive spraying against curl the spray must be applied to the dormant tree, and to judge of the severity of a coming attack of curl before growth begins is too uncertain a method to warrant the indorsement of practical growers. All influencing conditions may appear to favor a light attack of curl till after the spraying is completed, when a sudden change of temperature or a cold rain may develop a severe attack within the course of a few days. Under such conditions, incomplete or light spray work may cost the grower the major portion of his crop.

In case the severity of curl is about as presupposed, the number of peaches remaining on the tree being about what the tree should carry, it is still very probable that the grower has sustained a loss in the stoppage of growth of wood and fruit and in the fall of foliage equal to or above the expense of thinning. There is also a difference between hand-thinned trees and those thinned by curl. This disease is local in its action, not general. If one branch in the midst of diseased branches is thoroughly sprayed it will hold its fruit, while the peaches will fall from those not sprayed. This will show that the peaches of a diseased tree are not thinned evenly, as the disease is frequently not uniformly distributed over all branches of the tree. Then the fruit is for the most part nourished by the foliage of the branch which bears it, and hence if the disease is not equally distributed the foliage will be unequally distributed and the fruit unequally nourished. One portion of a tree may have an excess of fruit, even to the breaking of limbs, while another portion shows a deficiency. Besides the unequal thinning of fruit on different portions of a tree, arising from the unequal action of curl over the tree as a whole, there will also appear an unequal thinning of the fruit of individual branches. In this respect, one of the prime objects of hand thinning, the equalizing of the fruit distribution upon the branches, is lost when the thinning is caused by curl. Such fruit as remains upon the curl-thinned branches is apt to be largely toward the ends of the limbs.

The statements here made respecting the local action of the disease and the local nourishing of the fruit upon a limb or portion of a tree, are known to be correct, and have been established by a series of carefully conducted experiments on sprayed halves of trees. The details and results of this work are given in the concluding section of this chapter.

COST OF PICKING PEACHES.

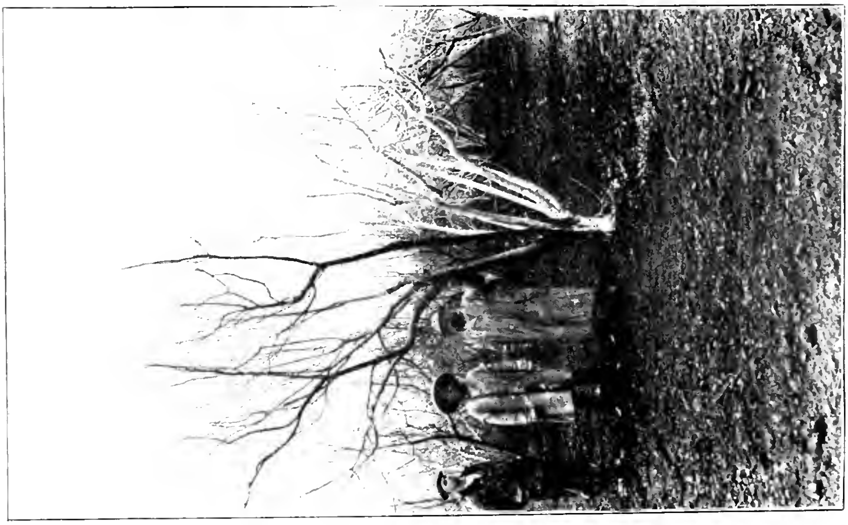
When considering the picking and sorting of peaches from sprayed and unsprayed trees a marked difference is noted in cost in favor of those sprayed. In the Rio Bonito orchard, where our experimental work was prosecuted, it has cost the proprietors $1 per ton to pick fruit from fully loaded sprayed trees. In contrast to this the cost of picking and sorting the fruit of the unsprayed trees just north of the experiment block, in the summer of 1895, was $3 per ton. This was on account of the scattered condition of the fruit on these trees, which were affected by curl in the spring like the control trees of the experiment block. This cost per ton was calculated with wages at $1 per day, the men boarding themselves, and where one sorter to five pickers was employed. We have here a difference of $2 per ton in the cost of picking and sorting fruit from sprayed and unsprayed trees. This added expense on unsprayed trees arises, of course, through the necessity of picking over a greater expanse of tree and orchard surface to obtain a given amount of fruit. It is believed that in this single item of picking the fruit enough is saved to more than cover the expense of spraying the trees and thinning the fruit.

THE LOCAL ACTION OF CURL ON FOLIAGE AND FRUIT.

RECORDS OF TREES SPRAYED ON ONE SIDE.

The study of the habits of *Exoascus deformans* and its influence upon its host led to the following investigation into the localization of the parasite upon the tree and its local rather than general effects.

1



2

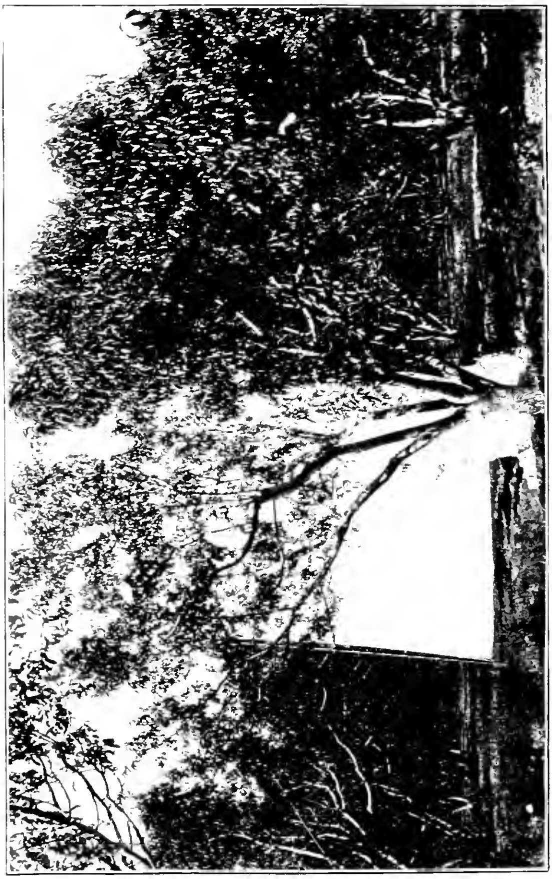


FIG. 1. TREE TREATED ON ONE SIDE; APPEARANCE WHEN DORMANT.

FIG. 2. TREE TREATED ON ONE SIDE; APPEARANCE AFTER DEVELOPMENT OF CURL IN THE SPRING.

DESCRIPTION OF PLATE XVI.

Fig. 1 shows the condition of the trees sprayed on one side (considered in the text, p. 123). The right side of the tree shown was sprayed with Bordeaux mixture, the left side was unsprayed. (Compare with Pls. XVII, XVIII, and XIX.)

Fig. 2 shows the condition of the tree sprayed on one side after curl had largely denuded the unsprayed half at the left.

Just north of the experiment block, in the continuation of the same orchard, was selected a row of 6 trees for treatment on one side. The spray used on half of each of the first three trees from the ea , was the standard Bordeaux mixture recommended by the Department, viz, 6 pounds copper sulphate, 4 pounds quicklime, and 45 gallons of water. The spray used on the following three trees was lime and sulphur, consisting of 10 pounds sulphur, 20 pounds lime, and 45 gallons of water. In doing this spraying an effort was made to treat only one-half of each tree. Each tree was first examined, and, in some instances at least, a large canvas stretched through it in such a manner as to divide it as nearly as possible into two equal parts. All the branches on one side were thoroughly sprayed, the canvas preventing any of the spray reaching the limbs of the other half. In this way the half of each of three trees was sprayed with each of the above-mentioned sprays.

A photograph showing the appearance of one of these trees shortly after treatment is shown in Pl. XVI.

May 10 and 18, 1895, when curl had reached its highest development, careful estimates of the loss of foliage were made for the sprayed and unsprayed sides of the 6 trees used in the experiment. The following table shows the results of these estimates:

TABLE 32.—*Foliage lost from sprayed and unsprayed halves of trees.*

Percentage of leaves which fell from—	Trees treated with Bordeaux mixture.(*a*) Tree No.—			Trees treated with sulphur spray.(*b*) Tree No.—		
	1.	2.	3.	4.	5.	6.
Sprayed half	2	4	6	18	15	15
Unsprayed hal	92	92	90	85	85	85

a Foliage estimated May 18, 1895.

b Foliage estimated May 10, 1895.

On May 8 the trees were examined, and the notes made at that time state that the sprayed and unsprayed sides presented a striking contrast. It is said that "the foliage on the sprayed half of the trees is perfection itself in almost all cases. It is very dense and abundant, both below on the limbs and above. The leaves are of a very dark, rich green, and are long, soft, and beautiful. The growth is very thrifty, in fact, unusually so. There are probably not more than 2 to 3 per cent of the leaves curled at all on the sprayed half, and these are confined to points at the top of the branches not properly sprayed. On the unsprayed half of these trees there is very little healthy growth. Probably 95 per cent of the leaves are curled, and most of them badly curled and distorted. Probably not less than 90 per cent of those produced thus far this spring will drop. The color of the foliage is yellow and sickly. Such leaves as are not curled are small and light in color. The foliage upon both lower and upper limbs is badly affected.

What little growth there is which is thus far free from curl is terminal—very little healthy or comparatively healthy growth is seen from lateral buds. As to fruit, I may say that much is dropping from the curled side and little from the other." (Pls. XVI and XVII.)

The work of thinning the fruit from the sprayed halves of these trees was not conducted at the time the sprayed trees of the general experiment block were thinned. The writer believes that the records of the fruit thinned from these trees were not kept except for one tree sprayed on one side with Bordeaux mixture. The fruit on the sprayed half of this tree was thinned May 8, 1895, and amounted to 1,145 peaches, which weighed 23 pounds, or very nearly 50 peaches to the pound. These peaches were very uniform in size and stuck tightly to the limbs. If they could have grown to the usual size when picked in the fall they would have given 381 pounds of fruit. No peaches were thinned from the unsprayed half of this tree.

The yield of the 6 trees was carefully determined by weighing and counting the fruit from the sprayed and unsprayed sides of each tree separately. The results of this work are shown in the following table:

TABLE 33.—*Yield of sprayed and unsprayed halves of trees.*

	Bordeaux mixture, tree No.—			Sulphur spray, tree No.—		
	1.	2.	3.	4.	5.	6.
Pounds of fruit gathered from—						
Sprayed half	284.8	361.6	286.7	112.2	189.3	64.6
Unsprayed half	14.3	50.6	25.3	48.6	80.4	35.3
Number of peaches gathered from—						
Sprayed half	718	1,064	836	303	450	172
Unsprayed half	40	147	74	132	220	94

By the preceding table it is shown that the sprayed half of tree 1 bore 718 peaches, weighing 284.8 pounds, while the unsprayed half bore only 40 peaches, weighing 14.3 pounds. In this case, as in the case of the other trees of this series, the localized position and action of the fungus of curl upon a tree is shown. The unsprayed half of the tree suffered so severely from the disease that it lost 92 per cent of its foliage and all but 14.3 pounds of fruit. This severe attack on one side of the tree appeared to have no influence whatever over the sprayed limbs of the other side, as the fruit on the sprayed half was thinned of 1,145 peaches, lost but 2 per cent of its foliage, and bore 284.8 pounds of as fine peaches as any in the orchard. On the other hand, the full and healthy covering of foliage on the sprayed side of the tree appears to have had no beneficial influence over the diseased side. Had it had any well-marked beneficial influence the fruit of the unsprayed half would have been retained, which was not the case. The same local action of the disease, and the same local nourishing influence due to the assimilative action of the healthy foliage may be

DESCRIPTION OF PLATE XVII.

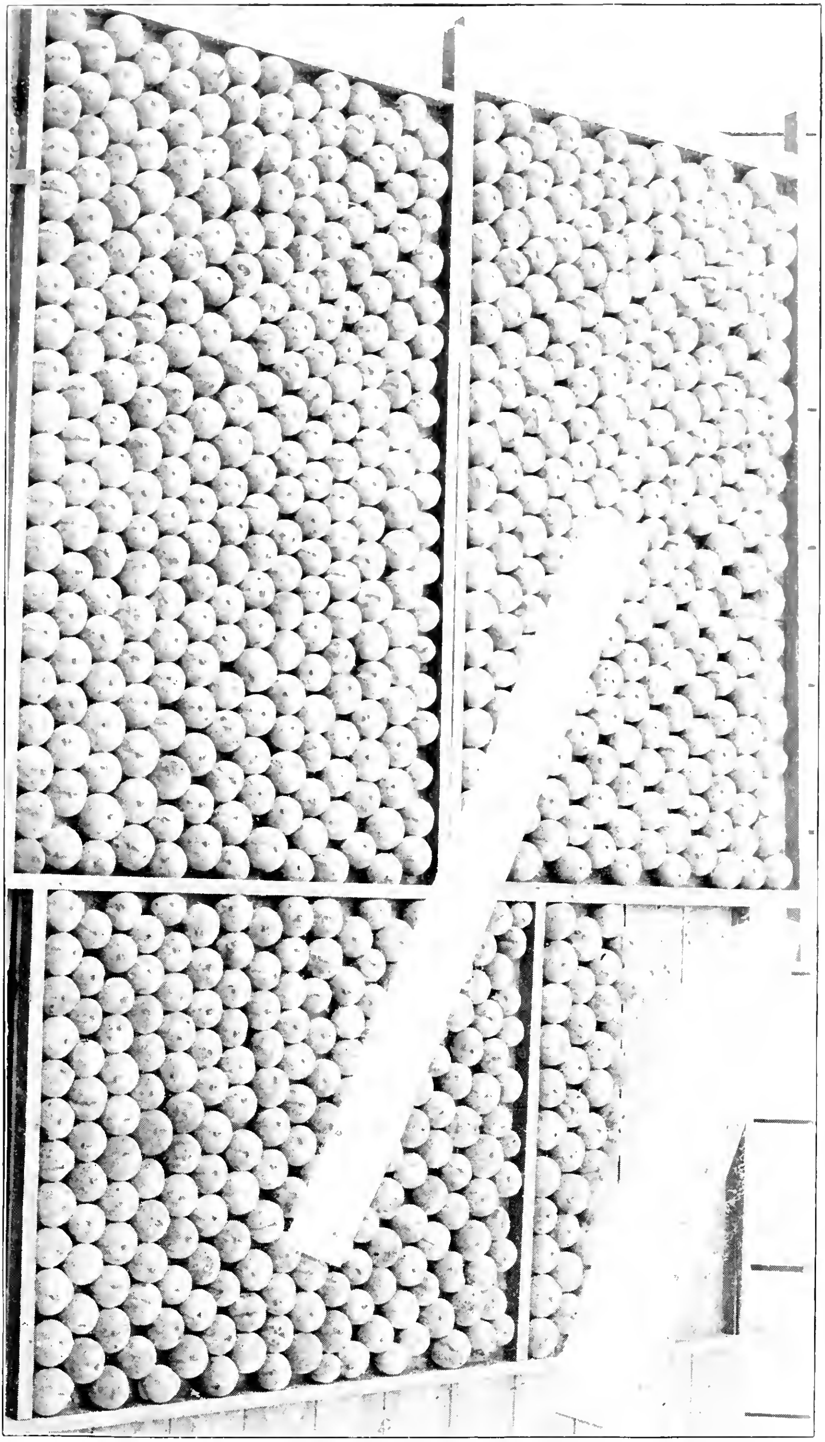
This plate shows the condition of one of the trees sprayed on one side at the time of picking the fruit. The leaves have been cut away with pruning shears to enable the photograph to show the fruit upon the sprayed half (right side) of the tree, and the absence of fruit upon the unsprayed half (left side). The sprayed half matured 284.8 pounds of the finest peaches; the unsprayed half matured only 14.3 pounds. Over 1,100 peaches were thinned from the sprayed half of this tree to enable the limbs to bear the crop, while the unsprayed half was unthinned except by curl. (For records of this and other trees sprayed on one side see Chapter VI, also compare with Pls. XVI, XVIII, and XIX.)

Condition, at Maturity of Fruit, of Trees Treated on One Side.

The leaves have been removed to show the fruit on sprayed side.

DESCRIPTION OF PLATE XVIII.

Peaches gathered from the tree sprayed on one side shown in the preceding plate. The fruit shown on the two drying trays at the left, together with that in the lower compartment of the tray at the right, was gathered from the sprayed half of this tree. The peaches shown in the upper right-hand compartment were all that matured on the unsprayed half of the same tree. The sprayed half bore 718 peaches, weighing 284.8 pounds; the unsprayed half bore only 40 peaches, weighing 14.3 pounds. (Compare with Pls. XVI, XVII, and XIX.)



FRUIT FROM TREATED AND UNTREATED SIDES OF SINGLE TREE.

DESCRIPTION OF PLATE XIX.

This is a photograph of a limb of the sprayed half of the tree shown in Pls. XVI and XVII, after the removal of the leaves with pruning shears. A good idea of the size and perfection of this fruit may be obtained from the plate. The color was strikingly high and rich. The size of the fruit is further shown by the fact that the peaches averaged 252 per 100 pounds. (See note on this work at the close of Chapter VI, p. 122; also refer to Pls. XVI, XVII, and XVIII.)

FRUITFULNESS OF LIMBS ON TREATED HALF OF TREE.

Leaves removed to show fruit.

seen in the condition of the foliage and crop on the sprayed and unsprayed sides of the other trees included in these experiments.

It even appears likely, both from observation of the trees and from the general laws of use and disuse and supply and growth, that the influence of the sprayed upon the unsprayed portions of the tree, in the presence of an attack of curl, is detrimental rather than beneficial. It is probable that the half of the tree in full foliage, instead of lending material aid to the defoliated side, tends to further rob that side, at least of the crude sap coming from the roots.

For the purpose of showing the reader the striking results obtained from these trees, several photographs were made at the time the crop was matured. In order that the fruit might be seen upon the tree the foliage was carefully cut away and a screen placed behind the tree (Pl. XVII). A single limb was also photographed, as shown in Pl. XIX. The fruit gathered from the sprayed and unsprayed halves of tree 1 is likewise shown in Pl. XVIII. The unusual size and brightness of color of the fruit from the sprayed half of this tree was very marked. The peaches averaged 252 per 100 pounds. The average of peaches for the large experiment block was, as before stated, 299 per 100 pounds. There was thus a gain of 18.66 per cent in size of fruit on the sprayed half of this tree over the average for the block.

CHAPTER VII.

PREVENTIVE SPRAY WORK CONDUCTED BY ORCHARDISTS.

GENERAL CONSIDERATION OF THE AUXILIARY WORK.

While planning the experiments already detailed it seemed desirable to set on foot a similar line of work among peach orchardists in general. It was thought that several advantages could be attained from such auxiliary and coincident work: (1) It would indicate the effectiveness or noneffectiveness of the sprays recommended, in controlling curl under the various conditions of variety, situation, soil, temperature, atmospheric humidity, seasonal variations, etc., existing in the many peach-growing sections of the country. (2) It would eliminate the personal element of the other experiments being conducted, and would introduce various new conditions of orchard work, thus pointing out the efficiency or needs of the general grower and indicating what features of the work should receive special attention in offering final recommendations. (3) It would introduce the methods of treatment in many peach-growing centers, and by means of the object lessons thus set up, it would effect a much more rapid and general adoption of such spraying methods than could be hoped for otherwise.

In advance of the inauguration of this work, which was begun in the fall of 1893, correspondence was opened with over 1,600 peach growers in all peach-growing centers of the United States. To each of these growers was sent a circular describing the nature and cause of peach leaf curl, outlining a series of spraying tests which it was desirable to have conducted for its prevention, and supplying the spray formulæ known to have given good results in California. Each grower was given the facts necessary to enable him to carry out the work, and was requested to furnish the Department with the results of his experiments.

A very large number of growers expressed their willingness and desire to assist in conducting these experiments, and a very considerable number have done so in many of the peach-growing centers. It may also be said that the number of growers who have adopted annual spraying methods as a result of this introductory experimental work is large and is constantly increasing. In fact, the spraying of peach trees for curl has become very general in many of the peach-growing centers of the United States where the disease prevails.

Of the reports which have been received of work conducted by the growers, it is thought best to include a few from those regions where curl is most common. The reports given are of much value, and in numerous cases they show that the experiments were carefully carried out. Representative reports will be given from the lake shore fruit belt of Michigan, from the Willamette Valley, Oregon, where peach culture has been greatly checked by curl, and from several growers in California and elsewhere. An effort has been made to present these reports, which have been carefully tabulated, in as compact form as possible.

NOTES ON THE AUXILIARY EXPERIMENTS IN MICHIGAN.

A very considerable number of peach growers in the more northern portion of the Michigan fruit belt received from the Department a request to undertake spraying experiments in the winter of 1893–94 for the prevention of peach leaf curl. Among these orchardists was Mr. Smith Hawley, of Ludington. This gentleman, as well as several other growers of Mason and Oceana counties, entered heartily into the work, the result being that at present a very large number of orchardists are annually spraying for curl in that region. The work conducted by Mr. Hawley involved the testing of a number of sprays in early and late winter with one and two applications. It was very carefully carried out, and as the disease developed quite seriously in that region in the spring of 1894 his results are most interesting and valuable. The data supplied by his report are presented in the following table and notes:

TABLE 34.—*Experimental work conducted by Mr. Smith Hawley, of Ludington, Mich., in the spring and summer of 1894.*

Letter of formula and No. of experiment.	Formulæ.	Variety of trees.	Age of trees.	Nature of soil.	Number of trees—		Date of—		Percentage of leaves lost by—		Date when loss of leaves was estimated.	Pounds of fruit produced by—	
					Sprayed.	Unsprayed.	First spraying.	Second spraying.	Sprayed trees.	Unsprayed trees.		Sprayed trees.	Unsprayed trees.
			Years.										
(A) 1	15 lbs. sulphur; 30 lbs. lime; 10 lbs. salt; 60 gal. water	Crawfords Early	12	Heavy sand and clay loam.	10	10	Apr. 17	....	10	50	June 15 and June 22	288	99
(C) 2	5 lbs. copper sulphate; 5 lbs. lime; 45 gal. water	Hales Early	12	Sand and clay loam.	12	12	Apr. 12	....	8	50	....do	801	519
(B) 3	10 lbs. sulphur; 20 lbs. lime; 10 lbs. salt; 60 gal. water	Crawfords Early; Hales Early; Hills Chile	5	....do	21	21	Jan. 19	Apr. 17	15	50	....do	666	213
(B) 4 (C)	First spraying: 10 lbs. sulphur; 20 lbs. lime; 10 lbs. salt; 60 gal. water; Second spraying: 5 lbs. copper sulphate; 5 lbs. lime; 45 gal. water	Crawfords Early; Hales Early; Hills Chile	5	Clay loam	21	21	Jan. 19	Apr. 12	5	50	June 22	342	243
(C) 5	5 lbs. copper sulphate; 5 lbs. lime; 45 gal. water	Crawfords Early	12	Sand and clay loam.	10	10	Feb. 8	Apr. 12	3	40	June 15 and June 22	437	324
(A) 6	15 lbs. sulphur; 30 lbs. lime; 10 lbs. salt; 60 gal. water	Crawfords Early; Barnards Early	12	....do	23	23	Jan. 19	....	5; 8	50; 75	....do	991	666
(B) 7	10 lbs. sulphur; 20 lbs. lime; 10 lbs. salt; 60 gal. water	Crawfords Early	12	Clay and sand loam.	10	10	Jan. 19	....	20	50	....do	279	225
(C) 8	5 lbs. copper sulphate; 5 lbs. lime; 45 gal. water	Early Louise	15	Sand and clay loam.	18	17	Feb. 8	....	3	90	....do	1,017	63

The preceding table gives the details of eight of Mr. Hawley's experiments. The experiments are distinguished by numbers (1–8), and the formulæ used by letters (A, B, and C). Mr. Hawley's notes on these experiments were written chiefly on two dates, the first immediately after the estimates of foliage were made and the second shortly after the fruit was gathered. His statements in general are given in the following notes:

Experiment 1:

June 23, 1894.—This experiment was made under rather unfavorable circumstances, as the wind came up quite strong after I had commenced, and consequently I could not do the work as thoroughly as I wished, but the results now promise to be entirely satisfactory. The foliage is perfectly fresh and green, and apparently the peaches are going to hang on. Another thing that now appears to be well established is that the earlier spraying is the better. [See notes under experiment 2.] There is now quite a perceptible difference to be noticed between early and late spraying as regards the foliage.

October 1, 1894.—This experiment has demonstrated the effectiveness of the spray used. While the crop was not large, owing to the unhealthy state of the trees from leaf curl last year, yet it was about three times as large on the sprayed as on the unsprayed trees. The fruit was much nicer. I could easily pick out the baskets of fruit from the sprayed trees.

Experiment 2:

June 23, 1894.—This experiment has given entire satisfaction so far, as the foliage of the trees is perfect and the fruit is hanging on well. This experiment, taken in connection with the others, indicates that the blue vitriol solution, C, acts quicker than the sulphur solution. The winter sprayings seem fully as effective with the sulphur solution as with the blue vitriol,but the spring spraying is not quite as good.

October 1, 1894.—While the difference in the amount of fruit gathered from the sprayed and unsprayed trees is not as great as in some of the other experiments, yet the effect is fully as apparent, for these trees were not nearly as badly affected last year as some others, and consequently they all had a fair load of fruit. There was a far greater difference noted in the foliage than in the fruit.

Experiment 3:

The first spraying of this experiment was on January 19, and was followed by a heavy rain storm, which lasted twenty-four hours, and will undoubtedly prevent the full benefit of the work from being realized, but the work was very thoroughly done and may be effective.

June 23, 1894.—The second spraying was well done, and at this date the effect seems to show (1) that formula B is not strong enough to have the desired effect; and (2) that two sprayings are not much better than one, provided the work is thoroughly done with one spraying, and provided, also, the spraying is followed by good weather.

October 1, 1894.—This experiment has given greater satisfaction than anticipated. The proportion of sprayed to unsprayed fruit is better than expected at the time of the estimate on the loss of foliage.

Experiment 4:

June 23, 1894.—The contrast between the sprayed and unsprayed trees at this date is very decided in this experiment. The first spraying was on the same date as experiment 3, and followed by rain. The last was done April 12 with formula C, and was well done, and the trees now look fine.

October 1, 1894.—The results of this experiment are rather disappointing, as I was led to believe when I made the estimate of the loss of foliage in June that the results would be more satisfactory than with experiment 3. Whether the solutions used had the effect of neutralizing each other, or whether formula B, having been first applied, prevented any benefit from formula C, I can not tell.

Experiment 5:

June 23, 1894.—The first spraying of this lot was followed by ten hours' rain, the last spraying by good weather. The treated trees present a fine appearance, but the contrast is not so great as in some other experiments, for the control trees are an outside row and apparently not as badly affected as those farther in the orchard. I do not anticipate a very large difference in the fruit yield.

October 1, 1894.—This experiment has turned out just as I thought it would. The difference in the amount of fruit from the sprayed and unsprayed trees is not great, yet it is quite satisfactory considering the conditions.

Experiment 6:

June 23, 1894.—This experiment was thoroughly made, but was unfortunately followed by twenty-four hours of warm rain, commencing ten hours after the spraying, so that the result is not as satisfactory as desired, but the effect is so noticeable that the difference can be seen half a mile away.

October 1, 1894.—The results of this experiment are entirely satisfactory. In spite of the fact that the spraying was followed by rain and then by very cold weather, the yield of fruit was one-third more on the treated trees than on the untreated trees, but what pleases me most is the very great difference in appearance of the trees now. Those that were treated have made double the growth this season that the untreated trees have. They are holding their leaves late and have twice the buds set for another year, and are fresher and healthier in every way.

Experiment 7:

June 23, 1894.—The result of this experiment thus far seems to show that the formula used is not strong enough to accomplish the work desired. There is at this date less difference to be noted between the treated and untreated trees than in any other experiment.

October 1, 1894.—This experiment has resulted about as I thought it would, from the appearance of the trees in June. I do not think formula B is strong enough.

Experiment 8:

June 23, 1894.—I regard this as one of the most valuable experiments in the series. It has so far shown the best results. The untreated trees look as though a blight had struck them, appearing at this date as if they were going to die, while the sprayed trees look as fresh and healthy as young trees that never had any disease. One curious thing I have noticed is in relation to a branch from one of the untreated trees which reaches across to one of the treated ones. This branch, of course, got sprayed when the tree was sprayed with which it mingles, and it is as full of leaves and fruit as the treated tree, while the balance of the tree to which it belongs is bare of leaves and fruit.

October 1, 1894.—The final results of this experiment have proved what I expected. There is a greater difference in yield than in any other experiment, while the difference in appearance between the treated and untreated trees is yet very marked. The treated trees look as fresh and healthy as young trees, while the others still look very bad. These trees have always been very heavy bearers, and consequently have not attained a very large size. They were never very badly affected by leaf curl till this year.

In the eight experiments described by Mr. Hawley the percentages of net gain in fruit of the sprayed trees over the unsprayed were as follows:

TABLE 35.—*Percentages of net gain in fruit shown in eight spraying experiments conducted by Mr. Smith Hawley, of Ludington, Mich.*

Experiment No.	Formula.[a]	Net gain.	Experiment No.	Formula.	Net gain.
		Per cent.			*Per cent.*
1	A	191	5	C	35
2	C	16	6	A	49
3	B	171	7	B	21
4	B and C	41	8	C	1,121

[a] See table 31.

Owing to the fact that Mr. Hawley's experiments were conducted with different varieties of peach, an accurate comparison can not be instituted between them. From the very excellent results obtained in experiment 8, where the unsprayed trees lost 90 per cent of their leaves and the sprayed trees only 3 per cent, and where the net gain in fruit by the sprayed trees was 1,424 per cent of the yield of the unsprayed trees, the writer believes Mr. Hawley's conclusions are correct, viz, that the spray used in this experiment gave the best results. That the same spray did not give equally striking contrasts in experiments 2, 4, and 5 is probably due mainly to the fact that the trees of these experiments were not of the same variety as those of experiment 8, but were much more resistant to disease, hence no spray could have produced in the former experiments the same contrast between sprayed and unsprayed trees. That the trees of experiments 2, 4, and 5 were not as badly diseased as those of experiment 8 is shown to be a fact, for the unsprayed trees of the latter experiment lost 90 per cent of their leaves from curl, while those of the former experiments lost only 50 per cent. The same evidence is given by the fruit. The unsprayed trees of experiment 8 bore only 3.7 pounds of fruit per tree, while the unsprayed trees of experiments 2, 4, and 5 averaged 45.7, 11.6, and 32.4 pounds of fruit per tree, respectively.

From the preceding facts it appears that the most active and satisfactory spray used by Mr. Hawley was that containing 5 pounds of copper sulphate, 5 pounds of quicklime, and 45 gallons of water. This is especially interesting from the fact that this spray also gave the best results among the 35 formulæ tested by the writer in the Sacramento Valley.

The relative value of the stronger sulphur spray (formula A) and the Bordeaux mixture used by Mr. Hawley (formula C) is well brought out in an experiment conducted by him on a somewhat similar scale, but with a single variety of peach—Hills Chile. This experiment admits of very satisfactory comparisons being drawn, and is summarized in the following table:

TABLE 36.—*Experiment No. 9, conducted by Mr. Smith Hawley.*

Row No.	Formula used.	Variety of trees.	Age of trees.	Number of trees.	Date of spraying.	Total yield of fruit.	Net gain of fruit over yield of unsprayed trees.
			Years.			*Pounds.*	*Per cent.*
1	A	Hills Chile	5	6	April 12	270	328
2		do	5	6	Unsprayed	63	
3	C	do	5	6	February 8	306	354
4	A	do	5	6	January 19	189	200

The preceding experiment shows that Mr. Hawley obtained from his Hills Chile trees a net gain in fruit of 354 per cent by spraying with the Bordeaux mixture (formula C), and a net gain of 328 per cent with the stronger sulphur spray when applied on April 12 and 200 per cent when applied on January 19. These results indicate that the early winter treatment will probably not prove as effective in Michigan as a treatment of the trees shortly before the buds swell in the spring. It is probable, however, that the copper sprays will act more quickly than the sulphur sprays, on which account the latter should be allowed somewhat more time for action than the copper sprays, by applying them a little earlier in the spring. The copper sprays may be applied until the first buds begin to open, if necessary, but such a late application of the sulphur sprays would endanger the buds and new growth.

The following are Mr. Hawley's notes on this experiment:

Experiment 9:

June 23, 1894.—This experiment, although on a small scale, has been very intersting and instructive, and has been noted and admired by all who saw it. The rees stand on a slope, and a person standing on the opposite slope, only a few rods away, can see every tree, and the best possible chance is had to observe the effect of the different sprays, and to compare the treated with the untreated trees. The contrast at this time is very remarkable. The trees were quite badly affected by leaf curl last year.

October 1, 1894.—The contrast between the treated and untreated trees is very great as regards yield of fruit, and the contrast in the trees themselves at this date is quite as remarkable. The treated trees look fresh and healthy and have made a fine growth, while the untreated trees look sickly and have made very little growth, looking, in fact, a year or two younger, as regards size, than the others.

Late in the season of 1894 Mr. Hawley tested the sulphur and copper sprays to ascertain the comparative action of the same upon buds which were considerably swollen. He learned that the sulphur spray injured the buds to such an extent as to reduce the yield, while it prevented curl. The copper spray, however, prevented curl and gave a decided increase in yield. He thus reaches the conclusion that formula A is more injurious to buds than formula C. While this is true if the spray is applied at too late a date, it may be safely applied at an earlier date. It should also be mentioned that the sulphur sprays have insecticidal properties much superior to those of the copper sprays.

The Department work conducted by Mr. Hawley seems to have clearly demonstrated the possibility of controlling the most severe attacks of curl in the lake shore region of Michigan with a single spraying, when this is done thoroughly and at the proper time. In experiment 8 the untreated trees were so badly affected that, as already stated, 90 per cent of the foliage and all but 3.7 pounds of the fruit fell from the trees, but by spraying similar trees Mr. Hawley saved all but 3 per cent of the leaves—a gain of 2,900 per cent of foliage—besides increasing the yield of fruit 1,424 per cent. In other words, the sprayed trees held 30 times as much spring foliage and over 15 times as much fruit as the unsprayed trees at their side, all being of the same variety.

In the southern portion of the Michigan fruit belt a number of growers assisted the Department in conducting experiments. Among the reports received from that section is one by Mr. George Lannin, of South Haven. Mr. Lannin's work is summarized in the following table:

TABLE 37.—*Experimental work conducted by Mr. George Lannin, of South Haven, Mich., in the spring and summer of 1895.*

[Nature of soil, sandy.]

Letter of formula and No. of experiment.	Formulæ for 45 gallons of water.	Variety of trees.	Age of trees.	Number of trees—		Date of—		Percentage of leaves lost by—		Date when loss of leaves was estimated.	Fruit produced by—	
				Sprayed.	Unsprayed.	First spraying.	Second spraying.	Sprayed trees.	Unsprayed trees.		Sprayed trees.	Unsprayed trees.
			Years.								*Lbs.*	*Lbs.*
(*D*) 1	10 lbs. sulphur, 20 lbs. lime, 5 lbs. salt.	Barnard	6	10	10	Apr. 10	May 17	20	40	July 10	1,200	830
(*E*) 2	5 lbs. copper sulphate, 10 lbs. lime.	Hills Chile	6	10	10	...do...	June 25	15	35	...do...	1,300	600
(*F*) 3	2 lbs. copper sulphate, 3 pts. ammonia.	Hales Early	6	10	10	...do...	...do...	20	40	...do...	1,760	680
(*G*) 4	5 oz. copper carbonate, 3 pts. ammonia.	Crawfords Late.	6	10	10	...do...	June 8	10	30	...do...	1,800	700

The spray formulæ tested by Mr. Lannin were not included in the work of Mr. Hawley, and are therefore characterized as Formulæ D, E, F, and G. As Mr. Lannin sprayed different varieties of peach trees with 4 formulæ, the experiments can not be compared with one another to advantage. The value of all the sprays used is shown, however, by the gain in fruit obtained. The percentage of net gain in fruit was 44, 116, 158, and 157 per cent, respectively. These figures show that the eau celeste (Formula F) and the ammoniacal copper carbonate (Formula G) gave satisfactory results. The action of the disease on the foliage of the trees of experiment 3 was more severe than it was on the foliage of the trees of experiment 4. The unsprayed trees of the former experiment lost 10 per cent more of their leaves than the trees of the latter. The percentage of gain in fruit from the sprayed trees of experiment 3 was, however, fully as great as that from the sprayed trees of experiment 4. This shows that the eau celeste (Formula F) was more effective in combating the disease than the ammoniacal copper carbonate, which was applied in experiment 4.

Mr. F. N. Chesebro, of South Haven, sprayed 19 Crawfords Late and 19 Oldmixon trees in the spring of 1894, leaving 19 trees of each variety for comparison. The formula used was 15 pounds of sulphur, 30 pounds of lime, and 10 pounds of salt to 60 gallons of water. Mr. Chesebro did not report the exact yield of his trees, but stated that the sprayed trees lost 20 per cent of their foliage and the unsprayed trees 80 per cent—a saving of 60 per cent of the foliage by a single spraying. His report is as follows:

TABLE 38.—*Experimental work conducted by Mr. F. N. Chesebro, of South Haven, Mich., in the spring of 1894.*

[Variety of trees, Crawfords Late and Oldmixon Cling; nature of soil, sandy loam.]

No. of experiment.	Formula.	Age of trees.	Number of trees—		Date of spraying.	Per cent of leaves lost by—		Date when loss of leaves was estimated.
			Sprayed.	Unsprayed.		Sprayed trees.	Unsprayed trees.	
		Years.						
1	15 lbs. sulphur 30 lbs. lime 10 lbs. salt 60 gal. water	13	38	38	Mar. 7	20	80	June.

Mr. J. F. Taylor, of Douglas, Mich., reported favorably upon the spray work conducted by him in 1894. He used three different sprays, treating 50 trees with each, and leaving a like number unsprayed for comparison. The formulæ used were those designated as A, B, and C, in the spray work of Mr. Smith Hawley. Mr. Taylor says, in regard to his work:

The blossom buds had swollen somewhat when I began spraying, but the leaf buds were quite dormant. Formula A was used on March 29, Formula B on April 6, and Formula C on April 20. Blossoms began to open on the last days of April, and by the 6th of May trees were well covered with bloom. The trees sprayed were 6 years old, and of the following varieties: St. John, Barnards Early, Hinman, Switzerland, Gold Drop, and Early Freestone. Some of these varieties curled very badly last year, especially Early Freestone. The soil is quite uniformly a gravelly loam, with clay subsoil under all varieties. I made only one application with each formula. I think two applications would have been better. I sprayed 50 trees and then omitted 50 in each plat, or with each formula. I think Formula C gave as good results as any of them.[1]

After the trees were in full leaf I invited neighboring fruit men to go through the orchard and note the conditions of the trees sprayed and unsprayed. They found the foliage of trees that had been sprayed almost free from curl, while the unsprayed trees were badly curled. * * * The unsprayed trees had a larger percentage of small dead limbs through the top than those that were sprayed, and the prospect for future crops is therefore better where the trees were sprayed. * * * I hope to follow the work up more extensively next spring, and will begin the work earlier in the season, if necessary. If Formula C will continue to give as good results as it did last spring, I prefer to use it.

Mr. S. I. Bates, of Shelby, Mich., sprayed a few Stump the World trees in the spring of 1894, leaving an equal number unsprayed for comparison. The crop from the sprayed trees was double that from the unsprayed trees at their side, and a large percentage of the foliage was also saved. Mr. Bates states that the spray seems to put new life and vigor into the trees, especially young trees. With respect to the action of curl on old trees, he writes that there is an old orchard just across the road from his own which has had curl until the trees have no bearing wood left except at the extreme tops, and the owner "does nothing to prevent the disease and gets but little fruit."[2]

NOTES ON THE AUXILIARY EXPERIMENTS IN OREGON.

The climatic conditions under which peach culture is pursued in Oregon and Washington vary greatly. At the east of the Cascade Mountains the conditions approximate in many districts those prevailing in much of California. At the west of this range local influences determine the greater or less adaptation of each valley or region to the cultivation of the peach. Generally speaking, however, the humidity of the atmosphere for a major portion of the year is much in excess of that prevailing generally at the east of the Cascades or in California. In this respect also this northwest region is quite distinct from the conditions met with in most of the peach-growing regions of the East. In fact the climate of western Oregon and Washington is such as to call for separate consideration in connection with our present work. For this reason special effort has been

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[1] This is the same formula that was found very satisfactory by Mr. Smith Hawley, at Ludington, Mich., and by the writer in the Sacramento Valley.

[2] There are thousands of such peach orchards in the peach districts of the United States. To those who are interested in the renewal of young and bearing wood upon lower limbs and upon old trees, the writer would refer to the data presented in Chapter V of this bulletin, where the influence of sprays on the vegetation of trees has been quite fully considered.

made to carry out spraying experiments in western Oregon, so that the needs of the growers west of the Cascades could be supplied.

The great rainfall which annually occurs on the west side of the Cascade Mountains makes the vegetation of that region especially liable to fungous diseases, and the peach is no exception to this rule. In the Willamette Valley, Oregon, along the lower Columbia, and in the basin of Puget Sound in Washington, peach leaf curl has become a great hindrance to extensive peach culture. In view of these facts, many peach growers of Oregon and Washington were requested by the Department to conduct experiments for the control of the disease, and it was taken up by a number in 1894 and again in 1895. Several of the gentlemen who conducted such work prepared reports of the same, which should prove of much interest and value to the peach growers of both States.

Among those who entered heartily into the work was Mr. M. O. Lownsdale, of Lafayette, Oreg. This gentleman conducted very extensive spraying tests according to plans supplied by the Department, both in 1894 and 1895, using in his work as many as 30 acres of young peach trees in 1894. At the close of his experimental spray work Mr. Lownsdale gave the following general facts respecting the situation in the Willamette Valley, in which Lafayette is situated, being the center of an extensive fruit-growing region of Yamhill County:

I hand you herewith my report of experiments for the prevention of peach leaf curl for the season of 1895, to which I desire to add a few words upon the status of the peach industry in the Northwest.

Peach growing has been abandoned to a great extent in the Willamette Valley because of the attacks of the shot-hole fungus and leaf curl. Growers have not understood the causes of their troubles, and have attributed them to peculiar climatic conditions, or have grouped them under the indefinite term blight; but now that the nature of these fungous troubles is better understood, and the remedies suggested have proved so efficacious, it seems that the abandonment of the industry may have been premature. The success of the preliminary experiments has restored the confidence of orchardists in a great measure, and as it becomes widely known that our fungous troubles can be controlled, increased attention will be given to peach growing.

Experiments through a series of four years on a block of 6 acres of Early Charlotte peaches indicate that it may be possible to prevent these destructive fungi from getting a foothold in an orchard. This block of trees, which was planted in dormant bud, has received an annual treatment in October and two treatments each spring with the ammoniacal copper carbonate, with the exception of the spring of 1895, when your modified Bordeaux was applied. Neither leaf curl nor shot-hole fungus has developed in this block. A fair crop of fruit was harvested this summer—the fourth from the bud—and the trees are healthy and have grown luxuriantly. If intending planters would select perfectly healthy trees—either yearling or dormant buds—and would give them one treatment in autumn, as the Department has suggested, in addition to the spring treatment for leaf curl, it is probable that peach growing would again become profitable in the Willamette Valley. I am convinced that if the efficacy of the modified Bordeaux mixture for the control of leaf curl had been known five years ago the industry would have been flourishing to-day, for with the treatment for leaf curl, which adds so much vigor and sturdiness to the tree, as indicated by the pushing out of dormant buds on lower branches, the liability to attacks of other fungi would have been lessened, and it would then have been difficult for the great shot-hole wave to sweep over our orchards as it did in 1893 and 1894.

The quality of peaches grown in the Willamette Valley is unsurpassed. No locality in the United States can produce more delicious fruit. It seems judicious, then, to attempt to save this industry and render it profitable again. To this end it is to be hoped that the Department's methods for the prevention of these fungous attacks will be widely adopted.

The spray work conducted by Mr. Lownsdale in the spring of 1894 involved the spraying of some 1,700 young trees and the testing of 10 spray formulæ. With each of the 10 experiments was included a considerable number of unsprayed trees left for comparison, these control trees being of the same variety as the trees sprayed in the same experiment, and in each case they were so located at the sides or among the sprayed trees as to admit of just comparison. Mr. Lownsdale's report upon this extensive work is given below. All the spray formulæ prepared by him were for 45 gallons of water:

Thirty acres of peach trees were devoted to experimental work under your direction. These trees were Crawfords Early and Early Charlotte (a seedling from the Crawfords Early). In addition to these tests 10 acres were left wholly untreated as a block check against the main experiments. All these trees were 3 years old, and had curled so badly in 1893 that they had twisted into shapeless masses, though they had partially recovered later in the season. The general plan of work was to treat a block of at least 100 trees with each formula, leaving intervening check rows untreated. In some instances check rows were interspersed through the treated block, it being desirable to have all conditions as nearly alike as possible.

Formula A (10 pounds sulphur, 20 pounds lime, 10 pounds salt) was applied March 21, 1894, to 264 trees in 8 rows, with 2 control rows on each side of the block. Curl appeared in about 3 per cent of the foliage of the sprayed trees, while 60 per cent of the foliage of the untreated controls was affected.

Formula B (5 pounds sulphur, 10 pounds lime, 5 pounds salt) was applied March 23 to 204 trees in 4 rows, with 2 check rows on each side of block. About 3 per cent of foliage was affected, while untreated check rows curled very badly.

Formula C (5 pounds sulphur, 10 pounds lime) was applied to 166 trees on March 22 in a block 4 rows wide, with the customary 2 check rows. Curl developed on about 10 per cent of the foliage of the treated trees, and upon about 60 per cent of that of the controls.

Formula G (6 pounds copper sulphate, 10 pounds lime) was applied to 42 trees on March 17. About 5 per cent of foliage was affected on the sprayed trees, but the controls were so badly affected that they scarcely survived the summer.

Formula H (3 pounds copper sulphate, 5 pounds lime) was applied March 20 to 186 trees in a block 6 rows wide. About 8 per cent of the foliage of the sprayed trees was affected, while the controls were as under Formula G.

Formula I (2 pounds copper sulphate, 3 pints 26° ammonia) was applied March 20 to 26 trees with 26 check trees. About 5 per cent of curl developed on treated trees, while the check row was very badly injured.

Formula J (4 pounds copper sulphate, 5 pounds sal soda, 3 pints 26° ammonia) was applied March 20 to 26 trees, with 2 check rows of 26 trees. Curl developed on 3 per cent of the foliage of the treated trees, but the controls were almost destroyed.

Formula K (5 pounds sulphur, 15 pounds lime) was applied March 19 to 278 trees in a block 10 rows wide, with control rows of 69 trees each on each side. Curl appeared on about 2 per cent of the foliage of the treated trees, while the check rows were, as in the previous year, a mass of curled leaves and twisted branches. Formula K was also applied to 25 Salway trees and to 15 Alexanders, which had curled very badly for many years, the Salways always being defoliated completely. These trees were 8 years old. No curl appeared on either variety.

Formula L (5 pounds copper sulphate, 15 pounds lime) was applied March 13 and again March 21 to 262 trees, with 7 check rows interspersed through the block. Less than one-fourth of 1 per cent of curl appeared on the treated trees of this test, while the check rows were almost destroyed by the disease. The greater portion of these untreated trees have been dug up and replaced (February 13, 1895). Treated trees in this block made an excellent growth, though cultivated only moderately, and a great majority were absolutely free from curl.

The ammoniacal copper carbonate, Formula M (5 ounces copper carbonate, 3 pints 26° ammonia), was applied March 22 to 210 trees, 2 check rows of 69 trees being left alongside. Less than 3 per cent of curl appeared on the block, while 65 per cent of the foliage of the control trees was curled. This formula was also applied twice, at intervals of two weeks, upon 5 acres of trees upon which no curl could be found. This experiment, though remarkably successful, was not as conclusive as desired, as no control trees were left. This was upon a block of thrifty trees, of which I did not care to sacrifice any portion to an experiment. The same treatment had preserved them the previous year, and I feared a change.

All my treated trees have grown satisfactorily this year, but the 10-acre check block of untreated trees was so nearly destroyed by curl that all the trees will be dug up. Several hundred are dead, and of the remainder I think no tree has had a growth of 12 inches.

It will be seen from Mr. Lownsdale's report of the work in 1894 that several of the sprays used gave most excellent results. On May 18 of that year he wrote:

Curl has developed moderately, and everywhere the better condition of treated over untreated trees is apparent. The trees treated with 5 pounds of copper sulphate and 15 pounds of lime may be said to be absolutely free from the curl and the experiment a success. This block was sprayed twice in March. The check rows in this block and alongside are curled as badly as any trees except seedlings.

The modified eau celeste (Formula J) is also giving good results, as is the 5 pounds of sulphur and 15 pounds of lime; but I believe the copper sulphate, 5-pound formula, is in the lead. This may be attributed to more thorough work, as most of the other sprays were only applied once.

Owing to the fact that no fruit records could be obtained from Mr. Lownsdale's experiments in 1894, as the trees were yet too small, arrangements were made for the testing of some of the more valuable sprays in the spring of 1895. The experiments of 1895 show the gain in both foliage and fruit, though the yield was low, resulting from the use of 5 sprays—1 sulphur and 4 copper. The experiments were confined to the Crawfords Early variety, and in each experiment the trees received two sprayings in March. All trees were 4 years old, but rather small. Mr. Lownsdale's data on this work are presented in the following table:

TABLE 39.—*Experimental work conducted by Mr. M. O. Lownsdale, of Lafayette, Oreg., in the spring and summer of 1895.*

[Variety of trees, Crawfords Early; nature of soil, red hill.]

No. of experiment.	Formulae for 45 gallons of water.	Age of trees.	Number of trees. Sprayed.	Number of trees. Unsprayed.	Date of— First spraying.	Date of— Second spraying.	Leaves lost by— Sprayed trees.	Leaves lost by— Unsprayed trees.	Date when loss of leaves was estimated.	Fruit produced by— Sprayed trees.	Fruit produced by— Unsprayed trees.
		Yrs.					*Per ct.*	*Per ct.*		*Lbs.*	*Lbs.*
1	10 lbs. sulphur; 20 lbs. lime; 5 lbs. salt	4	86	91	Mar. 7	Mar. 27	10	35	June 18	346	187
2	5 lbs. copper sulphate; 10 lbs. lime	4	110	68	....do....	....do...	5	35	....do...	480	62
3	2 lbs. copper sulphate; 3 pts. ammonia	4	116	87	Mar. 9	....do...	6	30	....do...	867	193
4	5 oz. copper carbonate; 3 pts. ammonia	4	268	67	Mar. 8	Mar. 28	Trifling.	30	....do...	1,264	......
5	5 lbs. copper sulphate; 15 lbs. lime	4	189	91	Mar. 9	....do...	None.	40	....do...	1,048	15

But few comments upon the preceding table are required. It makes the fact perfectly evident that two spring sprayings are sufficient to almost absolutely control leaf curl in the Willamette Valley. In a letter written June 25, 1895, Mr. Lownsdale says:

Peach leaf curl has not developed as badly in this section as it did last year. I have estimated that about 40 per cent appeared on most of my control trees. Two sprays with lime, 10 and 15 pounds, and copper sulphate, 5 pounds, were an absolute success. Lime in the amount of 15 pounds gives the best results, there being 100 per cent of healthy foliage on trees sprayed with this amount and 5 pounds of copper sulphate. Practically the same results were obtained with two applications of the ammoniacal copper carbonate. It is impossible to find a curled leaf on acres and acres of treated trees.

In the Rogue River Valley, in the southern tier of counties of Oregon, the conditions are somewhat more favorable for peach culture than in much of the Willamette Valley. The climate is somewhat intermediate in character between that of northwestern Oregon and northern California. Peach culture is quite extensive about Ashland, Medford, etc. The reports of Mr. E. F. Meissner, of Kerby, Josephine County, and of Mr. N. S. Bennett, of Medford, Jackson County, are fairly representative of those received from experiments conducted in southern Oregon. Mr. Meissner's report again shows the great effectiveness of 5 pounds of copper sulphate, 10 pounds of lime, and 45 gallons of water. With this formula he sprayed 4 Salway trees 4 years old, leaving an equal number unsprayed for comparison. Two treatments were given, the first February 22, the second March 10, 1895. From the sprayed trees 10 per cent of the foliage was lost from curl, while from the unsprayed trees 90 per cent was lost, leaving the trees nearly bare. Unfortunately, frost killed the buds, and no comparison of fruit was possible, but it is safe to say that the fall of 90 per cent of the leaves would have caused the loss of the crop, while 10 per cent loss would have occasioned little, if any, falling of fruit. Mr. Meissner writes respecting his work that the copper sulphate spray "has given far better results than the sulphur, lime, and salt," and that "the trees sprayed with the bluestone mixture look the best of any in the orchard."

Mr. Bennett used the 5-pound formula for the Bordeaux mixture as given for Mr. Meissner. He sprayed but once, on March 11, 1895. The 29 trees sprayed averaged 44 pounds of fruit per tree, while the single control tree yielded but 9 pounds, or a net gain in fruit of 388 per cent. The fact of most interest in connection with this work is, however, that the variety treated was the Elberta, which is probably more universally susceptible to leaf curl than any other variety now grown in the United States. The control of curl on this variety was almost absolute, as will be seen from the following letter from Mr. Bennett:

> I send you to-day a report of the spraying for leaf curl. The experiment was an honest trial, and I feel very jubilant over the success. I have reported only the Elberta variety, as it was one of that kind which I left unsprayed. I am more than pleased with the results, and can say that a good trial is all that any man needs who has the welfare of his orchard at heart (his pocketbook as well). The peaches from the sprayed trees were first-class, clean, and sold at the highest market price. I notice a very marked difference in the general health of the trees in favor of those sprayed. The leaves lost by the sprayed trees were, perhaps, one-half of 1 per cent. The unsprayed tree was a little above an average tree in the spring. There were 29 sprayed trees, which yielded an average of 44 pounds of choice fruit to the tree, nearly half of which packed 56 peaches to the box. I sprayed 75 Wheatland trees with the same success as far as leaf curl is concerned. They are fine, healthy trees now, and bore a good crop this season. They have been bad about curling, but I left an Elberta because that variety is the worst to curl, and if spraying did them no good I intended to grub them out.

Mr. P. W. Olwell, of Centralpoint, Oreg., applied the sulphur spray to 400 Muir trees in his orchard, leaving 25 trees unsprayed for comparison. The formula used by Mr. Olwell was 15 pounds of sulphur, 30 pounds of lime, and 10 pounds of salt to 60 gallons of water. His trees were 5 years old, growing in black, loamy soil. They were sprayed March 10. The sprayed trees did not lose any foliage from disease, while the control trees lost 25 per cent. The fruit records were not reported.

NOTES ON THE AUXILIARY EXPERIMENTS IN CALIFORNIA.

Besides the experimental work conducted by the writer in the Sacramento Valley in the years 1894 and 1895, a considerable number of growers assisted in carrying on experiments in different portions of

California. Reports have been received from several of these growers, and while in some instances they are not as complete as desired, the results shown are amply sufficient to determine the practical value of the work undertaken.

Among the more complete and carefully prepared reports is one from Mr. A. D. Cutts, of Live Oak, Sutter County. The work was carried out in the winter of 1892–93, and was one of the experiments which led to the writer's detailed series of experiments outlined in the present bulletin. In this orchard the spray was not used in 1893 for the control of leaf curl, but was applied for the purpose of destroying the San José scale, which was gaining a foothold in the orchard. The trees infested by scale were scattered through a 40-acre block of the Crawfords Late variety. These trees had been marked, and in February, 1893, were thoroughly sprayed with the sulphur spray, consisting of 15 pounds sulphur, 30 pounds lime, 10 pounds salt, and 60 gallons water. Only a few of the trees were entirely sprayed. As curl developed seriously in that region in the spring of 1893, the contrast between the scattered sprayed trees and the remainder of the block was very striking, and Mr. Cutts kindly consented to preserve the records of yield of a few of the sprayed and unsprayed trees for use in this connection. In the table which follows is shown the amount of fruit produced by each of the 9 sprayed trees included in Mr. Cutts's records, as well as the weight and number of first, second, and third quality peaches. The same facts are given for an equal number of neighboring unsprayed trees for comparison.

TABLE 40.—*Experimental work conducted by Mr. A. D. Cutts, of Live Oak, Cal., in the spring and summer of 1893.*

[Crawfords Late, 4 years old.]

No. of tree.	Sprayed trees.							Unsprayed trees.						
	Total pounds of—				Number of—			Total pounds of—				Number of—		
	Fruit.	First-quality fruit.	Second-quality fruit.	Third-quality fruit.	First-quality peaches.	Second-quality peaches.	Third-quality peaches.	Fruit.	First-quality fruit.	Second-quality fruit.	Third-quality fruit.	First-quality peaches.	Second-quality peaches.	Third-quality peaches.
1	156	115	32	9	276	96	29	41	23	12	6	102	56	56
2	226	189	20	17	735	126	130	2	......	2	......	......	4	......
3	180	145	28	7	615	110	45	1	......	1	......	......	3	......
4	119	100	13	6	385	70	54	......	......	......	......	......	......	......
5	180	146	25	9	605	138	60	2	......	2	......	......	5	......
6	176	154	17	5	568	86	32	......	......	......	......	......	......	......
7	279	225	34	20	815	151	139	1	......	1	......	......	3	......
8	55	38	12	5	148	60	30	3	......	3	......	......	8	......
9	126	106	15	5	367	65	27	8	8	......	......	18	......	......
Total.	1,497	1,218	196	83	4,514	902	546	58	31	21	6	120	79	56

The average yield of fruit of the sprayed trees given in the table was 166.22 pounds per tree, while the average yield of the unsprayed trees was but 6.44 pounds. This represents a gain in fruit by the sprayed trees above the yield of the unsprayed trees of 24.8 times the yield of the latter. In other words, there was a gain in yield of 2,481 per cent from spraying. Much valuable information was also supplied by Mr. Cutts in relation to the preparation and application of sprays, and the writer has considered these subjects in other portions of the bulletin. Some of the more striking photographs of sprayed and unsprayed trees have also been obtained from Mr. Cutts's orchard, as well as the records of fruit buds elsewhere discussed (Pls. VII and XX).

The report of a test of the Bordeaux mixture (5 pounds copper sulphate, 10 pounds lime, and 45 gallons water) was furnished by Mr. H. B. Gaylord, of Auburn, Placer County. This experiment was made in the spring of 1895. Mr. Gaylord sprayed 10 Heaths Cling peach trees and 4 nectarine trees, the variety of which was not stated. The spraying was done February 15. Mr. Gaylord states that the unsprayed nectarines curled so badly that they bore no fruit at all, while the 4 sprayed trees yielded 320 pounds. He says that every alternate tree was sprayed in a row of nectarines, and that the sprayed peach trees were in the worst places in the orchard. Respecting the result of the work Mr. Gaylord writes, in part:

> I herewith send you a partial report on the experiment for leaf curl. I used only one formula. The result is perfectly satisfactory. I sprayed some peach and some nectarine trees, both with good results. One nectarine tree sprayed has not a curled leaf, while one of the same kind, about 15 feet from it, which was not sprayed, has lost nearly all its leaves. The contrast is so great that it would be worth while to have them photographed. A neighbor, Mr. G. P. Dixon, used formula 3 (2 pounds copper sulphate, 3 pints ammonia, and 45 gallons water) with the same results, so that I am satisfied that the copper sulphate is what does the work.

Mr. Gaylord also states that no leaves were lost from the peach trees sprayed, while all of the leaves curled on the unsprayed trees of the remainder of the orchard.

In Amador County an extensive experiment was made in the spring of 1895, by Mr. George Woolsey, of Ione. Mr. Woolsey sprayed some 2,500 trees of various varieties of peach and nectarine with 5 pounds of copper sulphate, 10 pounds of lime, and 45 gallons of water, and left 720 trees unsprayed for comparison. The spraying was done from February 20 to March 10. Most of the sprayed trees lost no foliage, but a few in a wet situation lost not to exceed 25 per cent, while the unsprayed trees lost not less than 50 per cent of the leaves and a large amount of fruit.

Mr. Woolsey gives some notes respecting the work in the spring of 1895, as follows:

> A block of about 200 trees, Salways 12 to 15 years old, on well-drained soil, and 500 Salways 4 years old, adjoining, I did not spray, thinking they were curl proof. I regret I did not spray them. * * * The leaves are dropping, as well as a large percentage of the fruit. I shall certainly spray them in the future. * * * The

DESCRIPTION OF PLATE XX.

Sprayed and unsprayed Crawfords Late trees in the orchard of Mr. A. D. Cutts, Live Oak. The tree at the right was sprayed in February, 1893, with lime, sulphur, and salt; the trees at the left were untreated. See "Notes on auxiliary experiments in California," for a full account of the work at Liveoak. (Photographed in May, 1893, after most of the diseased leaves had fallen from the unsprayed trees. Compare with Pl. VII.)

TREATED AND UNTREATED CRAWFORDS LATE TREES, LIVE OAK, CAL.

apparent result of spraying, one application, is as follows: Four control trees of Early Rivers, adjoining trees sprayed March 2, are badly curled, leaves dropping, and also the greater portion of the fruit. The adjoining sprayed trees of this tender variety are all right (no curl) and make quite a marked contrast. Besides these, 4 white nectarines and 4 Bilyeau peaches, left at the same time, show curl and loss of fruit, although not as badly as the Early Rivers. The surrounding sprayed trees look vigorous and healthy, with no curl.

Mr. Woolsey was among the first peach growers to adopt the copper sprays for the control of curl. His first experiments were made in 1892, and they proved so satisfactory that he sprayed quite extensively in 1893 and again in 1894. The work in 1893 was of special interest, as the following extract from a communication received from him will show:

I sprayed nearly all my peach and apricot trees. I say nearly all; for, time pressing, I found I would not get over all the peaches, so to save what I considered the most valuable portion, viz, the young lower growth, I had that sprayed and left the tops unsprayed. The season was a damp one and leaf curl was very prevalent with my neighbors. On my place all trees sprayed were exempt, all others badly affected and crops on them almost a failure. On the ones partly sprayed there was a healthy growth on the lower part of the trees, while they were denuded of foliage above.

Mr. Woolsey's work in 1894 was negative, owing to the nondevelopment of the disease that season.

Two peach growers of Eldorado County, Mr. John M. Day, of Placerville, and Mr. A. L. Kramp, of Diamond Spring, furnished the writer with reports of their experiments conducted in the spring and summer of 1895. Mr. Day tried 4 formulæ, each showing a decided saving of foliage, but the fruit was lost from frost. The spray used by Mr. Kramp was composed of 10 pounds sulphur, 20 pounds lime, 5 pounds salt, and 45 gallons of water. He sprayed 600 trees, 3 years old, of the Hales Early, Briggs Early, and Wilcox Cling varieties, and 3,000 unsprayed trees were left for comparison. The sprayed trees lost no foliage and yielded 48,000 pounds of peaches, while the unsprayed trees lost not less than 50 per cent of their leaves and yielded 60,000 pounds. The average yield of the sprayed trees was thus 80 pounds per tree, while the average yield of the unsprayed trees was but 20 pounds, a net gain of 300 per cent.

Gen. N. P. Chipman, of Red Bluff, has been using for at least two years a formula for Bordeaux mixture which gave the writer exceedingly good results at Biggs (see row 21 of the writer's experiments, p. 117). Mr. Chipman writes that his experiments were upon several varieties of peach trees and that excellent results were obtained. He further says: "I used equal parts, or 5 pounds bluestone, 5 pounds quicklime, and 45 gallons water. I believe you have found an infallible remedy. I have used this spray two years with good effect." Mr. Chipman first observed the effects of this spray in the experiment block at the Rio Bonito orchard, in the summer of 1895.

NOTES ON THE AUXILIARY EXPERIMENTS IN NEW YORK, INDIANA, AND OTHER PEACH-GROWING STATES.

Much experimental work for the control of leaf curl has been undertaken at the suggestion of the Department by the peach growers of New York, Indiana, Illinois, Ohio, Kentucky, Maryland, Pennsylvania, Georgia, Tennessee, North Carolina, Arkansas, Missouri, Kansas, and other peach-growing States not already considered in this bulletin. For instance, 80 prominent peach growers of various peach-growing centers of New York were given full instructions for the control of curl in the winters of 1893–94 and 1894–95, and requested to report their work, which in a number of instances was carefully done. The same is true of 54 growers in Ohio, 135 in Pennsylvania, etc., and in each case where the work was properly conducted the results were in harmony with those already discussed in this chapter. For this reason, as well as from the fact that the work already considered has been selected from those sections of the country which are fully representative of the different climatic conditions, it is not thought necessary or desirable to enter much further into the details of the work. One or two experiments may be mentioned, however, before closing the consideration of this phase of the subject.

Mr. Joseph M. Cravens, of Madison, Ind., reported almost absolute success in the control of curl in his orchard. The sprayed trees of the 4 experiments made in no case showed more than 3 per cent of curled leaves, while the amount of curl on the foliage of the unsprayed trees ranged from 25 to 45 per cent. Mr. Cravens states in a letter accompanying his report that he sprayed separate rows through his orchard which were sufficiently far apart not to have the spray affect the intervening rows even if the wind blew at the time of application, and further that he is satisfied that two of the sprays used would have given absolute results had they been applied to every portion of every twig.

Mr. W. T. Mann, of Barkers, N. Y., sprayed 25 trees with the lime, sulphur, and salt spray April 9, 1894, and left 25 trees at their side without spraying for comparsion. On May 28 only 42 diseased leaves were found on the 25 sprayed trees, while as high as 40 per cent of curled foliage was present on some of the unsprayed trees. On the same date as the other spraying was done 25 trees were sprayed with Bordeaux mixture, while 21 were left for comparison. By May 28 only 59 curled leaves had developed on the entire 25 sprayed trees, while of the 21 unsprayed trees several had as high as 30 to 35 per cent of curled leaves. Mr. Mann says that from the fact that among the 50 trees treated not one showed an appreciable amount of disease, while all through the orchard trees were badly affected, was to him very satisfactory evidence of the value of the treatment, especially as he did not undertake the work with any great degree of confidence as to successful results.

Mr. James A. Staples, of Marlboro, N. Y., states that in the seasons of 1894, 1895, and 1896 he made the spray tests on peach trees for leaf curl which had been suggested by the writer, and says he is well satisfied that the disease can be controlled by proper spraying. He states that the winter treatment gave him the best results.

Mr. A. D. Tripp, of North Ridgeway, N. Y., states in his report of spray work for curl that he treated 208 trees and left 320 trees unsprayed. From the sprayed trees he gathered "360 baskets of as fine fruit as ever went to market." The baskets were one-third of a bushel, and the peaches averaged 56 to the basket. From the untreated trees only 15 baskets were gathered, and a portion of this fruit was imperfect. The variety was the Elberta.

CHAPTER VIII.

PREPARATION, COMPOSITION, AND GENERAL CHARACTERS OF THE SPRAYS USED.

PREPARATION OF THE COPPER SPRAYS.

It is not the intention to consider in this place the many forms of copper sprays which have been used at one time or another in the treatment of fungous diseases, but to confine the discussion to those forms tested in the present work.

Most of the formulæ for those copper sprays which have been tested in the treatment of peach leaf curl have been personally prepared at one time or another and the results they gave have been carefully studied. Several other formulæ have been recommended by the writer, but these were prepared and applied by the growers themselves, so that for the results of this work their reports have been consulted. There are still a few other formulæ for copper sprays which have been reported upon, but these are the suggestions of others or were chosen by the growers themselves.

The different copper sprays which have been tested in separate form (not in union with other fungicides) are shown in the following list. This list includes 22 distinct formulæ. Each formula is that used with 45 gallons of water, except the first for Bordeaux mixture, which was with 48 gallons.

TABLE 41.—*Copper sprays applied for the control of peach leaf curl.*

Copper sulphate solution:

- *4 pounds copper sulphate, 45 gallons water.
- *2 pounds copper sulphate, 45 gallons water.

Bordeaux mixture:

- †24 pounds copper sulphate, 45 pounds lime.
- *6 pounds copper sulphate, 15 pounds lime.
- ‡5 pounds copper sulphate, 15 pounds lime.
- *3 pounds copper sulphate, 15 pounds lime.
- ‡6 pounds copper sulphate, 10 pounds lime.
- *5 pounds copper sulphate, 10 pounds lime.
- *3 pounds copper sulphate, 10 pounds lime.
- *5 pounds copper sulphate, 5 pounds lime.
- *4 pounds copper sulphate, 5 pounds lime.
- *3 pounds copper sulphate, 5 pounds lime.

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* Prepared and tested by the writer, and in many cases also tested by growers.

† Chosen and tested by grower.

‡ Recommended by the writer, but tested by the growers.

Bordeaux mixture—Continued

*2 pounds copper sulphate, 5 pounds lime.
*6 pounds copper sulphate, 4 pounds lime.
*6 pounds copper sulphate, 3 pounds lime.
*3 pounds copper sulphate, 2 pounds lime.

Eau celeste:

*4 pounds copper sulphate, 3 pints ammonia (26°).
*2 pounds copper sulphate, 3 pints ammonia (26°).

Modified eau celeste:

*4 pounds copper sulphate, 5 pounds sal soda, 3 pints ammonia (26°).
*2 pounds copper sulphate, 3 pounds sal soda, 2 pints ammonia (26°).

Ammoniacal copper carbonate:

*5 ounces copper carbonate, 3 pints ammonia (26°).
*3 ounces copper carbonate, 2 pints ammonia (26°).

* Prepared and tested by the writer, and in many cases also tested by growers.

The preparation of the copper sprays containing different chemical constituents will be considered in the order in which they appear in the preceding list.

COPPER SULPHATE SOLUTION.

Copper sulphate ($CuSO_4.5H_2O$), commonly called blue vitriol or bluestone, forms, when dissolved in water, one of the most active fungicides known. This chemical, the composition, manufacture, and sources of supply of which will be more fully considered in a following chapter, dissolves in cold water, but somewhat more readily in hot water. As usually sold, the crystals are large, but a fine form may also be had in the market. If the large crystals are purchased and it is desired to dissolve them rapidly, they may be ground in a bone or shell mill before placing in the water. This has frequently been done by the writer when quick work was necessary.

Copper sulphate may be manufactured by dissolving the black oxide of copper in sulphuric acid, or by the various modifications of this process hereinafter discussed. A watery solution of this chemical is strongly acid, and for this reason a simple solution of copper sulphate is very corrosive and injurious to tender plant tissues, as foliage and opening buds. To avoid this injurious action, efforts have been made to obtain from the copper sulphate solution a spray retaining the fungicidal action of the copper, but by the addition of other chemicals to neutralize or largely remove its acid reaction and consequent corrosive effects upon plants. As a result there are a very considerable number of copper sprays, representing various modifications of the simple solution of copper sulphate.

Owing to the acidity of a solution of copper sulphate, the sulphate should not be dissolved or handled in metal dishes of any kind, especially those of iron. The copper will often go to the metal, thus injuring the effectiveness of the spray, and the acid may also injure or destroy the dishes. The most suitable vessels for dissolving copper sulphate for work such as here discussed are those composed wholly of wood, preferably of oak, and may be in the form of barrels, casks, vats, or tanks, of a capacity corresponding to the respective needs of the growers. For small orchards a few good oak barrels of 45 or 60 gallons capacity are very suitable. As concentrated solutions of copper sulphate can be made, enough of the sulphate can be easily dissolved in a 60-gallon barrel to serve for 300 or even 1,200 gallons of spray when properly reduced. It is well, when possible, to use 2 gallons of water to each pound of sulphate when dissolving the latter, but stock solutions may be of two to four times this strength. A solution of copper sulphate is heavier than water, so that it is an advantage in hastening the dissolving process to retain the chemical near the top of the water. If this can be done, the heavier copper solution will settle to the bottom of the barrel, leaving the purer water to continue the dissolving action upon the sulphate. The placing of the copper in a gunny sack and suspending the latter in the water has been recommended, but it is thought that other means more suitable may be found. The use of sacks or other cloths about the spray tanks is hardly advisable, as the freer the tanks are kept from lint, strings, fibers, etc., arising from straining cloths, sacks, frayed staves, and stirring sticks, the less trouble the sprayer will have with his nozzles in the orchard, and the better, quicker, and cheaper can the spray work be done.

Instead of a sack, a clean willow or hard-wood splint basket may be used for suspending the chemicals. A box may also be easily made for the purpose. It should have a diameter, when about 1 foot deep, sufficient to hold the copper sulphate to be dissolved, and it should be open at the top, with strong 1-inch slats across the bottom, the latter to be set one-fourth inch apart. If the box be fitted with a strong hoop bail it may be suspended in the barrel by placing a stick through the bail and across the top of the barrel. As a rule, however, the writer has found it sufficient to place the copper sulphate directly in the bottom of a good oak barrel, filling the latter one-third to one-half full of water, and stirring and crushing the crystals with a clean hard-wood pounder. A half hour's work is sufficient to dissolve many pounds of copper sulphate in this manner. With three or four good barrels one man can thus keep a large spraying gang supplied with material, if the water be convenient. It is always an advantage to place the copper in water in the barrels over night, when possible, as sufficient material is thus easily made ready in the morning for a half day's spraying. It is an advantage to strain all water before the copper sulphate is added, as afterwards ordinary strainers are liable to be injured by the acid, and, as before stated, the use of cloth strainers is not advisable.

The eyes and hands should be protected as much as possible from injury by this spray (p. 171). The unaltered solution of the copper sulphate is not only unpleasant to handle and apply, and injurious to tender vegetable tissues, but it is quite injurious to all metallic parts of pumps, hose, extension rods, and nozzles, nozzles being eaten out very rapidly by it. For these various reasons the solution of copper sulphate is rarely used as a spray in an unmodified form. In most cases its corrosive action is more or less altered or neutralized through the addition of some modifying agent. In other words, the copper sulphate solution is used as a base or stock solution for the preparation of several more or less noninjurious and equally effective sprays, as the Bordeaux mixture, the eau celeste, the modified eau celeste, the ammoniacal copper carbonate, etc. For this purpose it may be prepared in a concentrated solution, to be used as a stock solution for the preparation of any of the modified sprays mentioned, as already pointed out.

A convenient strength for stock solutions is 1 pound of copper sulphate to 1 or 2 gallons of water. In using stock solutions, two matters should always be considered: (1) The pails, barrels, or tanks used should be carefully gauged and marked, so that the number of gallons of water or of the solution they contain may be known and not guessed at.[1] (2) Before dipping from a stock solution any required number of gallons, the solution should be thoroughly stirred, otherwise the last dipped out will be very much stronger than that coming from the top, and consequently the work will be inaccurate and often very unsatisfactory; moreover, neglect of this precaution might, in many cases, lead to the injury or even to the destruction of the plants treated. It may also be said that the copper sulphate solution should be cold when used in the preparation of Bordeaux mixture, eau celeste, modified eau celeste, or ammoniacal copper carbonate.

BORDEAUX MIXTURE.

Bordeaux mixture is prepared by uniting the milk of lime with a solution of copper sulphate. The reaction which takes place when the two solutions are united as well as the other chemical phases

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[1] The following rules for measuring square and round tanks and casks may prove of value in this connection:

Circular cisterns.—Multiply the square of the diameter in feet by the depth in feet and the product by $5\frac{7}{8}$ for the contents in gallons.

Circular casks or barrels.—Multiply the square of the average diameter in inches by 34, and that by the height in inches, and point off four figures. The result will be the contents in gallons and decimals of a gallon. The average diameter of a barrel may usually be obtained by adding the greatest diameter to the least diameter and dividing by 2.

Square tanks.—Multiply the width in feet by the length in feet, and that by the depth in feet, and that again by $7\frac{48}{100}$, which will give the contents in gallons. Another and simple method is to multiply the length, width, and depth in inches, and divide by 231, which will also give the contents in gallons.

of the subject, have formed the base for much discussion and investigation, which it is not necessary to consider here, especially as these chemical changes are variously interpreted by different writers. Those interested in the history and chemistry of Bordeaux mixture may learn of the extensive literature upon these subjects by referring to the writings of Lodeman,[1] Fairchild,[2] and others.

In the union of the milk of lime with a solution of copper sulphate there is produced a mixture having great value as a general fungicide, and, as already shown, of especial value for the treatment of peach leaf curl. The mixture possesses several advantages for orchard work over a simple solution of copper sulphate: (1) The addition of sufficient milk of lime to a simple solution of copper sulphate neutralizes the acids of the latter to such an extent that the resulting mixture is practically noninjurious to foliage and buds, while still retaining the fungicidal qualities of the simple sulphate solution. (2) The corrosive action of Bordeaux mixture upon pumps, pipes, nozzles, etc., is comparatively slight. This is of great advantage in doing uniform and thorough work. (3) The lime of Bordeaux mixture causes the spray to become visible upon the trees sprayed, and while this is not desirable in the spraying of maturing fruits, and is avoided by adopting other sprays, it is of very great value in the treatment of bare dormant trees, as it enables the workman to distinguish the sprayed from the unsprayed portions of the tree, and thus to complete his work more thoroughly than could otherwise be done. In case of the employment of hired help for applying sprays, as is usually done, the superintendent or owner of the orchard may know beyond question by the appearance of the trees whether or not his men are doing satisfactory work. As thoroughness is a matter of prime importance in the treatment of peach leaf curl, too much stress can hardly be placed upon this advantage of Bordeaux mixture over several other sprays. (4) The adhesive qualities of Bordeaux mixture are very great, and therefore it is even more desirable for a winter than for a summer spray. This is especially so in portions of the country where the summers are dry, as on the Pacific coast. (5) The whitening of the trees by the use of Bordeaux mixture, provided the spraying is done somewhat early in the winter, is claimed to retard the development of the buds. The unsprayed trees absorb more heat, which causes the buds to swell during warm days in winter, thus making them liable to injury from subsequent cold.[3]

The methods of preparing Bordeaux mixture for large and small orchards may vary according to the requirements and facilities of the

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[1] Lodeman, E. G., The Spraying of Plants, Macmillan & Co., 1896.

[2] Fairchild, D. G., Bordeaux Mixture as a Fungicide, Bull. No. 6, Division of Vegetable Pathology, U. S. Dept. of Agr.

[3] Whitten, J. C., Winter Protection of the Peach, Mo. Agr. Exp. Sta. Bull. No. 38. Some of the conclusions from the work of Mr. Whitten are: Whitening the twigs and buds by spraying them with whitewash is the most promising method of winter protection tried at the Missouri Station; whitened buds remained practically dormant

growers, but the general principles involved remain the same. As a common example, the manner of preparing the 5-pound formula will be described: In a 45 or 60 gallon barrel place 5 pounds of copper sulphate and add 10 or 12 gallons of water. Pound and stir the copper sulphate until wholly dissolved. In a half barrel slake 5 pounds of quicklime and reduce with 10 or 12 gallons of water. Strain the milk of lime into the copper solution, stir thoroughly, and add sufficient water to make 45 gallons in all. The copper and lime solutions should both be cold when united. When the water is added and the whole is well stirred the spray is ready to be applied.

For the manner of preparing the stock solution of copper sulphate to be used for Bordeaux mixture the reader is referred to pages 148 and 149, where full instructions will be found. In respect to the addition of lime to the copper solution, it may be said that the milk of lime resulting from the slaking of 2 pounds of good quicklime in 6 or 8 gallons of water is sufficient to neutralize a solution of 3 pounds of copper sulphate. Larger amounts of copper should receive larger amounts of lime in proportion. In case foliage is to be treated, however, it is well before using the mixture to test it according to one of the methods given,[1] or to bring the weight of quicklime used to three-fourths,

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until April, when unprotected buds swelled perceptibly during warm days late in February and early in March; whitened buds blossomed three to six days later than unprotected buds; 80 per cent of whitened buds passed the winter safely, and only 20 per cent of unwhitened buds passed the winter unharmed. These facts point to those sprays having large amounts of lime as most valuable in protecting buds, and they should be considered in those sections of the country where the buds are liable to winter injury. A fall spraying may also be a decided advantage in such situations in addition to the early spring spraying for curl.

See also on this subject the January number of the Canadian Horticulturist, 1899, pp. 18–20.

[1] There are at present several convenient methods practiced in making Bordeaux mixture to determine if enough lime has been added to the copper sulphate solution to prevent injury when the mixture is applied to foliage. We adapt the following two tests from Farmers' Bulletin No. 38 of this Department, p. 7: (*a*) After the milk of lime and copper sulphate solutions have been united and thoroughly stirred, hold the blade of a penknife in the mixture for at least a minute. If metallic copper forms on the blade or the polished steel surface assumes the color of copper plate, the mixture is still corrosive and should receive more milk of lime. If the blade remains unchanged, the mixture may be safely applied to most foliage under favorable weather conditions. (*b*) Pour some of the mixture into a saucer, hold between the eyes and the light, and breathe gently upon it for at least half a minute. If the mixture is properly made, a thin pellicle, looking like oil on water, will begin to form on the surface. If no pellicle forms, more milk of lime should be added. A third test (*c*) may be made with a 20 per cent solution of ferrocyanide of potassium: After the milk of lime is added to the copper sulphate solution, and the whole is thoroughly stirred, dip up a coffee cup full and add to this a few drops of the ferrocyanide of potassium solution. Allow the cup to stand a few minutes and then pour off the mixture carefully. If a red precipitate is found at the bottom of the cup, the mixture requires more milk of lime, which should be added until no such red precipitate is formed when the test is repeated.

four-fifths, or five-sixths of the weight of the copper sulphate used. With the present experiments it has been unnecessary to take this matter into consideration, for the spray was applied to dormant trees, not likely to be injured by any moderate spray. In nearly all the formulæ tested for curl the pounds of lime employed were equal or greater than the number of pounds of copper sulphate used.

The lime used in preparing Bordeaux mixture should be unslaked lime or quicklime of the best quality. There is no economy in using poor lime, and air-slaked lime should never be used. The use of poor or air-slaked lime is apt to result in an imperfectly neutralized, and very granular, unsatisfactory spray. While the slaking of lime and the preparation of a milk of lime is a very simple matter, it is one which few people not accustomed to the process will do well the first time. If not properly slaked, there are apt to be hard particles in the spray, causing trouble with the nozzles. In slaking lime, water should be added to the lime only fast enough to keep it from overheating, adding a little more each time as the heat increases. With some lime the use of a little hot water to start the slaking will hasten the process. With a little practice this work can be done so as to result in a perfect putty or cream of lime. When the thick, creamy consistency is obtained, it is well to allow the mixture to stand for half an hour, if possible, while hot, being sure that enough water is present to prevent drying out. If the Bordeaux mixture is then to be made, cold water should be added to the lime putty, or cream, and the whole stirred until it becomes a milk of lime and is cool. About 3 gallons of water should be added for each pound of lime. This cool or cold milk of lime should now be strained through a wire sieve or strainer into the copper sulphate solution, previously prepared, and the whole thoroughly stirred.

The solution of copper sulphate should also be cold when the milk of lime is added. After the two solutions are thoroughly united the mixture may be reduced to the required amount with cold water, when the spray is ready for use. The lime and copper solutions should never be united more than a few hours before the spray is to be applied. When making Bordeaux mixture wooden vessels should be used, as barrels, half barrels, tanks, etc.

For peach leaf curl the amount of copper sulphate and lime to be used to 45 gallons of water will vary according to the views of the grower, after making a study of the results obtained from the different formulæ tested in the present series of experiments.

EAU CELESTE.

The preparation of eau celeste is very simple. To each 2 pounds of copper sulphate dissolved in 6 or 8 gallons of water add 3 pints of strong ammonia, stir thoroughly, and dilute to 45 gallons. The stock solution of copper sulphate may be used in preparing this spray. Four pounds of copper to 3 pints of ammonia for 45 gallons of water has also proved an effective winter spray.

For dormant trees this spray is safe, but for the treatment of foliage it is too corrosive and burning. It is also quite corroding to nozzles and other metallic portions of the spraying outfit.

MODIFIED EAU CELESTE.

The modified eau celeste is less injurious to foliage than the eau celeste, but is more liable to injure tender leaves and buds than is well-made Bordeaux mixture. Its preparation is nearly as simple as that of the eau celeste. To 4 pounds of copper sulphate dissolved in 10 or 12 gallons of water add 3 pints of strong ammonia, dilute with water to 45 gallons, and stir in this mixture 5 pounds of sal soda (common washing soda) until dissolved. In preparing this spray of different strengths the same proportions of the chemicals may be maintained.

AMMONIACAL COPPER CARBONATE.

The ammoniacal copper carbonate spray is one of great usefulness in the treatment of fruits for fungous diseases, especially where the spotting of fruits by the use of lime is to be avoided. The fungicidal value of this spray is, however, far inferior to the ordinary Bordeaux mixture. In the treatment of peach leaf curl it has proved less satisfactory than several of the other copper sprays.

The manner of preparing this spray is simple. Place 5 ounces of copper carbonate in the bottom of a 3-gallon crock. From a 2-gallon vessel full of water pour about one-half pint of water upon the copper carbonate and stir the latter until it becomes like paste. Now add the remainder of the 2 gallons of water, stir again, and then pour into the mixture 3 pints of 26° ammonia. After this has been thoroughly stirred, it should be covered and allowed to stand for half an hour, when the whole should be added to a barrel containing 43 gallons of water. When well mixed this spray is ready to be applied.

A concentrated solution of copper carbonate in strong ammonia may be made as above described, using but one-half of the amount of water. If such a solution is very tightly stoppered in a large demijohn or jug it may be kept as a stock solution, ready for use at any time. By knowing the amount of copper carbonate in each quart of such a stock solution enough may be measured out at any time to prepare a given number of gallons of spray of any desired strength.

The copper carbonate used in the preparation of the present spray is frequently not obtainable in quantity at the drug stores in smaller towns. It is also frequently the case that druggists in such places charge two or three and sometimes four or five times as much as it is worth, making the ultimate cost of the spray beyond the reach of the grower. For this reason the writer gives, on page 183 of this bulletin, a simple way of preparing the copper carbonate on the farm at a minimum figure.[1]

PREPARATION OF THE SULPHUR SPRAYS.

While the use of copper sulphate as a base for sprays intended for the control of fungous diseases is very general, there are special diseases or combinations of diseases which may be more cheaply, and often more successfully, treated with sulphur in the form of powder or spray. The world-wide use of sulphur for the control of powdery mildew of the grape is a well-known example. It is also known that sulphur possesses valuable insecticidal qualities, and many of the scale insects and mite diseases of our fruit trees may be readily controlled by the use of sulphur so combined and prepared as to be applicable as a spray. For many years the most successful and almost the only treatment of the San José scale on the Pacific coast has been by sulphur sprays. This scale is very injurious to peach trees, and the time for the application of sulphur for its treatment is during the winter, at the time of treatment for peach leaf curl, when the tree is dormant. It has already been shown in this bulletin that such a winter treatment of the peach tree with sulphur sprays will also control peach leaf curl. For this reason, and the fact that the San José scale is constantly spreading throughout the East, much attention is here given to the presentation of this form of spray, one application of which may control two serious diseases. Experiments conducted by the writer have shown that the pear leaf mite may be controlled by the winter use of sulphur sprays, and it is thought probable that their use will also control the oyster-shell bark louse of the apple, which has become almost a scourge over much of the East and in the Pacific Northwest.

As in the case of copper sulphate sprays, it has also been found that the sulphur sprays may be most satisfactorily prepared by com-

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[1] In view of the work of Mr. C. L. Penny, published in Bulletin 22 of the Delaware Agr. Exp. Sta., 1893, the amount of water recommended to be added before the strong ammonia water is poured upon the carbonate of copper is much greater than formerly used by the Department. Mr. Penny conducted a somewhat extended series of experiments to ascertain the solubility of copper carbonate in ammonia gas as it is contained in ammonia water of different strengths. He found that a given amount of ammonia gas in a weak solution of ammonia water dissolves more copper than the same amount of gas in a strong solution. A given weight of ammonia gas in a 2 to 4 per cent solution of ammonia water dissolves more copper carbonate than an equal weight of gas in either a weaker or stronger solution. The gas in a 2 to 4 per cent ammonia water will dissolve its own weight or more of copper carbonate. On the other hand, the ammonia gas in a 10 per cent solution of ammonia water will dissolve but 60 per cent of its weight of copper carbonate, and ammonia gas in a 20 per cent solution dissolves only about 35 per cent of its weight of copper. Furthermore, the ammonia gas contained in ammonia water of less than 2 per cent strength rapidly loses its power to dissolve copper carbonate as the solution is weakened.

bining sulphur with lime. Salt has also been used in connection with these sprays in several formulæ.

In the following table are shown the various formulæ for sulphur sprays which have been tested for the control of peach leaf curl. All formulæ are for 45 gallons of water, except where otherwise stated.

TABLE 42.—*Sulphur sprays applied for the control of peach leaf curl.*

* 15 pounds sulphur, 30 pounds lime, 10 pounds salt, 60 gallons water.
* 10 pounds sulphur, 20 pounds lime, 10 pounds salt, 60 gallons water.
† 15 pounds sulphur, 30 pounds lime, 10 pounds salt.
* 10 pounds sulphur, 20 pounds lime, 10 pounds salt.
† 10 pounds sulphur, 20 pounds lime, 5 pounds salt.
* 5 pounds sulphur, 10 pounds lime, 5 pounds salt.
† 5 pounds sulphur, 10 pounds lime, 3 pounds salt.
† 15 pounds sulphur, 30 pounds lime.
† 10 pounds sulphur, 20 pounds lime.
† 10 pounds sulphur, 8 pounds lime.
† 6 pounds sulphur, 4 pounds lime.
† 5 pounds sulphur, 15 pounds lime.
† 5 pounds sulphur, 10 pounds lime.
† 5 pounds sulphur, 5 pounds lime.

* Recommended by the writer, but tested by the growers.
† Prepared and tested by the writer, and in numerous cases also tested by growers.

It takes longer and is more difficult to prepare the sulphur than the copper sprays; but where the sulphur may be obtained at liberal wholesale rates the expense of the two classes does not vary greatly. For facts respecting the sources of sulphur, etc., the reader is referred to page 190.

The sulphur sprays are prepared by boiling the ingredients (sulphur, lime, and salt, or sulphur and lime) in water for not less than two hours. So far as the writer's experiments are concerned, there has resulted no apparent advantage in the treatment of curl by the addition of salt to these sprays. The usual method which growers having small orchards follow in preparing sulphur sprays is to slake one-third to one-half of the lime required, in the vessel in which the boiling is to be done. When slaked to a thin cream the sulphur is stirred in, all lumps of sulphur having been first pulverized. Boiling water is now added to make one-half to two-thirds the amount required by the formula. This mixture is boiled for not less than one and one-half hours, only boiling water being added if it becomes necessary to reduce the mixture. If the boiling is done in a kettle or iron pan, great care is necessary to prevent the caking and burning of the materials. When the mixture has boiled for the time stated or longer, the remainder of the lime is slaked and the salt is added to it and well stirred in. This lime and salt mixture is now added to that which has been boiled and the boiling is continued for at least one-half hour longer. The boiled spray should now be strained through a fine wire strainer into the spray tank or barrel, and enough boiling water added to make up the full amount of spray required by the formula. The spray may be boiled to advantage longer than two hours, but should never be boiled for a less time if the best results would be obtained. The sprays should be applied to the trees as hot as possible. The spray is more effective and easier to apply when hot, and contact with the air cools it sufficiently so that twigs of dormant trees are not injured by the heat.

The method of preparing the sulphur sprays here outlined is practically that which has been followed in California for many years. In the series of experiments here described, however, an effort has been made to ascertain if salt is necessary in this spray, and also whether there is any disadvantage in uniting all of the lime and sulphur at first. After a comparison of the results obtained from sprays with and without salt and of those in which the lime was added in two portions and at different times with those prepared by adding all of the lime and sulphur at first, it has not been possible to detect any advantage from the salt nor from the more complex method of preparing. This relates, of course, to the use of these sprays for the control of curl, but it is believed that the same will hold true in their use for the control of insect pests. The writer has personally prepared and tested a very large number of these sprays, and recommends the omission of salt, and further, that all of the lime and sulphur be united and reduced with boiling water before the cooking begins in all cases where the spray is to be applied either as a fungicide or insecticide, and where the method of boiling below described is followed. This will both cheapen and simplify the process.

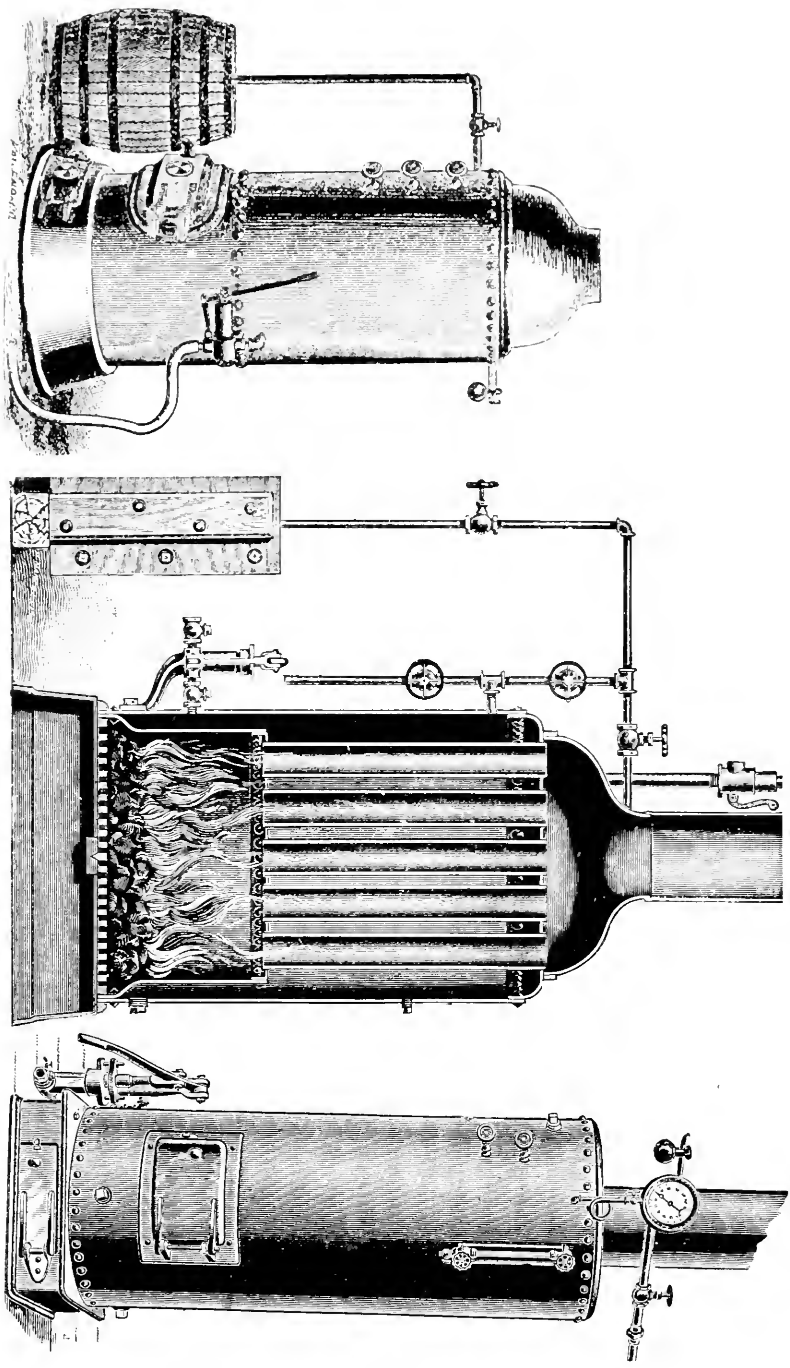
While many growers may feel obliged to prepare the sulphur sprays in kettles or iron pans, experience has shown that they may be boiled much more uniformly, more easily, and oftentimes better in barrels or wooden tanks by using live steam as the source of heat. These facts are widely recognized on the Pacific coast, and the knowledge is put into practice by some of the leading fruit growers, many of whom have established special steam cooking plants for preparing and handling the sulphur sprays. Some of these spray-cooking appliances are on quite an extensive scale and others more limited, being adapted to the needs or facilities of the growers. As the sulphur sprays have been widely used in California and Oregon, and are likely to become much more generally used throughout the East, especially as they are particularly intended for winter application to all deciduous trees and are known to be of marked value both as insecticides and fungicides, the more improved methods of preparing them will be of general interest to orchardists, and several are here given. Three types of cooking plants are described: (1) One adapted to the needs of an orchard of 10 acres, (2) one suited to the needs of an orchard of 100 acres, and (3) one of sufficient capacity to prepare sprays for the treatment of 500 to 1,000 acres of trees.

For small orchards sulphur sprays may be prepared in barrels by the use of steam. Upon a solid plank platform 3 feet wide, 12 feet long, and raised 18 inches above the ground, place three oak barrels holding 60 gallons each. Each barrel should have a bunghole through one side about 1 inch above the bottom, which is stopped with a long wooden plug while the spray is boiling in the barrel. The upper heads of the barrels should be removed, and each may be nailed in two parts to serve as a cover for the barrel while the spray is being boiled. Near one end of the row of barrels is set the boiler in which steam is to be generated. From the dome of this boiler a steam pipe should extend horizontally over the row of barrels, and not less than 2 feet above them. The farther end extends downward at a right angle, by means of an elbow, to within 6 inches of the bottom of the last barrel. Where the pipe passes over the first and second barrels, downward-extending pipes are connected by means of proper couplings, and extend to within 6 inches of the bottoms of the respective barrels into which they reach. In each of the downward-extending pipes is fitted a valve about 18 inches above the barrels, by means of which the inflow of steam may be controlled for each barrel separately. The lower end of each of the pipes leading into the barrels is left open for the escape of steam. With a sufficient head of steam a barrel of water may be brought to the boiling point with such an appliance in about five minutes. By having three barrels, as here suggested, two may be kept almost constantly filled with boiling sprays, while the third is filled with boiling water for use in slaking lime, filling the barrels after the sulphur is added, and reducing the spray to the required amount in the spray tank. With such an appliance for boiling, provided the two barrels for spray are charged alternately one hour apart, 60 gallons of well-made spray may be sent to the orchard about once an hour, after allowing each lot two hours of constant boiling. In preparing the spray for boiling, the lime is first slaked to a cream of lime in the bottom of the barrel, the pulverized sulphur is stirred in, the barrel is filled two-thirds full of boiling water, a top is placed over the barrel, and the steam is turned on by opening the valve above the barrel. Within a very few minutes the steam will bring the contents to a seething boil, and this can be maintained for the two hours required without danger of overheating and with little care, except of course that required to maintain and regulate the steam supply. The steam stirs the spray sufficiently when boiling. When thoroughly boiled the bunghole near the bottom of the barrel is opened by removing the long plug, and the spray is drawn off into pails and strained into the spray tank through a fine wire strainer. When the barrel is nearly empty enough boiling water is added to make up the amount of spray required by the formula, and this is then drawn off. Before a new charge of spray materials is placed in the barrel, the latter should be removed from beneath the steam pipe and cleaned. Convenient boilers suited to boiling one or more barrels of spray are shown in the illustrations given. (Pl. XXI.)

For orchards of 100 acres the boiling of sprays in barrels is too slow. The plan adopted by Mr. A. D. Cutts, at the Riviera Orchard, will here be given as admirably answering the purpose for such orchards. In this spray-boiling plant the live steam is obtained from the dome of the boiler of a 20-horsepower thrashing engine, and while cooking sprays from 60 to 80 pounds steam pressure is maintained. The spray is boiled in two rectangular vats or tanks, built of 2-inch dressed sugar pine. The inside measure of these tanks is, length 5 feet, breadth 3 feet, depth 30 inches. These tanks have the ends mortised into the side and bottom planks from one-fourth to three-eighths of an inch. Two long bolts run diagonally across at each end to hold the head in place, and in addition the planks are nailed together with 40[d] cut nails. Each of these tanks will hold approximately 280 gallons of spray. They are raised 4 feet above the ground upon a strong and well-braced framework. They stand side by side with a platform between about 4 feet wide, on which a man may stand to attend to the spray while boiling. One end of each tank is toward the boiler, and the other, which is supplied with a faucet or sirup gate for drawing off the spray, extends to the side of a driveway. The steam is supplied to each of the tanks directly from the dome of the boiler. From the steam dome a 1½-inch pipe leads to near the ends of the tanks. This is connected with a transverse 1-inch horizontal pipe extending laterally to a point opposite the center of each tank and level with the tops of the tanks. The ends of this 1-inch pipe now turn at a right angle and extend to the center of the top of the ends of the tanks, turn down on the inside of the tanks to the bottom of the same, and then extend along the center of the bottom to near the farther end, where they are closed by having an iron cap screwed over the end. Through each side of that portion of the 1-inch pipe which extends along the inside of the bottom of each tank are drilled 6 small holes for the escape of the steam into the tanks. In the pipe leading to each tank is placed a globe valve for separately controlling or preventing the flow of steam to each of the tanks. When a tank of spray is ready to go to the orchard, the spray is run into another tank situated on a low truck wagon, the truck being first driven under the end of the boiling tank which is to be emptied. The low truck with the spray is then driven to the spray tanks in the orchard, and the spray is pumped from the truck tank to the spray tank, without delaying the work of the sprayers. The spray is strained twice, first when drawn off from the boiling vats through the faucet, and second when it is

DESCRIPTION OF PLATE XXI.

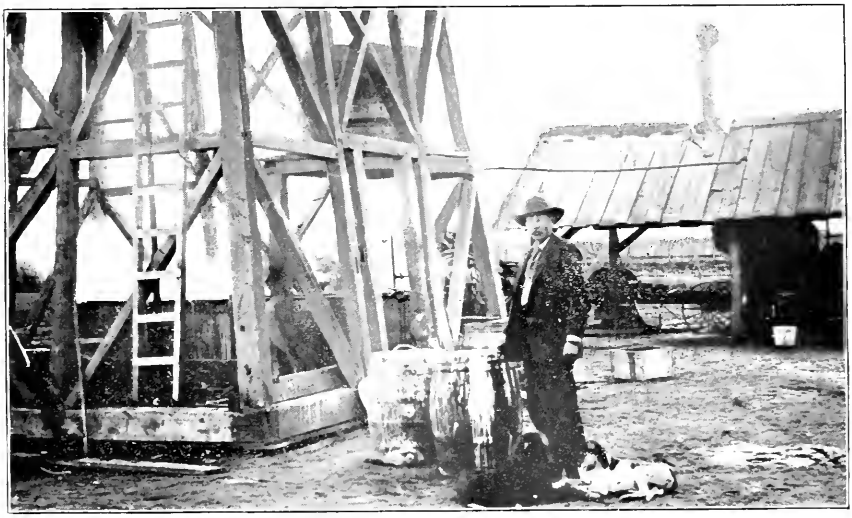
Steam spray-cooking appliances for small orchards. Figs. 1 and 3 show boilers suited to cooking sprays in 1 to 3 barrel lots; fig. 2 shows a boiler connected with a tank in which larger quantities of spray may be boiled at one time. These cooking appliances are well adapted to use in ten-acre orchards (p. 157). (Compare with Pl. XXII.)

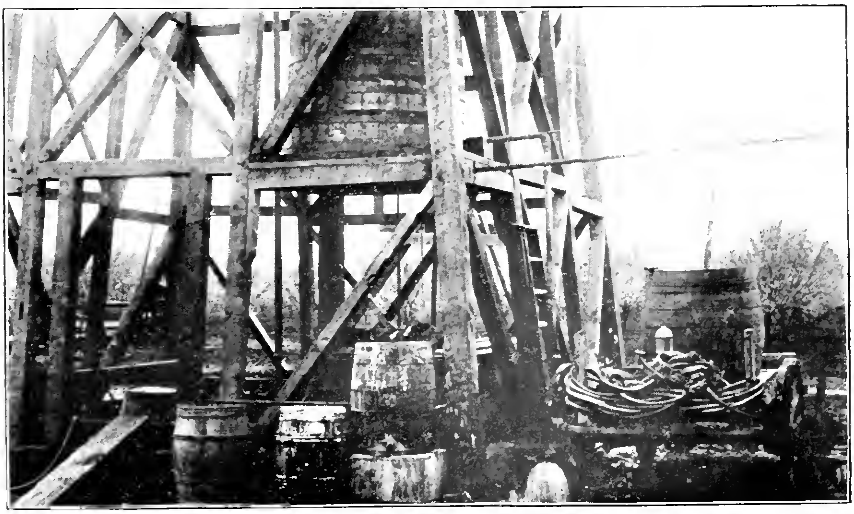


STEAM SPRAY-COOKING APPLIANCES FOR SMALL ORCHARDS.

pumped from the truck tank into the spray tank in the orchard. The brass strainer cloth employed by tinners in making strainer pails is used for this purpose. It is very necessary to strain well, as in the unstrained spray there are always dregs that fill the nozzle and delay work. Mr. Cutts says that in tanks of this kind it is necessary to stir the spray frequently while boiling to thoroughly mix the different ingredients. Three hours' boiling is better than two. He also says that one man, at $2 per day, will tend the boiler and prepare from 1,500 to 2,000 gallons of spray per day, and that it will require about one-half cord of 4-foot wood to generate the steam in such a boiler as he uses.

In preparing the sulphur sprays for orchards containing 500 to 1,000 acres of trees it is desirable to have tanks of larger size than those used by Mr. Cutts and to avoid as much pumping and transferring of the sprays as possible. One of the most convenient and complete spray-cooking plants for orchards of large size which has thus far been seen by the writer will here be described. This plant is at the Rio Bonito orchard. The water for preparing sprays at this orchard is obtained from a well and is forced by means of a rotary force pump run by steam power into a large storage tank elevated upon a heavy framework some 30 feet above the ground. About 10 feet above the ground and at one corner of the open framework of the tank house is placed a circular tank holding about 300 gallons. This is a storage tank to receive the spray when prepared for the orchard. The bottom of this circular tank is supplied with steam pipes, so that the contents may be kept hot and ready for use. From the outer side of this storage tank, near the bottom, is a discharge pipe with valve and hose attached, through which the spray may be run by gravity into the tops of the 300-gallon spray tanks on wagons which are used in the orchard. These wagons are driven to the side of the storage tank and filled with boiling spray in a few minutes, much as street-sprinkling tanks are driven under the elevated hydrants and filled. The boiling tank proper is built of 2-inch surfaced pine plank within a firm framework, properly bolted, and rests firmly upon the ground. It is situated within the heavy framework of the water tank house. This boiling tank is approximately 18 feet long, 3 feet wide, and 3 feet deep, and its full capacity is 1,200 gallons. In the center of the tank house is a water pipe connected with the large water tank above. Near the bottom of this standpipe are hydrants for the attachment of hose, thus allowing of water being drawn directly from the water supply above into the boiling tank by opening a hydrant. An unlimited supply of cold water is thus always at hand without the necessity of lifting a pailful by hand. The steam pipe for heating the sprays in the boiling tank extends from end to end along the bottom within the wooden tank, and every 2 or 3 feet along this pipe are cross pipes leading toward each side of the tank. The ends of the central pipe and its branches are closed. Along both sides of this main pipe and its lateral branches are drilled small holes for the escape of steam into the tank. The flow of steam to the tank is controlled by means of a globe valve in the steam supply pipe, the valve being conveniently placed for the workman at the tank. Broad board covers are made for covering the whole tank when the boiling is in progress. As in the case of the spray-boiling plant of Mr. Cutts, the main steam pipe leads from the tank directly to the steam dome of the boiler. The spray is prepared in the boiling tank of double strength, and when sufficiently boiled is elevated to the storage tank above by means of an appliance planned like an injector of a boiler. An iron pipe about 2 inches in diameter leads from the boiling tank upward and over the top of the storage tank described. In this pipe is placed the injector, which is supplied with two lateral connections. One of these connections is with the cold-water supply pipe, and the other is with the main steam supply pipe. In each of the pipes connected with the injector are placed globe valves for the control of the inflow of water, steam, and hot spray. When it is desired to fill the storage tank above with hot spray from the boiling tank below, the valve opening into the steam pipe leading from the injector to the steam dome is opened. The live steam at once escapes through the injector into the pipe leading to the storage tank and then out of the end of the pipe. The valves leading to the boiling tank and the cold-water supply are now opened in such a manner that about equal parts of cold water and hot spray are admitted to the injector, and the escaping steam, by means of its tendency to form a vacuum, soon causes a combined stream of hot spray and cold water to follow up the pipe and escape into the storage tank above. There is thus established a kind of steam siphon, which soon carries up 150 gallons of boiled spray and an equal amount of cold water, filling the 300-gallon storage tank with spray of the required strength, the strength of the spray in the boiling tank being double that required. This work is accomplished by a careful adjustment of the inflow of steam, spray, and water to the injector, the storage tank being filled without the necessity of lifting a pound of spray by hand. The combining of the cold water with the hot spray in the injector is found to be necessary to the proper working of the latter as the temperature of the injector would otherwise become too high for efficient work. When the storage tank is full, steam is turned into the pipes situated at its bottom, and the spray is again heated to the boiling point and kept very hot until drawn off into a spray tank and taken to the orchard. The facility with which a plant of this description may be operated will depend to quite an extent upon the nature and capacity of the boiler used for generating steam. The more easily steam can be generated and the greater capacity for steam which the boiler possesses the better for the work.





STEAM SPRAY-COOKING APPLIANCES FOR LARGE ORCHARDS.

DESCRIPTION OF PLATE XXII.

Fig. 1 shows sulphur, lime, and salt spray-cooking appliances used on the Rio Bonito Rancho. The heavy framework at the left supports a large water tank not shown in the photograph. This tank is filled from a well by means of a steam rotary force pump, and supplies all water required in cooking and reducing sprays. On the ground, at the farther side of the framework of the tank, is shown a long wooden vat from which steam is issuing. This rectangular vat, described on page 159, is capable of cooking about 900 gallons of sulphur spray of double strength, and is seen in full operation in the illustration, the heat being applied by means of steam pipes at the bottom. The steam pipe is shown leading from the dome of the boiler in the shed at the right and in the background of the photograph. The round tank shown above the right end of the cooking vat holds 300 gallons of spray, ready for application to the trees. This tank is filled from the cooking vat by means of a steam injector, described on page 160, and the spray is maintained at a high temperature by means of steam pipes in the bottom, as in case of the cooking vat proper.

Fig. 2 should be considered in connection with fig. 1. The large, round tank, standing above the barrels, is the storage tank for sulphur spray after it has been prepared in the long vat below. This tank holds 300 gallons—sufficient spray to fill the tank seen on the wagon. The wagon tank is filled by gravity, the spray flowing into it through hose running directly from a spout at the bottom of the storage tank. A valve in this spout regulates or stops this flow of spray as desired. One of the spray wagons used in this large orchard is shown. The pump stands crosswise behind the corner stakes at the back of the wagon. These stakes serve to prevent the hose from falling beneath the wheels, as all lines of hose extend from the rear of the wagon when in use in the orchard.

By referring to Pl. XXII and the descriptions of figures the reader may obtain a good idea of the arrangement of this extensive spray cooking plant, as well as of the boiler supplying steam.

PREPARATION OF COMBINED COPPER AND SULPHUR SPRAYS AND NOTES ON OTHER SPRAYS TESTED.

For many years the use of combined copper and sulphur sprays has been practiced by peach growers in Oregon, and as they have reported good results the writer prepared the following four formulæ of this character for the control of curl.

BORDEAUX MIXTURE AND SULPHUR SPRAYS COMBINED.

The formulæ of the combined Bordeaux mixture and sulphur sprays tested are given in the following list:

List of sulphur sprays combined with Bordeaux mixture.

3 pounds copper sulphate, 10 pounds sulphur, 20 pounds lime.
3 pounds copper sulphate, 10 pounds sulphur, 10 pounds lime.
3 pounds copper sulphate, 5 pounds sulphur, 10 pounds lime.
2 pounds copper sulphate, 5 pounds sulphur, 10 pounds lime.

In preparing these combined sprays, which were found somewhat more effective in the control of peach leaf curl than the sulphur sprays alone, the Bordeaux mixture was added to the fully prepared sulphur spray. A portion of the lime given in the formula was reserved for making the Bordeaux mixture, while the remainder of the lime was combined and boiled with the sulphur in the manner already described. When the sulphur spray had been placed in the spray tank, the Bordeaux mixture, which had been freshly prepared from the copper sulphate and the remainder of the lime, was added, and after thorough mixing was at once applied to the trees. The union of the yellow sulphur spray with the blue Bordeaux mixture forms a spray of a distinct green color. The application of this spray is similar to that of the sulphur spray, requiring the same class of nozzles.

MISCELLANEOUS SPRAYS.

A large number of sprays not included in the preceding descriptions have been prepared and tested for peach leaf curl, and some of them have been discussed in other portions of this bulletin. Several of them were tested for the purpose of learning the value of the separate ingredients of the leading sprays, as salt, lime, etc. Among these were lime, applied as a simple milk of lime; salt, applied in solutions of different strengths; and lime and salt combined, applied as a whitewash. Sulphur was tested in the form of sulphide of potassium, applied in various strengths in liquid form, and the union of this sulphide of potassium with milk of lime was also tested. Iron sulphate, sulphur, and lime were tested in combination by adding to the sulphur spray a mixture prepared by uniting the milk of lime with a solution of iron sulphate. The union of the milk of lime with the iron sulphate solution produced a lead-colored mixture resembling Bordeaux mixture in consistency, and when united with the sulphur solution the color was dark green or approaching black. Iron sulphate and lime were also tested separately.

While some of these sprays gave evidence of considerable fungicidal action, none of them gave results which would warrant their substitution for the sprays already considered in previous chapters, and hence it is unnecessary to enter further into details respecting their preparation. The results of their use may be learned in the chapters of this bulletin which relate to the action of the sprays on the foliage and the fruit.

GENERAL CHARACTERS OF THE SPRAYS TESTED.

There are certain general characters of sprays adapting them or making them unsuitable for various classes of work, and to these it may be well to allude.

THE ENDURING QUALITIES OF THE SPRAYS.

In the work here described careful notes were made on the enduring or weathering qualities of the sprays tested.

During the last week in April and first week in March, 1895, 35 sprays, of different formulæ, were applied in the experimental block in the Rio Bonito orchard, most of them to 10 large trees, as has heretofore been shown. On August 10, or five months after the spraying was completed, the trees of each experiment row were examined to ascertain as far as possible the enduring or weathering qualities of the sprays, and according to the notes made at that time the appearance of the sprays upon the trees, after five months' weathering, may be grouped under the following four heads or classes:

(1) Sprays showing quite distinctly upon the trees on August 10.
(2) Sprays moderately evident on August 10.
(3) Sprays little evident on August 10.
(4) Sprays not observable on August 10.

The sprays classed under the first head, were those applied to rows 1, 3, 7, 9, 13, 15, 18, 19, 21, 22, 25, 33, 36, 41, 44, 45, 50, 54, 56, and 57; under the second head, those applied to rows 6, 10, 12, 16, 28, 42, 48, and 51; under the third head, those applied to rows 27 and 35; and under the fourth head, those applied to rows 30, 32, 38, 39, and 47. By referring to page 73 the reader will find a table giving the formulæ for sprays applied to each of the rows named, and an examination of these formulæ will bring out the following facts: All the sprays included under the first two headings contain lime, while those under headings 3 and 4 contain none; all formulæ containing 15, 20, or 30 pounds of lime to 45 gallons of water fall under the first head. Of the 18 sprays containing 4, 5, 8, and 10 pounds of lime, 10 fall under the first heading and 8 under the second; copper sulphate enters into the composition of 8 of the 10 sprays falling under the first head, while the remaining 2 contain iron sulphate; of the 8 sprays which fall under the second heading, only 1 contains copper sulphate, and that but 2 pounds, while 5 are sulphur sprays.

These facts seem to show that the union of copper sulphate and lime produces a spray possessing decidedly greater weathering qualities than the union of sulphur and lime.

In the following list are shown the pounds of lime contained in the various sprays tested; the numbers of the rows of trees to which each amount of lime was applied; the position of each spray as grouped according to its apparent weathering qualities into classes 1, 2, 3, or 4; and references showing the nature of all the sprays containing lime:

Weather-resisting qualities of sprays.

30 pounds lime in formula, class 1, rows 1 † and 7†.
20 pounds lime in formula, class 1, rows 3†, 9†, 13†, 36†*, and 44°.
15 pounds lime in formula, class 1, rows 15*, 33*, and 57†.
10 pounds lime in formula, class 1, rows 18†*, 19†*, 41*, 45*, 50††, 54*, and 56†††; class 2, rows 6†, 12†, and 48†°.
8 pounds lime in formula, class 2, row 10†.
5 pounds lime in formula, class 1, rows 21*, 22*, 25*; class 2, rows 28*, 42†°, and 51†.
4 pounds lime in formula, class 2, row 16†.
No lime in formula, class 3, rows 27 and 35; class 4, rows 30, 32, 38, 39 and 47.

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† Sulphur and lime, or sulphur, lime, and salt.
†* Copper sulphate, sulphur, and lime.
° Lime.
* Copper sulphate and lime.
†† Iron sulphate and lime.
††† Iron sulphate, sulphur, and lime.
†° Potassium sulphide and lime.

It may be well to state in connection with the above list that while all the sprays not containing lime are classed under the third and fourth heads, this arrangement may not correctly represent their respective enduring qualities. As they are without lime, the eye can not detect their presence in many cases where it is possible the chemicals may really be present in effective quantity, and it is therefore apparent that the value of such a list is largely of a comparative nature among those sprays containing more or less lime in various combinations.

The general facts appear to be, as already indicated, that the copper sprays are more enduring than the sulphur sprays, considering pound for pound of lime in their composition, and also that the amount of lime may be much less in the copper than in the sulphur sprays and still maintain the enduring qualities. It is likewise the opinion of the writer that where a winter spray of copper and lime has proved of poorer weathering quality than is desirable in a given climate, the copper should be increased as well as the lime when greater resistance to weathering is sought. In other words, while the increase of lime enhances the weathering qualities of the spray, it also has a tendency to retard or obscure the action of the copper it contains, unless the latter is increased somewhat in proportion to the increase of lime.

THE CORROSIVE ACTION OF THE SPRAYS.

As the present use of sprays has been limited to their winter application, the notes on their corrosive action relate largely to the action upon dormant trees or upon the vegetation immediately following the commencement of spring growth. In each case these remarks relate to the use of sprays upon peach trees, which are known to be among the most tender deciduous fruit trees commonly grown in the temperate zone.

The sulphur sprays of the greater strengths used in these experiments caused in many cases the loss of some of the finer and weaker inner growth of the trees. This is more apt to be the case, it is believed, when the spray is applied shortly before growth begins in the spring. Where very strong sprays of this class are to be used, it is well to apply them comparatively early in the dormant period, say four weeks earlier than the copper sprays. Sprays having not more than 10 pounds of sulphur to 45 gallons of spray may be used with little danger up to within four weeks of the swelling of the buds.

There is no danger of injuring twigs or buds with the copper sprays if properly prepared and applied before the buds have opened. Well-made Bordeaux mixture may be used even as late as the opening of the first blossom buds. The ammoniacal copper carbonate may also be safely used to a late date, and both may be again applied, if desired, after the trees have passed out of bloom. The simple solution of copper sulphate and the eau celeste may be safely used to within a week of the opening of peach buds, but they should never be used upon the foliage of the tree. Modified eau celeste is less corrosive than the eau celeste, and may be used until the first buds begin to open, but from observation in other classes of spray work it is believed to be unsafe to apply this spray to the leaves of the peach.

The injurious action of the sulphur sprays when combined with Bordeaux mixture is fairly to be compared with the action of the sulphur sprays alone when containing equal amounts of sulphur.

The spray composed of iron sulphate and lime is more apt to injure tender shoots and buds than the Bordeaux mixture, and such a spray can not be recommended for use upon foliage.

Milk of lime appears to be practically harmless when applied to dormant trees or to trees in leaf; hence any injurious action resulting from the use of sprays containing lime should be charged to the other ingredients or to the lime as altered or modified through combination with such other constituents.

ADVANTAGES OF DISCERNIBLE AND INDISCERNIBLE SPRAYS.

Reference has been made in a brief way to the advantages possessed by certain sprays in forming a visible deposit upon the surfaces sprayed. While sprays forming such a visible deposit are decidedly advantageous for all winter work, those leaving no such distinct deposit are most desirable for the treatment of fruit, especially when approaching maturity. The advantages of white sprays in the winter treatment of deciduous trees are obvious, it being possible with such sprays to clearly see what portions of the plant have been thoroughly and properly covered. This advantage may even make the difference between success and failure in the work.

Some recent experiments in applying whitewash or sprays containing large amounts of lime have tended to show that the opening of the buds may be somewhat retarded by such winter treatment. The theory is that whitening the trees prevents, to some extent, their absorption of heat from the sun's rays, and that this aids in keeping the trees in a dormant condition somewhat later than would otherwise be the case. Whether this will prove of enough importance to warrant the outlay for spraying remains to be shown. An illustrated article on this subject appeared in the Canadian Horticulturist for January, 1899.[1]

All sprays, both copper and sulphur, which contain lime are adapted to the purposes here considered. The Bordeaux mixtures and sulphur sprays used in the work described are distinctly observable upon the trees when applied, and after drying for a very short time the treated trees become decidedly white. The greater the amount of lime the whiter the trees. (Pl. XXIII.)

In the summer treatment of trees and plants having fruit approaching maturity, the use of clear sprays is often most to be recommended. The spray now best adapted for this purpose is the ammoniacal copper carbonate. A stronger spray, though making less showing than Bordeaux mixture, is the modified eau celeste. As this is apt to cause injury in some cases, it is desirable to use Bordeaux mixture for summer work up to a date when the fruit is approaching maturity, and then to adopt the ammoniacal copper carbonate. The time at which the summer use of Bordeaux mixture should be discarded for the ammoniacal copper carbonate will depend largely upon the amount of summer rains in the locality where used. In New York State, for instance, where summer showers are frequent, the lime-containing

[1] Orr, W. M., l. c., pp. 18–20. See further remarks on this subject on p. 150.

Bordeaux mixture could be used upon fruit until a later date in the summer than it could in California, where almost no summer showers occur, and where the lime would remain upon the fruit until the latter was mature. This matter leads us naturally to the consideration of sprays adapted for wet and for dry localities.

SPRAYS ADAPTED TO USE IN WET AND IN DRY LOCALITIES.

Little can be said on this subject that has not been previously touched upon in this bulletin. A few general remarks, however, may be of advantage to the grower. The enduring qualities of sprays containing lime increase where the ratio of the other ingredients is maintained, very largely in proportion to the increase of the lime which the formulæ contain. For instance, the relative proportions of copper sulphate and lime being maintained, a Bordeaux mixture which contains 10 pounds of lime to 45 gallons of spray will obviously endure much longer upon the trees in a wet climate than a Bordeaux mixture containing but 5 pounds of lime to the same amount of spray. To avoid the loss in activity and effectiveness of a spray containing a large amount of lime, the fungicide, be it copper or sulphur, should be increased so as to maintain the same or nearly the same ratio between the copper and lime which exists in the spray containing less lime. It is advised, therefore, that sprays to be used in a wet climate, especially those intended for winter application, should be made stronger, both in lime and in the essential fungicide they contain, than is found necessary in a dry climate. If two sprayings are necessary, both should be given the dormant trees.

In wet climates the conditions favorable to the development of curl and other fungous diseases are increased. This supplies a further reason for using sprays containing increased amounts of fungicide and having greater enduring qualities than sprays used in dry localities. The soil conditions in wet situations are apt to delay spray work till the last moment compatible with effective work. In such cases the amount of copper should be sufficient, if this class of sprays be used, to act promptly. If the Bordeaux mixture be applied under such circumstances, it will not be found desirable to reduce the copper below the equivalent of 1 pound of copper for each pound of lime, and a higher proportion may often be used to advantange on dormant trees.

CHAPTER IX.

THE APPLICATION OF SPRAYS.

GENERAL ACCESSORIES FOR WINTER SPRAYING.

To those who have sprayed for years and have learned by experience the most suitable appliances for such work the present remarks may not prove of direct value. They are especially intended, however, for those undertaking such work for the first time.

NOZZLES SUITED TO WINTER WORK.

The past few years have seen in the United States a very great increase in the styles and places of manufacture of nozzles and other spraying appliances. At the present time the number of styles and makes of nozzles often leads to confusion in the mind of the prospective sprayer. In fact, however, there are but few essential features to a good nozzle. The form of greatest importance for most classes of work is that which gives to the discharged spray a rotary or cyclone motion. This movement is given in a very simple manner by admitting the stream at an angle into a circular chamber in the nozzle, so that it first strikes the curving side of the chamber, and is thus forced to assume a circular or rotary motion. The revolving stream then passes through the small central opening of the discharge plate and widens into a cone-shaped spray, which gives to this nozzle certain advantages not enjoyed by several other types now on the market. Spray from such a nozzle covers a greater area without moving the nozzle than is covered with most other types. There are nozzles, however, capable of throwing spray to greater heights. The rotary motion assumed by the spray in the cyclone or Vermorel nozzles is a dissipation of force, at least in most forms of these nozzles, so far as concerns the throwing of sprays to a great distance. A type of nozzle first used near San José, Cal., and now bearing the name of that town, is perhaps better adapted to long-distance spraying, and has been extensively used on the Pacific coast. The spray is formed by the fluid passing, under high pressure, through a narrow slit in a rubber or metallic plate. Where the rubber plate is used the escape of small particles may take place through the temporary expansion of the opening in the plate.

The cyclone nozzles are now made by many manufacturers in different portions of the country, and may be obtained through any first-class hardware dealer in the United States. The San José nozzle is also obtainable through hardware dealers generally.

There are many types and styles of cyclone nozzles. Some are planned to throw the spray away from the workman, with direct or forward discharge (fig. 1). Others are so constructed that the spray is discharged laterally or at a more or less acute angle (figs. 2 and 3). In using these nozzles for winter work on deciduous trees it has been found that most thorough and most satisfactory work can be done with less waste of spray when nozzles having a lateral discharge are employed. The reasons for this are evident. Dormant deciduous trees are but a skeleton or framework, presenting to the sprayer but a limited surface for stopping a direct spray. For this reason, where a nozzle having a direct discharge is employed, a large portion of the spray will of necessity pass through the limbs of the tree and fall upon the ground, while at best it will pass through the tree but once. By using the cyclone nozzle with lateral discharge, however, the cone of spray may be directed upward through the whole top, and in falling back it passes through the tree a second time. Here is a decided gain in the limb surface which will be reached by the use of a given amount of spray. The nozzle having lateral discharge can also be handled to much greater advantage than the nozzle with direct discharge. By turning the extension pipe which bears the nozzle, the cone of spray may be directed upward, downward, or laterally upon the limbs as desired. This has proven of great advantage in doing thorough work.

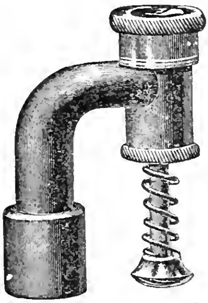

FIG. 1.—Cyclone nozzle, with direct discharge and degorger, for thin sprays.

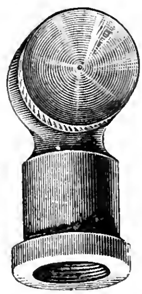

FIG. 2.—Cyclone nozzle, with lateral discharge, for thin sprays.

The ordinary lateral discharge cyclone nozzles are suitable for use with most of the copper sprays. For use with the sulphur sprays or Bordeaux mixture containing a large amount of lime, the common Vermorel or cyclone nozzle is rather too light and the opening too small. In California a special form of nozzle is in use for the application of such sprays (fig. 3). This nozzle is manufactured in San Francisco, and may be obtained from the leading hardware firms of that city. The nozzle is of the cyclone pattern, but is much larger, heavier, and stronger than the ordinary type of cyclone or Vermorel. The discharge opening is of sufficient size to allow of the use of thick sprays, and the discharge plate is heavy enough to withstand much wear from corrosive fluids. A fact of prime importance, however, for the work

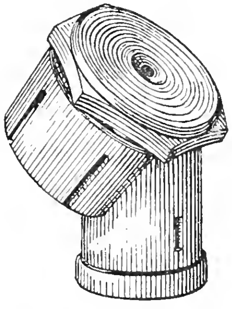

FIG. 3.—Heavy cyclone nozzle, with oblique discharge, for thick sprays.

being considered, is that the nozzle discharges the spray at an angle of about 45° with a line leading directly from the sprayer. This gives the nozzle the advantages of both the lateral and direct discharge. The work of either of these types (figs. 1, 2, and 3) may be accomplished with this angular discharge.

Makers of cyclone nozzles of all kinds are usually able to supply the discharge plates of the nozzles separately, and this is convenient for the grower, where the original discharge plates have been worn out. The separate discharge plates usually sell at 25 cents each.

HOSE AND EXTENSION PIPES.

Rubber hose of good quality is most satisfactory for all kinds of spray work. The strongest and best hose will usually prove cheapest if properly cared for. All hose should be thoroughly washed, both inside and outside, at the close of each day's work, and it should be well scrubbed, washed, and dried when the spray work is completed, and stored in a uniformly cool, dark, and medium dry place.

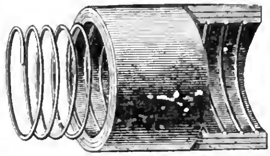

FIG. 4.—Wire-extended suction hose.

FIG. 5.—Bamboo extension pipe, with valve and hose coupling.

Practice varies somewhat as to the internal diameter of hose used. One-half inch is perhaps the most common size. The external diameter of the hose should not be so small nor its flexibility so great that it will easily kink and twist upon itself. Hose which does this is a constant source of annoyance, causing loss of time and often endangering itself. Where possible, it is best to have all lines of discharge hose leading from the pump pass from the back end of the wagon, between two short stakes, one at each corner. With such an arrangement there is little danger of its being caught in the wheels or run over by them. Many lines of hose are injured or destroyed in this way. The stakes at the back corners of the wagon also serve as a means of winding up the hose preparatory to going to or from the orchard.

Couplings for connecting 1, 2, 3, or 4 lines of hose with the pump may usually be obtained from responsible hardware firms, or through them from the manufacturers of the pumps used. The more common hose couplings are nearly always in stock at such hardware houses.

For most pumps it is well to supply wire-extended suction hose (fig. 4). Some styles have the spiral wire coil within the interior; others have it embedded in the rubber. When the metallic spiral is exposed to the spray in the interior of the hose it should be of brass, if possible, to enable it to withstand the corrosive action of the sprays.

Brass suction pipe strainers for attachment to the end of the pipe may be had of different forms. They are necessary when the end of the suction pipe is simply lowered into the spray tank or when it rests upon the bottom of the tank.

The extension pipes used by different growers vary. Some adopt common three-eighths or one-fourth inch iron tubing, while others obtain the bamboo-covered extensions, which latter contain one-fourth inch pipe. The essentials of an extension pipe are a brass coupling for connecting the hose, a good brass stopcock for controlling the flow of spray, a metallic pipe of sufficient length (which should be determined by the height of the trees to be sprayed), and upon the end of the pipe a thread and shoulder for the attachment of the nozzle and the reception of a washer. The ordinary length of extension pipes is 8 or 10 feet, but where trees are large a 12-foot pipe may be needed. Either of these lengths are now obtainable from dealers in spraying supplies in the form of bamboo extensions (fig. 5). There are advantages in the bamboo extension pipes over uncovered iron tubing. Where hot sulphur sprays are used the bamboo cover prevents the hands from feeling the heat, and where cold sprays are applied in very cold weather the bare, wet pipe is liable to chill or even freeze to the hand. The greater size of the extension pipe which is covered by bamboo also adds to the ease with which the pipe may be held and turned in the hands.

PROTECTION OF THE SPRAYER.

The nature of spray work makes it unpleasant for the workman, but much of this inconvenience arises from an incomplete or improper preparation for the work. Men who would not care to work in a rain storm without suitable covering are often improperly protected against the similar or worse conditions prevailing when they are spraying. In the spraying of large orchards it has been learned that one of the most suitable coverings for men who are applying sprays is a sailor's oilskin suit and sou'wester. This covering is light, impervious to wind and water, and is not as liable to crack as rubber clothing. Whatever form of head covering may be chosen it should be soft, so as not to be interfered with by limbs, and it should extend in front to protect the eyes and behind to protect the neck. It is always desirable to protect the hands with long rubber gloves, and these can usually be obtained from or through druggists. In selecting such goods, however, it is well to learn how long they have been held in stock by the dealer, and if they have been kept for more than a year it is best to order new ones from the manufacturer, as such goods soon rot when held in stock. Besides, new stock is no more expensive than old, and it will frequently endure twice as much use. Numbers 11 or 12 are usually about the right sizes for ordinary hands. Most wear can be obtained from gloves which are large for the hands, and in such the hands are not as apt to perspire. Where rubber gloves are not obtainable the hands may be greatly protected and kept soft by rubbing them thoroughly, as often as necessary, with a piece of beef suet.

If corrosive sprays are to be applied, such as the simple solution of copper sulphate, eau celeste, etc., it may be found necessary to protect the eyes. For this purpose ordinary clear glass goggles may be used, or the sprayer may provide himself with mica goggles of large size, such as are worn in some portions of the country by men employed about thrashing machines. Both the glass and the mica goggles may be usually purchased through druggists.

PUMPS FOR VARIOUS SIZED ORCHARDS.

The selection of a good spray pump is advisable. The difference between the first cost of a poor pump and that of a good one is little, while the difference in the expense of spraying an orchard with a poor and a good pump is apt to be considerable.

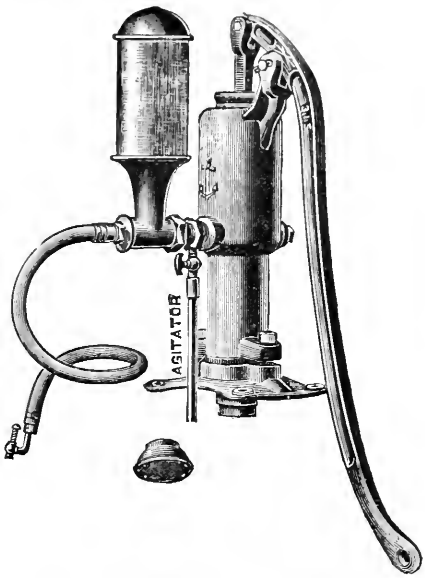

FIG. 6.—Spray pump for use on barrel or tank.

There are some features which every spray pump should possess. It should be furnished with an air chamber for the regulation of the flow, and the wearing parts should be of brass or brass lined. It should be strong and work easily, be supplied with means for firm attachment, and have capacity sufficient to maintain the required pressure without undue rapidity of stroke.

Pumps for small orchards should be capable of throwing two good sprays. Such pumps, suited for attachment to the top or side of barrels, or to other raised tanks or foundations, are shown in figs. 6 and 7. These pumps are supplied with air chambers and are of sufficient capacity for ordinary orchard spraying. Each has a connection for a small pipe leading down from the discharge pipe to the bottom of the barrel or tank. By opening a stopcock in the pipe a stream may be forced back into the tank close to the end of the suction pipe, thus serving to free the suction from deposit and to agitate the spray. These pumps can be obtained with brass-lined cylinders. The stroke is upward and downward. (See also Pl. XXVI.)

For orchards of medium to large size it is better to obtain more powerful pumps—those capable of throwing four strong sprays. The pumps shown in figs. 8, 9, and 10 are admirably suited for this class of work. Pumps of the type shown in fig. 8 are used in the 1,600-acre Rio Bonito orchard. In this orchard one man pumps for four men spraying (Pls. XXVII and XXVIII). In many portions of California the pneumatic pump, shown in fig. 10, is a favorite. It has been used extensively in the spraying of orange groves where the trees are large and where high pressure is necessary to throw the spray to their tops. The pumps shown in figs. 8 and 9 have perpendicular levers, thus avoiding the bending or stooping motion of the operator. The levers of each of the three styles shown are long, and both the strength and capacity of the pump is sufficient. The style of pumps, both for small and large orchards, to which attention is here called, will be found figured and listed in catalogues usually to be found in the hands of leading hardware dealers.

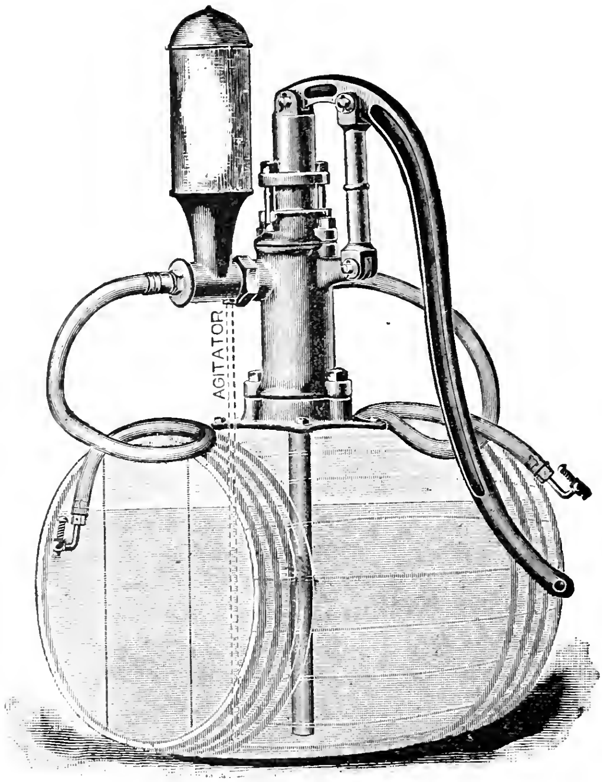

FIG. 7.—Spray pump for use on barrel or tank.

Within the past few years leading orchardists and others have tested, with varying success, the application of different motive powers to the operation of spray pumps. Steam and gasoline engines have received most attention for this purpose. Many of the power sprayers as now constructed are heavy, cumbersome affairs, which could never be of practical value in everyday orchard work. Of the machines or descriptions of the same which have come to the writer's attention, none have thus far appeared better adapted to practical and continuous orchard work than one in use at San Diego. This machine was planned and constructed for Mr. H. R. Gunnis, of San Diego, and has seen practical service for several years. It has been more or less changed and perfected from time to time, such improvements being made as have seemed best from experience gained in actual and extensive orchard work. This machine, as first called to the attention of the writer by Mr. Gunnis in the early part of July, 1895, is illustrated in Pl. XXIX. The photograph from which this plate was made was taken while the machine was being used in spraying a young orchard near Santa Barbara. In reference to the changes made since this photograph was taken, Mr. Gunnis writes:

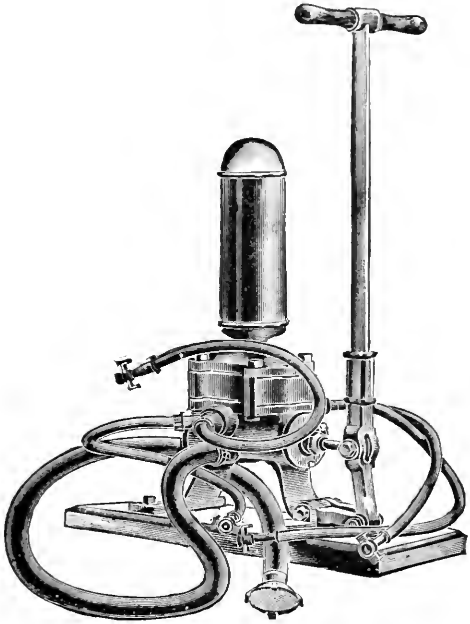
Fig. 8.—Spray pump for general orchard work, upright lever.

"The changes made in the machine since I corresponded with you regarding it in 1895 consist in the addition of a rotary supply pump and the use of a tender cart for hauling the material to the machine instead of having to shut down and go to the material every time the tank is emptied." Mr. Gunnis further says, under date of March 10, 1899: "The machine is still in constant use, and I can still say, as I wrote you over three years ago, that it has developed no defects whatever. Some of the parts wore out from actual service and have been replaced, but no changes have been made in its construction. * * * The use of the supply pump and tender increases the capacity of the outfit 25 or 30 per cent, especially in large orchards. In very small places it can also be used economically by two men, both spraying, as a good, steady team can soon be taught to move and stop at the word. In this case it is not necessary to use the tender."

While it is believed that the machine which Mr. Gunnis has built and operated is superior to any other of its class, I am informed that the gentleman contemplates still further improvements. In regard to these changes Mr. Gunnis says that he is now building from his own designs, and has almost completed, a small gasoline engine of 3 to 4 horsepower, weighing less than 200 pounds. This engine is intended for use with a spraying machine embodying all the features of his old apparatus, but lighter and more compact. He also has plans under way for a self-propelling machine, in which the extra power required will not cost half of what it does to feed a team, and which can be much more easily controlled.

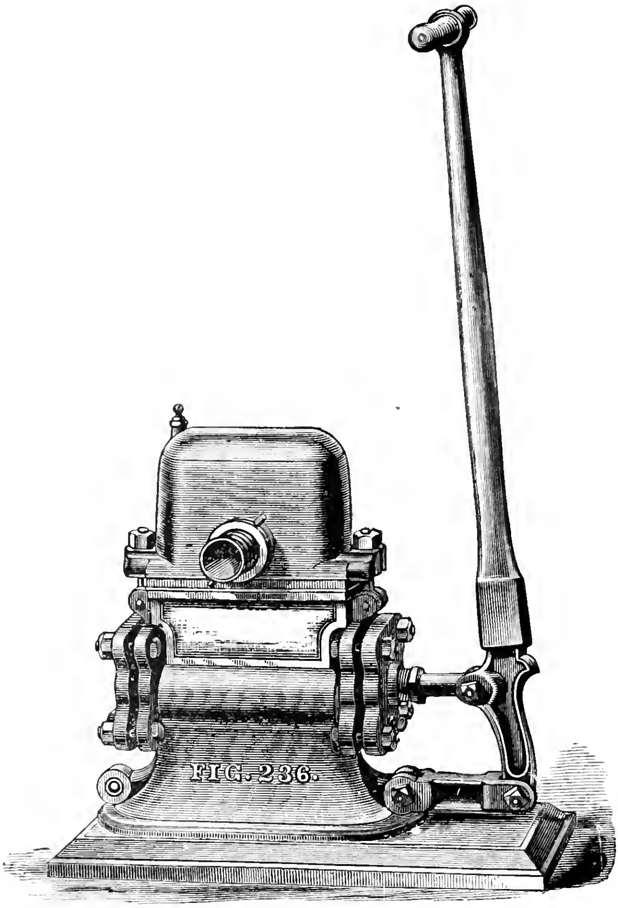

FIG. 9.—Spray pump for general orchard work, upright lever.

Pl. XXX shows the right and left sides of Mr. Gunnis's sprayer as it appeared after the addition of the rotary pump for filling the spray tank. A detailed description of this machine was prepared by Mr. Gunnis and published in the Yearbook of the Department for 1896 (pages 73 and 74), in an article by L. O. Howard, on the use of steam apparatus for spraying. Those wishing more complete details may refer to Mr. Gunnis direct, to whom the writer is indebted for the illustrations and facts here given.

SPRAYING TANKS.

A great variety of forms and sizes of spray tanks are in use. For small orchards, scarcely anything better could be desired than large oak barrels holding 60 to 80 gallons. These may be swung upon wheels separately if desired, but the most convenient way is to place them firmly in a one or two horse wagon. Large tanks, well hooped, are also very suitable for large orchards. Casks of this kind, holding 300 gallons, may easily be placed in the bottom of a two-horse wagon, leaving abundant room for placing and operating the heavy hand pump. Such casks are shown in Pls. XXVII and XXVIII. The manner of securing the tank by placing side timbers inside of the wagon bolsters is shown in Pl. XXII, as is also the stirring stick which projects from a square hole in the top of the cask.

Rectangular plank tanks are used by some, but it is generally found more difficult to keep them from leaking than in the case of casks, where the hoops may be tightened at will. Numerous spray carts, barrel attachments, etc., are illustrated in E. G. Lodeman's work on The Spraying of Plants.

The use of iron tanks is rare, and is hardly to be advised for general spray work, owing to the corrosive action of many sprays. For special sprays, as the kerosene emulsion, such tanks may, however, be safely employed.

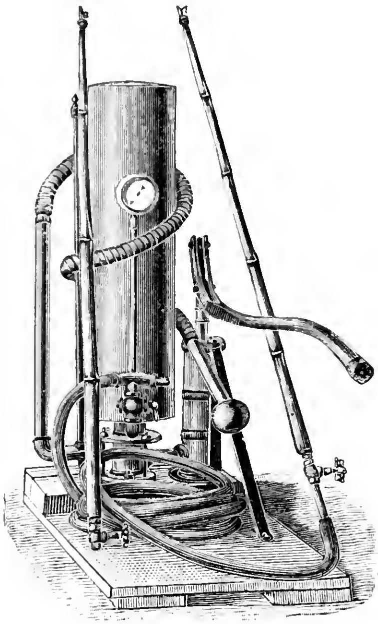

FIG 10.—Pneumatic pump for general spraying.

All spray tanks should be arranged in such a manner as to be easily cleaned, especially where Bordeaux mixture or the sulphur sprays are to be used, and they should be provided with some means for stirring or agitating the spray. The entrance to all suction pipes should be guarded with fine brass wire screen. It is well to wash the tanks out thoroughly at least once a day.

APPLYING WINTER SPRAYS FOR CURL.

A study of the many experiments conducted by the growers and described in this bulletin will give much information relative to the proper time for applying sprays for the control of curl. A presentation of a few general principles involved may, however, be properly made in this place.

THE TIME FOR WINTER SPRAYING.

The proper time for the application of winter sprays for the control of peach leaf curl depends very largely upon the conditions of climate, season, and situation of the orchard. The object to be attained is to prevent the fungus from infecting the first growth of spring. It has become apparent from the many and widely separated experiments which are here described that nearly if not all this infection results from the spores of the fungus, which are present upon the tree and not, as formerly supposed, from a perennial mycelium, and it naturally follows that these spores are to be destroyed or their germination prevented if the new growth is to be kept exempt from curl. When a spore is about to germinate or has just begun to germinate, its membranes are most tender and susceptible to fungicides. That most of the spores of *Exoascus deformans* enter upon the stage of germination at or about the time of the pushing of the first leaf buds in the spring admits of little doubt. That is the time when the tissues of the peach leaf are most tender, and when their infection by curl is actually known to take place.

The preceding facts indicate that the time when the fungicide is apt to do the greatest good is just before or at the time of the earliest pushing of the peach leaf buds. The spray should be everywhere present upon the trees just prior to the beginning of growth. To obtain this object it should be applied from one to three weeks before growth begins. This time may usually be determined by carefully watching the fruit buds, which show signs of swelling some time before they open. When they first begin to swell, the spray may be at once applied (Pls. XXIII, XXIV, and XXV).

This plan relates to regions of moderate rainfall, where a single thorough spraying, with sprays sufficiently strong and active, will prove sufficient. In regions of heavy precipitation more spray should be applied to the trees. It should be stronger and have greater adhering qualities, or else more than one spraying during the winter will be required to give the best results. If two sprayings are given, it is better to apply both to the dormant tree than to delay the second treatment till the leaf buds have opened The first spraying may be given in the fall or a few weeks before the second.

THE MANNER OF APPLYING WINTER SPRAYS.

The source of infection of the spring foliag of the peach by the fungus of leaf curl is local—i. e., it is to be found upon every portion of the tree. This fact is sufficient to show that any portions of the tree not reached by the spray will be as subjec to the disease as if no spraying had been done. It thus becomes apparent that very thorough work is essential to the general control of the disease upon the tree.

DESCRIPTION OF PLATE XXIII.

This plate shows the condition of the trees in the experiment block of the Rio Bonito orchard at the close of the spray work in the spring of 1895. The row of trees at the left has been sprayed; that at the right has been left unsprayed for comparison. The first 10 trees on the left have been treated with a spray containing a moderate amount of lime; the second 10 in the same row were treated with a spray containing more lime, and they are much whiter than those in the foreground. Each row of 10 sprayed trees on the left and the corresponding row of 10 unsprayed trees on the right constituted an experiment. The uniformity in the size of the trees in these experiments is here shown to advantage. It should be noted that the buds are still closed, while the spraying is completed.

APPEARANCE OF TREES AFTER TREATMENT, EXPERIMENT BLOCK, BIGGS, CAL.

Treated trees at left; untreated trees at right.

DESCRIPTION OF PLATE XXIV.

A portion of the Lovell trees in the Rio Bonito orchard left unpruned until too late to spray, many of the flowers being already open. This plate should be compared with Pl. XXV, which shows how the orchard should be pruned before spraying, and also with Pl. XXIII, which shows how far bud development may ordinarily be allowed to advance in the spring up to the time the spray work is completed.

UNPRUNED TREES; TOO LATE FOR TREATMENT.

Blossoms are opening.

DESCRIPTION OF PLATE XXV.

A properly pruned portion of the Rio Bonito orchard, which has developed too far for the best results of spraying. Spraying should be completed by the time the buds have developed as far as those shown in Pl. XXIII.

TREES PROPERLY PRUNED; TOO LATE FOR TREATMENT.

Blossoms are opening.

Thorough spray work requires that the sprays be applied in as calm weather as possible. Wind greatly retards and lowers the class of work done. Sprays should likewise not be applied when the twigs or limbs of the trees are covered by frost, snow, or sleet, or by the water of rains, dew, or heavy fogs. To avoid the presence of hanging drops of dew upon the limbs, it is frequently necessary to delay spraying until late in the morning. Such delay is preferable to the application of spray to the dripping trees. When the twigs are dry the spray dries where it strikes, and succeeding dews or showers, if the latter are not too heavy, will not wash off the spray to a very injurious extent.

If the sprayer is provided with suitable extension pipe and nozzle with lateral discharge, the work of spraying peach trees of ordinary size may be rapidly and easily done. The cone of spray is first turned upward under the base of one of the main limbs of the tree and the pipe moved so that the spray passes outward toward the end of the limb, spraying the entire under surface of the limb from base to tip. The sides and top of the limb are now sprayed, together with all of its terminal branches and twigs. Each main limb of the tree is treated in like manner, the sprayer passing about the tree as the work is completed. The habit of actively moving the nozzle back and forth while at work will soon be acquired by the workman desirous of doing good work, and by this means the most uniform spraying is accomplished.

SPRAYING WHERE OTHER DISEASES ARE PRESENT WITH CURL.

There are many peach diseases which may coexist upon the tree with curl. Many of these are amenable, in whole or in part, to treatment adapted to the control of curl, but in some cases where two or more are present it may be advisable to make slight alterations in the treatment. The following notes on some of the more common diseases may prove of value.

PRUNE RUST ON THE PEACH (*Puccinia pruni* Pers.).

It is a fact which does not appear to be generally known that prune rust infests the tender branches of the peach as well as its leaves. This has been found especially true in young trees. Spore clusters are found upon the young shoots before growth begins in the spring, showing that the disease winters over by means of spores produced upon and remaining attached to the branches, as well as by the spores produced upon the leaves and scattered over the tree. Where the trees are suffering from rust it is therefore apparent that a thorough winter treatment is required to clean the tree and prevent the spring infection, hence such spraying is recommended for the control of both curl and rust, though the full control of the latter disease is very difficult and will, at best, be necessarily followed by several summer treatments. There can be little doubt, however, that a thorough winter spraying will prevent a greater portion of the injury from rust than any single spraying applied at a later date, as it gives a practically clean tree at the opening of the season of growth. Winter sprays for the control of rust must be strong; but summer sprays if strong should be positively neutral and noncorrosive, as peach foliage is exceedingly tender.

MILDEW OF THE PEACH (*Podosphæra oxyacanthæ* De B.).

Peach mildew is widely distributed in the United States and in Europe. The fungus causing it attacks the leaves, fruit, and tender branches in the early part of the summer. The branches serve for the wintering over of the spores, thus aiding in supplying the source of spring infection. Winter treatment of the trees, with either the copper or sulphur sprays, will largely limit this spring infection, but later treatment with weak sprays will often be necessary for full control.

BROWN ROT OF THE PEACH (*Monilia fructigena* Pers.).

Brown rot of the peach has become one of the worst fungous diseases of the peach over large portions of the United States. It is quite general throughout most peach-growing sections of the East, and has become well established in the Pacific Northwest. It has been shown by Erwin F. Smith that the fungus winters over in the diseased branches and in the dried fruit adhering to the tree. These facts point to a thorough winter spraying with active fungicides as one of the first steps required in its treatment. Summer sprayings will also be required, and even when thoroughly followed up, the disease will prove hard to control. Too much stress can not be laid, however, upon the necessity of disinfecting the dormant tree as perfectly as possible by thorough winter treatment.

BLACK SPOT OF THE PEACH (*Cladosporium carpophilum* Thüm.).

This disease, which produces black spots upon the peach, is well known in many portions of the United States and in Europe, and in the East and South, especially in Texas, it has become quite troublesome. In some parts of Europe it has been known as a true epiphytotic. Whether this Cladosporium infests the branches the writer can not say, but it appears not improbable that such is true, or in any case that the spores probably find winter lodgment upon the tree itself. Black spot has been controlled in Texas by the use of the copper sprays, and there seems no reason to doubt that the winter treatment of the infected trees would largely tend to disinfect them and materially reduce the summer development of the disease.

WINTER BLIGHT OF THE PEACH AND OTHER SPOT AND SHOT-HOLE DISEASES, SUCH AS *Phyllosticta circumscissa* BERK., *Cercospora circumscissa* SACC., ETC.

In the Northwest, on the Pacific coast, there are several diseases of the peach not generally known throughout the East, and also several other diseases common to both sections of the country. These troubles are generally known as leaf spot or shot-hole diseases. One very widely distributed disease is that produced by *Cercospora circumscissa* Sacc., but one of the most troublesome diseases of this class that occurs in California and Oregon, is induced by a fungus not yet fully studied, which infests the tender and bearing branches and appears to begin its vegetative activity some time prior to the blooming of the tree in the spring. On account of the habit of the fungus to grow in the dormant or semidormant branches of the tree, the disease is termed by the writer the *winter blight* of the peach. It is one of those diseases which destroys the most valuable young growth of the tree, i. e., the shoots which are low and suited to the production of the finest fruit. This disease, in common with another quite prevalent on the Pacific coast and which is probably induced by a *Coryneum*, does most damage in the more humid localities. Both do their more serious work so early, as is also true of peach leaf curl, that summer spraying would have but little effect toward their control. Both induce gummosis of the affected branches, as is true of the action of many fungi, and is a well-marked result of the presence of *Coryneum beyerinckii* Oud. Winter blight has already been successfully treated with the winter sprays, and it is believed that such spraying is sufficient for its control, provided the work be done thoroughly and repeated each year.

There is no doubt that the winter treatment of the peach for curl is properly and essentially the first step for the control of any of the above-mentioned diseases. Too much can not be said in favor of this treatment, which disinfects the trees before vegetative growth begins. The striking thoroughness of such disinfection work may be seen from the records given below.

SOOTY MOLD OF THE PEACH.

When the Department spraying experiments began in the Rio Bonito orchard, there was everywhere present on the trunks, inner limbs, and older bark of the experiment trees a fungous "smut," or "sooty mold," giving the bark a black appearance when closely examined. Of the 58 rows included in this block, 35 were sprayed, as before stated, prior to March 10, and 23 left unsprayed for comparison. On August 10, 5 months after the spraying was completed, all but 4 rows were examined for the presence of sooty mold, with the following result:

Sprayed rows showing no sooty mold August 10: Nos. 1, 3, 6, 7, 10, 12, 13, 15, 16, 18, 19, 21, 22, 25, 27, 28, 33, 35, 36, 38, 39, 41, 45, 47, 48, 50, 51, 54, 56, and 57—total, 30 rows.

Sprayed rows showing a trace of sooty mold: Nos. 42 and 44 (sulphide of potassium was applied to row 42 and simple milk of lime to row 44)—total, 2 rows.

Unsprayed rows showing the presence of sooty mold upon the trees August 10: Nos. 2, 5, 8, 11, 14, 17, 20, 23, 26, 29, 34, 37, 40, 43, 46, 49, 52, 55, and 58—total, 19 rows.

Unsprayed trees showing no sooty mold, none.

Rows sprayed in 1894, but not sprayed in 1895: No. 4, no mold apparent; No. 24, some mold present; No. 53, a little mold present—total, 3 rows.

Rows for which no notes on sooty mold were obtained: Nos. 9, 30, 31, and 32—total, 4 rows.

The above notes show that records of the sooty mold were obtained from 32 rows of sprayed trees 5 months after treatment. Of these, 30 rows showed no sooty mold, while 2 showed a very little. Neither of these exceptional rows was sprayed with a generally recognized fungicide. On the other hand, of the 19 unsprayed rows examined, all showed sooty mold. The record for rows sprayed in 1894 but left unsprayed in 1895, shows that the trees had but little mold upon them 17 months after spraying.

The preceding facts show the disinfecting value of a single winter spraying, even where the whole tree surface is covered with fungous mycelium and spores.

ANIMAL PARASITES OF THE PEACH TREE.

Among the insect pests of the peach tree now prevalent in many parts of the United States, the San José scale (*Aspidiotus perniciosus* Com.) is probably the most injurious. This pest, as is already well known on the Pacific coast, can be controlled by winter spraying with the sulphur sprays considered in this bulletin. Where the insect is known to be present, the strongest of these sprays described should be used, and it would be well to apply it somewhat earlier in the spring than where weaker sprays are used.

All leaf-eating insects depositing winter eggs upon the tree may be largely controlled by the winter use of sulphur sprays. There is also a mite (*Phytoptus* sp.?) infesting the peach leaves in California, which the writer believes may be destroyed in this manner, from the fact that experiments conducted in 1895 in the Sacramento Valley showed that the same line of treatment is effective in the destruction of a related mite (*Phytoptus pyri* Sor.) upon the pear.

Mr. William N. Runyon, of Courtland, Cal., makes the following statement respecting the peach moth, which may also prove of value to growers suffering from this pest: "Incidentally I would state that experience shows that peach trees sprayed with lime, sulphur, and salt are not subject to the attacks of the larva of the peach moth. Some growers claim a saving of 90 per cent of affected fruit."

CHAPTER X.

NATURE AND SOURCE OF THE SPRAYING MATERIALS USED.

The following notes on the chemicals for sprays are presented for the general information of the fruit grower. The facts given are those which every sprayer should understand.

Spraying is frequently retarded or prevented owing to a want of information relative to the nature, sources of supply, or true value of the chemicals required. A grower uninformed upon the last-named point is often at the mercy of local druggists or other dealers. For example, copper carbonate can be made by the grower himself at from 13 to 14 cents per pound, and ammonia of 26° strength may be purchased at about 60 cents per gallon, while local prices have been known to range as high as $1 per pound for copper carbonate and $1.50 per gallon for ammonia, which makes it impossible to undertake spray work. The writer has found the same conditions prevailing in respect to prices for sulphur, which is used very largely in the sulphur sprays and for the treatment of mildew. In some cases the prices asked by dealers in the East have been 400 or 500 per cent higher than growers have for years been paying in California. It can not be expected that the sulphur sprays will be generally used in the East under such conditions.

COPPER SULPHATE (formula $CuSO_4 5H_2O$).

Of all fungicides thus far known, copper sulphate is the most important. It is commonly known as blue vitriol or bluestone in the United States. Its foreign names are largely equivalents of these terms, although the Germans also apply the name of copper vitriol (*Kupferritriol*).

When pure, copper sulphate crystallizes in large, blue, triclinic prisms. It contains about 25.3 per cent of copper, and dissolves in four parts of cold water and two parts of boiling water.

The presence of iron is indicated by a greenish color of the crystals or at the surface of a watery solution when exposed to the air. A solution of pure copper sulphate should be blue. The presence of a small amount of iron, which commonly occurs when copper sulphate is manufactured as a by-product in modern smelting works, does not necessarily detract from its value as a fungicide, while this by-product may often be purchased at a somewhat lower figure than a purer article. Spraying tests have been made by the writer for the comparison of pure commercial bluestone with that obtained as a by-product of smelting works, and which contained a considerable amount of iron, and the results showed that the latter article contained fully as great fungicidal value as the former.

The manufacture of copper sulphate is carried on at a considerable number of establishments in the United States, and various processes are followed. A large amount of this chemical is also imported, chiefly from England.

Bluestone is prepared by dissolving cupric oxide in sulphuric acid, or by oxidizing the sulphide of copper, the latter being the cheaper process. Mr. Alfred Rapp, a gentleman who has enjoyed a wide experience, has kindly supplied the following facts respecting the manufacture of copper sulphate by a leading smelting firm of the Pacific coast. He states that the copper is mainly derived from mattes produced in the blast furnaces, and, secondly, from an acid solution of sulphate of copper resulting from the precipitation of silver by metallic copper out of a sulphate solution. To bring the copper in the different mattes in solution they are first crushed and pulverized to about one-thirty-second of an inch or finer, and subjected to a roasting process by which the sulphur is nearly all oxidized. The roasted matte contains the copper as oxide and partly as sulphate, with a small amount still as sulphide. This material is pulverized once more and fed into lead-lined leaching tanks, where the acid copper sulphate solution is added, and, if necessary, sulphuric acid. The whole mass is heated by steam running through lead pipes. The copper oxide and the copper sulphate in the roast is thus brought in solution as a sulphate. About 80 per cent of the copper contained in the mattes is thus leached out. The resulting solution, of course, is not a neutral one, but still contains an excess of free sulphuric acid. This solution is transferred to other lead-lined tanks, containing, suspended from wooden sticks, strips of lead about 3 inches wide, the central portion of which is bent downward between the sticks so as to form a loop, which is held by the ends of the lead strips being bent over the sticks. The copper sulphate when run down to these crystallizing tanks is about 36° to 44° B. During the cooling process, which takes about four to seven days, the copper sulphate, or rather part of it, separates out of the solution as blue crystals, which are deposited upon the strips of lead. These crystals are dried and packed in barrels ready for the market. This, Mr. Rapp adds, is the general way in which bluestone is made the world over, except that they have at the works considered, in addition to the copper in the mattes, the acid copper sulphate solution from a silver refinery.

Water draining from copper mines sometimes carries copper sulphate in solution, in which case the crystals are procured by evaporating the excess of water. Barrels of copper sulphate weigh from 300 to 600 pounds.

The manufacturer's price of copper sulphate will depend largely upon the price of copper and sulphuric acid—two leading constituents, as they are sold in the market—and upon supply and demand. The cost to the manufacturer will not, however, necessarily depend upon the market value of copper and acid, for one or both may be obtained by him as by-products in other regular and profitable lines of manufacture, such as the smelting of gold and silver ores, etc.[1]

COPPER CARBONATE.

Copper carbonate as usually prepared shows the following formula: $CuCO_3 . CuH_2O_2$. It is widely used in the preparation of ammoniacal copper carbonate sprays, and is especially well adapted to the treatment of maturing fruit where subject to fungous diseases. As commonly sold on the market, the carbonate of copper is green and finely granular or powdery. It contains about 57.4 per cent of copper. Native minerals of similar composition occur, such as malachite and azurite.

Copper carbonate is manufactured by a number of firms in the United States, but much less extensively than the sulphate. In most cases it is prepared by adding to a solution of copper sulphate an excess of sodium carbonate (sal soda) in solution. This gives a flocculent mixture of pale blue color, afterwards changing to green. Heating makes the precipitate more granular.

Owing to the difficulty of obtaining carbonate of copper in smaller towns, as well as the high price usually charged for it, the Department has usually recommended that the fruit growers prepare it. The following instructions for this work were published by the writer in a circular sent to the peach growers of the country in 1894–95: In a barrel dissolve 6 pounds of copper sulphate in 4 gallons of hot

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[1] Owing to the somewhat enhanced value of copper at this time (March, 1899), the wholesale price of copper sulphate has advanced. San Francisco producers quote copper sulphate in barrels, f. o. b., at $5\frac{1}{4}$ cents, and carload lots at 5 cents per pound; Omaha quotations are, by the ton or carload, $5\frac{1}{2}$ cents; one New York firm quotes $5\frac{3}{4}$ cents by the barrel or ton and $5\frac{1}{2}$ cents by the carload, and a second firm quotes 6 cents by the barrel, $5\frac{9}{10}$ cents by the ton, and $5\frac{3}{4}$ cents by the carload; Denver quotations are 6 cents by the barrel, $5\frac{3}{4}$ cents by the ton, and $5\frac{1}{4}$ cents by the carload; Cleveland quotes 6 cents per pound in any quantity; one Philadelphia firm quotes 6 cents by the barrel, $5\frac{7}{8}$ cents by the ton, and $5\frac{3}{4}$ cents by the carload, and a second firm quotes $5\frac{3}{4}$ cents by the barrel, $5\frac{1}{2}$ cents by the ton, and $5\frac{1}{4}$ cents by the carload; Baltimore quotes $5\frac{3}{4}$ cents by the barrel, $5\frac{1}{2}$ cents by the ton, and $5\frac{1}{4}$ cents by the carload; Great Falls, Mont., quotes $4\frac{3}{4}$ cents per pound in carload lots and 5 cents per pound for less than carload lots, etc.

water. In another wooden vessel dissolve 7 pounds of washing or sal soda, in 2 gallons of hot water. The soda should be clear (translucent), and not white and powdery, as it appears when air slaked. When cool, pour the soda solution slowly into the copper solution. As soon as bubbles cease to rise fill the barrel with water, stir thoroughly, and allow the mixture to stand over night to settle. The next day siphon off all the clear liquid from the top with a piece of hose, fill the barrel with water, stir thoroughly, and allow it to stand a second night. Siphon off the clear liquid the second day, fill the barrel with water, stir, and siphon off the clear liquid once more the third day. Now pour the wet sediment from the barrel into a crock or other earthen dish, strain out the excess of water through a cloth, and dry slowly in an open oven, stirring occasionally, if necessary, to prevent overheating. Prepared in this manner there should be obtained, if none of the sediment in the barrel be lost, about 2.65 pounds of carbonate of copper.

Owing most probably to the comparatively limited sale of carbonate of copper, the market price has been and still remains too high. It can rarely be obtained for less than 30 to 40 cents per pound, which is from two to three times the cost to the grower when it is prepared at home. This condition reacts upon the manufacturer by causing the grower to make his own carbonate, the market never feeling his demand. With fungicides which the grower is unable to prepare the conditions are different. His needs increase the demand in the market, and increased demand tends ultimately to lower prices.

The cost of copper carbonate when prepared by the grower will depend upon the cost of copper sulphate and sal soda. Quotations of March and April, 1899, placed copper sulphate at 5 cents per pound by the barrel and sal soda at $\frac{4}{10}$ of a cent per pound in like quantity. At these rates the grower should be able to prepare the carbonate of copper at about 12.3 cents per pound. Quotations on larger lots of sal soda and copper sulphate placed the price at $\frac{4}{10}$ of a cent and $4\frac{3}{4}$ cents per pound, respectively. At these prices the raw materials for a pound of copper carbonate would cost about 11.8 cents. These facts show that wholesale druggists and manufacturing chemists could place the carbonate upon the market at 15 or 20 cents per pound and still make a good profit, even when buying their sodium carbonate and copper sulphate in the open market. If we go a step farther back, however, we may see that the first cost of copper carbonate can be greatly reduced below any figures here given. Ten-elevenths of the cost is seen to depend upon the price of copper sulphate, and the first cost of this latter depends upon the cost to the manufacturer of sulphuric acid and copper. Both of these articles may be produced as by-products of modern smelting processes. A firm at Blacksburg, S. C., informs the writer that they employ gold-bearing pyrites for the manufacture of sulphuric acid, the sulphur fumes being driven off with heat and condensed in lead chambers in the usual way. The acid, the firm states, pays the expenses, hence the gold collected is a by-product with them. For the same purpose sulphur may be obtained by heat from several kinds of pyrites—that is, from the sulphides of copper and iron. As already shown in the notes on copper sulphate, copper for the production of this chemical may be derived largely from the mattes of silver smelting works. In view of the fact that both the copper and sulphur of copper sulphate may be obtained as by-products in the extensive gold and silver smelting works, the first cost of this chemical can certainly be placed at a figure admitting of the manufacture of copper carbonate at a very low cost. It could probably be placed on the market to-day by the leading smelting companies at 15 cents per pound and still leave a liberal profit on first cost. It is to be hoped that this matter will be looked into by some of the larger smelting firms, and that the carbonate of copper may soon be had on the market at prices which are not prohibitive to its purchase by the horticulturists of the country.[1]

AMMONIA (*formula* NH_3).

Ammonia is of gaseous nature and strongly alkaline in reaction. It is readily taken up or dissolved in water, in which form it is used in preparing the ammoniacal copper carbonate, eau celeste, and modified eau celeste—three of the more important copper sprays. A strong solution of ammonia may be commonly had on the market or from the manufacturers. Such a solution contains, by weight, about 28 per cent of ammonia gas, and is sold as 26° ammonia, as shown by Baumé's hydrometer test. A weaker solution is often prepared by druggists and is sold as ammonia water, or aqua ammonia. This often contains no more than 10 per cent of ammonia gas, and is obtained by reducing the stronger article with water. It is scarcely necessary to add that there is no economy in buying this dilute liquid. The price is apt to be out of proportion to the strength, and if quantities are to be shipped long distances there is a needless increase of freight, owing to the

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[1] The following quotations on copper carbonate were received March, 1899: St. Louis quotes 10-pound lots at 27½ cents per pound, 100-pound lots at 25 cents per pound, and 1,000-pound lots at 23 cents per pound, f. o. b.; one Philadelphia firm quotes 10-pound lots at 23 cents per pound, 100-pound lots at 22 cents per pound, 1,000-pound lots at 21 cents per pound, f. o. b., and a second house quotes 28 cents per pound for ordinary quantities and 21 cents per pound by the barrel; New York quotes 10-pound lots at 35 cents per pound, 100-pound lots at 28 cents per pound, and 1,000-pound lots at 22 cents per pound f. o. b.; Boston quotes 10-pound lots at 20 cents per pound, 100-pound lots at 18 cents per pound, and 1,000-pound lots at 16 cents per pound.

The writer invites attention to the great variation in quotations from different centers of trade. It is satisfactory to note that quotations just received from Boston indorse the view already expressed, that carbonate of copper can be placed upon the market at about 15 cents per pound and leave a sufficient profit to the manufacturer.

added percentage of water. It is always desirable to specify the strength of the ammonia solution when obtaining quotations.

Plants and animals furnish the main sources of commercial ammonia. In each case the ammonia is obtained through the decomposition or destructive distillation of the organic matter. Mr. Mallinckrodt, of the Mallinckrodt Chemical Works, of St. Louis, and president of the Pacific Ammonia and Chemical Company, states that there are, as already indicated, but two prime sources from which aqua ammonia is obtained, viz. "bone liquor," obtained as a by-product in the manufacture of bone coal, and "gas liquor," obtained from the scrubbing of gas in works for the manufacture of coal gas. A similar source is also found in the making of coke. It is further stated that ammonia is obtained from bone liquor almost exclusively in the form of sulphate of ammonia, often of crude quality, which is used in the manufacture of fertilizers. Gas liquor is partly worked into a sulphate of superior quality, but mostly into aqua ammonia, by what is called the direct process. It is redistilled and aqua ammonia made therefrom. Aqua ammonia obtained from this source is largely used in the manufacture of ice and for other technical purposes. Obtained in this way, it is said to be the cheapest article of good quality that can be supplied.

A crude concentrated ammoniacal liquor is also largely made by concentrating gas liquor without purification. This concentration is carried on mainly at smaller works for the purpose of transporting the liquors in a more concentrated form, to save the expense of freight, to works where crude liquor is redistilled and manufactured into pure aqua ammonia. The concentrated liquor is, however, also largely used in the preparation of nitrate of ammonia, which is used in the manufacture of powder, but most largely in the manufacture of soda ash. This crude liquor contains, besides a small amount of free ammonia (NH_3), a considerable amount of carbonate, sulphide, cyanides, and other ammonia salts, together with tarry and empyreumatic matter resulting from the destructive distillation of coal. The strength of this liquor can not be made greater than 15 to 20 per cent, and it is doubtful if it could be advantageously used as a substitute for aqua ammonia in the preparation of sprays. The ammoniacal liquors obtained in the manufacture of coal gas are entirely a by-product.

As the gas works of the United States have been largely supplanting coal gas with water gas, in the manufacture of which ammonia is not obtained, the quantity of ammonia produced in the country has been steadily decreasing, and the demand is being supplied principally from England. Both aqua ammonia and anhydrous ammonia are made largely from imported sulphate of ammonia, and very large quantities of the imported article are also consumed in the manufacture of fertilizers.[1]

[1] San Francisco's quotation on ammonia water of 26° hydrometer test, in drums of about 750 pounds, f. o. b., is 7½ cents per pound.

SODIUM CARBONATE (*formula* $Na_2CO_3.10H_2O$).

Sodium carbonate, sal soda, or washing soda is used in making carbonate of copper from the sulphate of copper and in preparing the modified eau celeste. As obtained in the market it is in colorless, monoclinic crystals, showing a strongly alkaline reaction to litmus paper. When exposed to the air much of the water of crystallization is lost from the crystals, which rapidly effloresce or slake to a white powder. When perfect, nearly two-thirds of the crystals, by weight, is water.

Carbonate of soda dissolves in 1.6 parts of water at 59° F. and in 0.2 part of boiling water. When a solution of sal soda is added to the solution of copper sulphate in making copper carbonate, or to any other acid solution, a decided effervescence takes place, so that in making the copper carbonate the two solutions used should be united slowly or they may overflow the containing vessels. The more common impurities found in sodium carbonate are sodium chloride (common salt) and sodium sulphate (Glauber's salt). These impurities are due to the source and manner of manufacture of the sal soda, but are not usually present in the latter in sufficient amount to require attention in the spray work being considered.

The sources of sodium carbonate are somewhat numerous, but the commercial supply of to-day is derived mainly from common salt or from natural deposits of the carbonate. In nearly all arid countries carbonate of soda is frequently found in the soil in such quantities as to be injurious to vegetation. West of the Missouri River large accumulations of the different soluble salts of the soil are frequently met with. In the East such accumulations are prevented by the greater rainfall, the salts being eventually washed from the soil and carried to the sea, but in the West they often coat the ground, appearing white or black, and are known as "alkali beds," owing to the frequent presence of strongly alkaline salts, such as sal soda. The most abundant constituents of these deposits are sodium sulphate, sodium chloride, and sodium carbonate. The sodium chloride and sodium carbonate are, when in excess, so injurious to vegetation as to constitute a leading bane of the horticulturist of the western half of the United States. In the great plateau region between the Rocky Mountains and the Siérra Nevada and Cascade ranges are vast stretches of alkaline soils, the soluble salts of which accumulate in lakes and along water courses through the drainage of the winter rains. During the long, dry summer these waters evaporate to a considerable extent, leaving the salts deposited along the margins of the lakes and rivers.[1] In some cases these deposits of alkali are composed largely of sodium carbonate, and in several instances, after passing through a simple purifying process,

[1] These deposits are very well shown in the illustrations of Bull. No. 14, Division of Soils, U. S. Dept. of Agr.

this salt is obtained in a quite pure state, the original deposits containing as high as 90 per cent of sal soda. This latter is obtained from the soda lakes of South America, Egypt, etc., as well as from those of the United States. There are several such soda lakes in Wyoming, Nevada, and California. Large amounts of sal soda are crystallized from crude carbonate of soda obtained from Soda Lake, near Ragtown, Nev. This lake is known as Big Soda Lake, to distinguish it from a smaller soda lake near by. The lake is a beautiful sheet of water, lying in a depression of the desert, the water being about 150 feet in depth at the deepest point. It is very close to the old emigrant road running from the sink of the Humboldt River to Carson River. The separation of carbonate of soda from the waters of this lake is largely by solar evaporation. In the fall the salts deposited are taken up, washed, passed through a furnace, and shipped in sacks to San Francisco, where the soda is refined and bleached for various uses. The principal uses on the Pacific coast are in glass-making and borax-making. It is stated that sal soda obtained as here described is practically a pure article, though the natural color is somewhat yellow or brownish. It is generally useful, except as a fancy article for the retail trade. For such purposes it must be bleached with chloride of lime, after which it presents beautiful crystals.

There is also a large plant in operation at Owens Lake, Cal., getting out carbonate of soda from the waters for the Pacific market. This product, with that above described, is nearly equal in strength and purity to the eastern and the imported product, so much so that consumers are safe in using the western product, if desired. All or most sodas (carbonates) found on the Pacific coast proper are in the form of sesquicarbonates, and are often so much contaminated with sulphates and chlorides that much expense is entailed in their separation, and they are therefore of little value as sources of supply.

The second great commercial source of sal soda is common salt. The salt deposits of the country are vast and inexhaustible in quantity. The Onondaga Salt Group of the Upper Silurian alone underlies much of the large extent of country, as well as the Great Lakes, situated between Salina, N. Y., and Green Bay, Wis. At certain points the salt deposits of this group are known to exceed 100 feet in thickness. The deposit is tapped by wells at Warsaw, N. Y., in western Ontario, in eastern and in western Michigan, and elsewhere. The rock salt of western Michigan is 20 to 30 feet in thickness, and is reached at a depth of 1,800 to 2,200 feet. Other large salt deposits are found in Kansas and in numerous other portions of the country.

Sal soda is manufactured from salt on a commercial scale according to two leading processes. The older of these is known as the Leblanc process, and has been extensively employed in England and throughout Europe. It involves two steps in the manufacture, (1) the conversion of salt into sodium sulphate, and (2) the decomposition of sodium sulphate and its conversion into sodium carbonate. The first operation is known as the "salt-cake" process, and the second as the "soda-ash" process. The first step is carried out by the application of sulphuric acid to the salt and the decomposition of both in a furnace, the double decomposition resulting in the formation of hydrochloric acid and sodium sulphate. The hydrochloric acid is condensed and preserved, while the salt is converted by heat into a hard cake of acid sodium sulphate. There is usually in this cake, however, more or less unaltered sodium chloride. In the second step the salt cake is pulverized and mixed with an equal weight of pulverized limestone or chalk and half its weight of fine coal. This mixture is heated to fusion in a furnace, being constantly stirred or revolved. The combustion of the coal under the heat which is maintained seems to convert the sodium sulphate into sodium sulphide, and the decomposition of the sodium sulphide and limestone, with the interchange of elements, produces calcium sulphide and sodium carbonate. The resulting mass is cooled in iron receivers, broken up finely, and digested in tepid water. The alkali dissolves and leaves the insoluble impurities. The sodium solution is evaporated, and when dry the mass is calcined with one-fourth its weight of sawdust, to more fully convert the alkali into carbonate. This product—the soda ash of commerce—is again dissolved in hot water, and the solution filtered and allowed to cool. As the solution cools the carbonate of soda is deposited in large, transparent crystals, such as are supplied to the trade. Soda ash was formerly largely imported from England, but in the last few years has been made in the United States to a very large extent. The dissolving of the soda ash and the crystallizing of the sal soda is carried on extensively by firms not manufacturers of the ash. A St. Louis firm states that they crystallize the solution of soda ash in tanks holding about 8,000 pounds each. After the crystallization has progressed sufficiently, which takes from ten to fourteen days, according to the temperature of the weather, the mother lye, which contains all the impurities, is drawn off and the sal soda is then broken, dried, and packed in barrels. It is stated that a newer process is to crystallize the solution in small tanks, holding perhaps 200 pounds. In this small quantity the liquid crystallizes in a very short time, say over night, but does not give any mother lye, and consequently no impurities are removed.

A system entirely different from the Leblanc process is in use in the United States in some of the leading salt regions and has come very largely into use in Europe. It is known as the ammonia soda process, or the Solvay process. It consists in decomposing a solution of common salt with ammonium bicarbonate, whereby the greater part of the sodium is precipitated as bicarbonate, while the ammonia remains in solution as ammonium chloride. This latter salt is heated with lime to liberate ammonia, which is then reconverted into bicarbonate by the carbonic acid evolved in the conversion of the sodium bicarbonate into monocarbonate by heat. The ammonium bicarbonate thus reproduced is employed to decompose fresh portions of sodium chloride, so that the process is made continuous.[1]

SULPHUR (*symbol* S).

The value of sulphur as a fungicide, insecticide, and germicide nas been known for many years. Its use in a powdered state has been long followed in hothouses and vineyards, and its application in the treatment of parasitic skin diseases of man and the lower animals, and in the control of fermentation in fruits and wines is equally well known. In connection with potash and soda it has been applied to the treatment of fungous diseases in the form of sulphides of these bases.

The recent marked use of sulphur in preparing sulphide of lime for the spraying of trees is believed to have been first suggested in California, the idea coming, it is thought, from the use of sulphur in a similar form as a dip to kill scab mites on sheep. The spraying of trees infested by scale insects was a natural application of its known insecticidal qualities to the needs of the orchard. In combination with lime and salt it is now very widely used on the Pacific coast. These chemicals are boiled together for a considerable time, and result in the formation of one or more of the sulphides of calcium in liquid form. While the value of this spray is well established in regions west of the Rocky Mountains, its introduction in the East has been slow, though it is almost certain to have a wide application in that section in coming years, when the full importance of winter spraying for the control of insect pests and fungous diseases is more fully appreciated. This is more especially true where both of these classes of diseases occur at one time on the same host plant.

Sulphur is obtainable in the market in several forms and degrees of purity. The forms most common are known as brimstone, the flour of sulphur, and flowers of sulphur. Brimstone is sulphur in the solid form, flour of sulphur is ground brimstone, and flowers of sulphur is sulphur which has been sublimed. Common brimstone is the cheapest form on the market, flour of sulphur stands next in price, while flowers of sulphur comes still higher. The purity of any of these

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[1] Quotations on sal soda were received as follows during March and April, 1899: San Francisco quotes 50-sack lots at 60 cents per 100 pounds, 10-barrel lots at 70 cents per 100 pounds, and smaller quantities at 75 cents per 100 pounds; Los Angeles quotes by the barrel $1.25 per 100 pounds, and by the car in sacks $1 per 100 pounds; St. Louis quotes by the car load in barrels 55 cents per 100 pounds; New York quotes, f. o. b Syracuse, in jobbing lots, barrels of 375 pounds, 40 cents per 100 pounds; Fairport, N. Y., quotes 50 cents per 100 pounds, f. o. b.

forms is usually sufficiently high for the use of the horticulturist. Brimstone and flour of sulphur are usually about 98 per cent pure, while flowers of sulphur is almost entirely pure. Brimstone weighs most, flour of sulphur less, and flowers of sulphur least for a like bulk.

The horticulturist uses sulphur in all the above-named forms, brimstone being employed for bleaching fruit, nuts, etc., while flour and flowers of sulphur are used in field work for the control of insect and fungous pests. A simple mode by which one may test the purity of sulphur is to weigh out any desired amount and then dry and burn it; the weight of the remaining incombustible portion, added to the amount of weight lost in drying, determines the amount of impurities.

The sources of the sulphur supply of the United States are numerous and varied. A large amount of crude sulphur is imported, although much of the sulphur now used in the production of copper sulphate, sulphuric acid, and various other chemicals is obtained in the United States through the decomposition of several native metallic sulphides, such as the sulphides of iron and copper, which are known as iron and copper pyrites. It has been estimated that the amount of sulphur consumed in the United States in 1892 was 243,154 tons. The sources of this sulphur were as follows:

From 100,721 tons of imported brimstone (98 per cent) ....98,707 tons.
From 1,825 tons of domestic brimstone (98 per cent) .... 1,787 tons.
From 210,000 tons of imported pyrites (43 per cent) .....90,300 tons.
From 119,000 tons of domestic pyrites (44 per cent) ......52,360 tons.

At the present time the amount used is probably much greater than in 1892.

Great deposits of native sulphur are found in many foreign countries and in various portions of the United States. Most of the natural deposits occur in past or present mountain regions, and are of volcanic origin. "The exhalations of volcanoes include, as a rule, sulphurous acid (SO_2) and sulphureted hydrogen (H_2S), which two gases, if moist, readily decompose each other into water and sulphur, a circumstance which accounts for the constant occurrence of sulphur in all volcanic districts." It is estimated that 5,000,000 tons of sulphur exist in one deposit in Japan. The deposits of Sicily are famed the world over, and 400 distinct workings are said to exist in that island. In central Sicily, at Assoro, Imera, Villarosa, and elsewhere, large amounts of brimstone, in the form of short truncated pyramids, are commonly seen piled near the railroad stations, as wood is piled in the United States. These large blocks, probably weighing 100 pounds each, are brought to the railroad on the backs of donkeys driven down from the mines in the mountains in long trains. Large refineries, devoted to the refining of such brimstone, are located at Catania. The annual output of sulphur in Sicily is said to exceed 300,000 tons, and the present importation of the United States from Sicily is about 120,000 tons. The richer sulphur ores of Sicily run from 30 to 40 per cent of sulphur. A considerable quantity is also imported from Japan.

The leading native sulphur deposits of the United States are located in Nevada, Utah, California, Wyoming, and Louisiana. While the amount of sulphur ore in the country is inexhaustible, the writer is informed by a New York dealer that not to exceed 3,000 tons are mined here annually, which, of course, does not include the amount extracted from pyrites. Respecting the Utah sulphur mines, which are located in the foothills of the Wasatch Mountains and in Beaver County, about 200 miles from Salt Lake City, the writer has received the following interesting data from Mr. C. F. G. Meyer, of St. Louis: The sulphur supply at these Utah mines is practically unlimited, and the price of the product is governed entirely by foreign markets. The sulphur is found in an immense bed, the ore beginning at the surface of the earth and extending down to unknown depths. This ore is of a very soft character, containing sand, gypsum, and gravel, and has from 15 to 95 per cent sulphur. The profitable ore is mined through open cuts and hauled on a tramway to smelters. The smelters are cast-iron retorts and hold a ton of ore. Each charge is hermetically sealed and the retort is subjected to 40 atmospheres of steam pressure. Under this heat the sulphur percolates, in the shape of liquid sulphur, through the foreign matter into a pot below, from which it is drawn off and passes into a distilling vat for the purpose of permitting all foreign substance to settle to the bottom of the tank: thence it is drawn off into wooden molds, holding about 200 pounds, and allowed to cool, after which it is passed through a grinding process in an attrition mill. The product obtained by the above process is about 99 per cent pure, and forms the flour of sulphur, which is extensively used, as already indicated. For obtaining what is commonly known as flowers of sulphur, which is chemically pure, the ground sulphur is passed through a resubliming vapor process.

Respecting any possible advantage to the horticulturist by purchasing sulphur refined in Europe in preference to that refined in the United States, a prominent sulphur refiner of San Francisco has kindly supplied the following facts:

The sulphur refined is mostly from imported Sicilian and Japanese products. While there exists the remnant of a former prejudice against California sulphur, it should be of interest and value to know that there is absolutely no difference between that manufactured here and that manufactured in France, Italy, Denmark, and other European countries. Both start with the same raw material coming from Sicily, the same apparatus is employed, and even experienced foreigners are hired to refine the brimstone in the identical manner in which it is treated in the above places. There comes to the horticulturist no advantage, therefore, to offset the present duty of $8 per ton levied on the refined imported sulphur, and our agricultural population, it is claimed, is duped when demanding French, Italian, or other European refined sulphur. The same manufacturer further states that Sicily sulphur of 98 per cent purity is at present admitted to the United States duty free, and that it can be ground or sublimed in this country and sold at a price below the cost of the imported foreign-refined sulphur. It is also said, as to the comparative value to the horticulturist of ground (flour) and of sublimed sulphur (flowers), that for ordinary purposes domestic ground or powdered sulphur, which averages less than 1 per cent of impurities, will answer all requirements in a wash, being finer than the imported, the only impurity being a neutral, inert volcanic ash. The sublimed sulphur, as before stated, is identical with the imported and contains little, if any, trace of anything but elementary sulphur. It is lighter in bulk and more stringy than ground sulphur (if examined under the microscope), but is not usually enough better for agricultural purposes to offset the difference in price. In other words, the difference in purity percentage between ground sulphur and sublimed sulphur is not in any way commensurate with the difference in price, and a great saving could be effected by substituting the former for the latter in ninety-nine cases out of a hundred.

To these views the writer would add that the flour of sulphur is certainly what should be used in the preparation of sprays. As to the relative value of flour of sulphur and flowers of sulphur for powdering vines for mildew, there is a difference of opinion among vine growers, the ease with which the fumes are given off being considered of prime importance in the treatment of this disease.[1]

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[1] Quotations on sulphur in March, 1899, were as follows: New York quotes flour of sulphur in 250 pound barrel lots at $2.20 per 100 pounds, 100 pound sacks at $2.15 per 100 pounds, and car loads in barrels at $1.80 per 100 pounds, and in sacks at $1.75 per 100 pounds, all f. o. b. A second New York firm quotes roll brimstone at $2 per 100 pounds; flour of sulphur, heavy, at $2.20, and light at $2.25 per 100 pounds by the barrel; sublimed flowers of sulphur at $2.37½ per 100 pounds, in carload lots, f. o. b.; roll brimstone, $1.70 per 100 pounds; flour of sulphur, heavy, 100 pound bags, $1.75; 250 pound barrels, $1.80 per 100 pounds; light, 175 pound barrels, $1.85 per 100 pounds; flowers of sulphur, sublimed, $2 per 100 pounds. San Francisco quotes powdered sulphur, sacks or barrels, by the car load at $1.50 per 100 pounds, less quantity at $1.60 per 100 pounds; sublimed (flowers of sulphur), sacks or barrels, car load lots, $1.75 per 100 pounds, less quantity, $1.85 per 100 pounds; roll, barrels only, $1.85 per 100 pounds; refined, barrels only (quality same as roll), $1.75 per 100 pounds; crude, sacks, $1.40 per 100 pounds.

CHAPTER XI.

PEACH VARIETIES AND NURSERY STOCK IN RELATION TO CURL.

COMPARISON OF PEACH VARIETIES.

It is a well-known fact that certain peach varieties are less susceptible to curl than others. When planting, many growers strive to select varieties which are known to be comparatively resistant. This has led nurserymen to select and grow as hardy varieties as possible, and such selection has resulted in cultivated varieties becoming to some extent more hardy than the majority of seedlings. Of 97 peach growers who have stated whether, in their opinion, seedling or budded trees are most affected by curl, 50 say that seedlings are most affected, 19 think budded trees are affected most, and 28 growers have observed no difference between budded and seedling trees in this respect.

In spite of the fact that some varieties of budded peaches are quite hardy, many of the finest peaches grown are much subject to curl. There are also varieties which are hardy in one locality and become very subject to the disease when grown under different conditions. There are, in fact, so many influences, such as season, soil, situation, etc., that it has been difficult to decide, except in a few cases, whether a variety may be fairly classed as hardy or susceptible. It is found by wide inquiry that a peach which is considered hardy in one portion of the country is not resistant to curl in another. The views of peach growers vary so widely respecting the hardiness of varieties that it has been thought best to give the results as obtained, rather than strive to draw from them any final conclusions. Of a large number of growers who have been asked whether early or late-blooming varieties are most affected, 70 have expressed their views. A majority, or 42 of these growers, think there is no difference between early and late blooming varieties, 23 believe early blooming varieties most subject to the disease, and only 5 believe the late bloomers most affected. It would seem that the late blooming varieties may be less liable to injury, owing to the increased warmth when they push in the spring, but the difference is certainly not well marked. Respecting the hardiness of early or late maturing varieties, there appears to be little difference from the replies to the circular letter. Among 79 peach growers who have expressed their views, 22 think early varieties most subject to the disease, 16 believe the late varieties most subject to it, and 41 think there is no difference.

Besides the facts respecting the hardiness of varieties gathered by a circular letter addressed to the peach growers of the country in 1893, the following list contains such information on this subject as it has been possible to glean from the publications accessible to the writer. In this list are tabulated 191 peach varieties and a few nectarines in relation to their resistance to curl. So far as possible the form of the glands, the season of ripening, and the adhesion of pit is shown.[1] The susceptibility to curl is shown in three columns—little susceptible, medium susceptible, and very susceptible. Every record for or against a variety has been obtained from a distinct source from all other records for that variety, and the list includes over 1,000 records. As a record under medium susceptible or very susceptible is against the variety, showing that it is subject to the disease, these two columns are added and the sum carried to a final column. This final column may thus be fairly contrasted with the first column, which gives the records of varieties little susceptible to curl. The entire list goes far to show that few varieties are practically free from curl in all localities, and that some of the finest varieties are very susceptible to it. (See for example the records under Crawfords Late, Crawfords Early, Elberta, Heath Cling, Lovell, etc.)

TABLE 43.—*Relations of peach varieties to peach leaf curl, with records of glands, time of ripening, and adhesion of pit.*

No.	Peach varieties.	Character of glands.	Season of ripening.	Adhesion.	Little susceptible.	Medium susceptible.	Very susceptible.	Total medium and very susceptible.
1	Aigle de mer, *Sea Eagle*	r	e	f		1		1
2	Albright	g	l	f	1			
3	Alexander	g	e	f	18	11	6	17
4	Alpha	r	e	c	2			
5	Amelia	r	e	f		2		2
6	Amsden	g	e	f	8	5	2	7
7	Austin	r	l	c		1		1
8	Beatrice	r	e	f			2	2
9	Beers (smock)	r	l	f	4	2	3	5
10	Bilyeaus Late	g	l	c		2	4	6
11	Bishops Early	g	e	f	1			
12	Bonanza	r	l	f	1		3	3
13	Boston				1			
14	Brandywine	g	l	f	2	2	1	3
15	Brett (Mrs.)	r	l	c		1		1
16	Brices Early		e			1		1
17	Briggs May	g	e	f	4	4	3	7
18	Bronson (seedling)	r	l	f	1		1	1
19	California (cling)			c			2	2
20	Canada	g	e	c	4			
21	Cape Clingstone			c		1		1
22	Cape Freestone			f		1		1
23	Cape Pavie				1			
24	Chairs (choice)	r	l	f			2	2

[1] In some instances it is known that the form of the glands of a variety is reported differently by different writers, and on this account a few errors may have crept into the table here given, but where it has been possible to determine such questions by referring to several authors it has been done. Unfortunately the writer has not been able to study this matter in the orchard except for a portion of the varieties given.

TABLE 43.—*Relations of peach varieties to peach leaf curl, with records of glands, time of ripening, and adhesion of pit*—Continued.

No.	Peach varieties.	Character of glands.	Season of ripening.	Adhesion.	Little susceptible.	Medium susceptible.	Very susceptible.	Total medium and very susceptible.
25	Charlotte				4		3	3
26	Chinese (cling)	r	l	c		2	10	12
27	Clemence	r	l	f	1			
28	Columbia	r	l	f	1		1	1
29	Comet	r	l	f	1	1		1
30	Cooledge (favorite)	g	e	f	1	2	3	5
31	Cots (cling)			c			1	1
32	Cranes Early Yellow		e		1			
33	Crawfords Early	g	e	f	29	25	26	51
34	Crawfords Late	g	l	f	10	18	27	45
35	Crimson Beauty	r	e	c	1			
36	Crocketts White	r	l	f		1		1
37	Crosby	r	l	f		1		1
38	Doctor Hogg	r	e	f		1		1
39	Downing						1	1
40	Dumont	r	e	f	1			
41	Early Albert	g	e	f			1	1
42	Early June		e			1	1	2
43	Early May		e				1	1
44	Early (red) Rareripe	s	e	f	1			
45	Early Rivers	r	e	f	1	3	7	10
46	Early Rose		e				1	1
47	Early Slocumb		e				1	1
48	Elberta	r	e	f	1	5	30	35
49	Ellison	r	l	f		2	1	3
50	Florin		e	f	2			
51	Fords Late White	g	l	f		1	1	2
52	Foster	g	e	f	12	7	3	10
53	Fox (seedling)	g	l	f			1	1
54	General Bidwell		l	f		1	5	6
55	George the Fourth	g	e	f	2	2		2
56	Georges Late		l		2	3	1	4
57	Globe	g	e	f	1	3	3	6
58	Gold Dust					1		1
59	Golden Cling			c			2	2
60	Golden Drop	r	l	f	4			
61	Governor Briggs	g	e	f	1			
62	Governor Garland		e	f	1			
63	Governor Wood					1		1
64	Grave Cling			c	1			
65	Grosse Mignonne	g	e	f	1	2	3	5
66	Grover Cleveland		l	c			2	2
67	Hales Early	g	e	f	11	4	13	17
68	Hales Late		l		1	1		1
69	Hardy White Tuscany						2	2
70	Hardy Yellow Tuscany				4			
71	Heath Cling	r	l	c	4	3	24	27
72	Heath Free			f	5	1	1	2
73	Henrietta, *Levys Late*	r	l	c	2			
74	Hills Chile	r	l	f	2	5	7	12
75	Honest Abe		e		7	1		1
76	Honey Cling			c			2	2
77	Hood Cling			c		1		1
78	Imperial (early)	g	e	f		1		1
79	Indian Blood (cling)	r	l	c			9	9
80	Ingles (seedling)				1			
81	Ironclad				1			
82	Jacques Rareripe	r	l	f	1		3	3
83	Japan Blood				1		1	1
84	Jenny Worrell				1			
85	Jenny Worthen	r	e	f	1			
86	Jones (seedling)	g	l	f	2			
87	Kalamazoo	r	e	f	1			
88	Kennedy (cling)			c	1			
89	Keyport White				1			
90	Kites Honey						2	2
91	Lady Palmerston	r	l	f		2		2
92	La Fleur	r	l	f		1	1	2
93	La Grange			f			5	5
94	Large Early York, *Honest John*	s	e	f	6	4	2	6
95	Large White Cling	g	l	c	1	2	3	5
96	Large Yellow						1	1
97	Late Admirable	g	l	f			2	2
98	Late Barnard	r	l	f	1	2	8	10
99	Late October		l				1	1

TABLE 43.—*Relations of peach varieties to peach leaf curl, with records of glands, time of ripening, and adhesion of pit*—Continued.

No.	Peach varieties.	Character of glands.	Season of ripening.	Adhesion.	Little susceptible.	Medium susceptible.	Very susceptible.	Total medium and very susceptible.
100	Late Rareripe	g	l	f			1	1
101	Lemon Cling	r	l	c	5	2	1	3
102	Lemon Free	r	l	f	1			
103	Lewis Seedling	r	e	f	2		1	1
104	Lewis Stanley					1		1
105	Lola (Miss)	r	e	f			1	1
106	Lord Palmerston	g	l	f	1	1	1	2
107	Lovell	g	l	f	1	2	13	15
108	Lovetts White	r	l	f			2	2
109	Lovetts Wonder					1		1
110	Lyons		l	c			1	1
111	Marys Choice				1	2		2
112	McClish					1		1
113	McCollister				1			
114	McCowan (cling)			c			1	1
115	McDevitts (cling)			c	2	1	1	2
116	McKevitts (cling)			c	1	2	1	3
117	Millers (seedling)						1	1
118	Moore	g	e	f		1		1
119	Morris White	r	e	f	1	5	2	7
120	Mother Porter		l	c	1			
121	Mountain Rose	g	e	f	10	5	1	9
122	Muir	r	l	f	9	11	1	15
123	Newhall		e	f	1			
124	Nichols Orange			c	3			
125	Noblesse	s	e	f		1		1
126	Oldmixon Cling	g	l	c	6	3	1	4
127	Oldmixon Free	g	l	f	1	1	10	11
128	Onderdonk	r	e	f	2		1	2
129	Orange Cling	r (?)	l	c	7	2		2
130	Oregon				2			
131	Pallas	g	e	f			1	1
132	Peen-To, *South China Saucer*	r	e	f			2	2
133	Perkins					1		1
134	Picquets Late	r	l	f	3	3	2	5
135	Plummer						1	1
136	Pratt	r	e	f	1			
137	President	g	l	f	1			
138	Red Ceylon						1	1
139	Red Cheek	g	l	f	1		1	1
140	Red Madeline				1			
141	Reeds Crawford	g	e	f			1	1
142	Reeds Early Golden						1	1
143	Reeves Favorite	g	l	f	2	4		4
144	Reeves Golden Yellow				1			
145	Reine de vergers, *Orchard Queen*	r	l	f			1	1
146	Richmond	r	e	f	2			
147	Roseville (cling)	g	l	c		1		1
148	Royal George	s	e	f	2		1	1
149	Runyons Orange	g	l	c	1	2	1	3
150	Sallie Worrell	s	e	f			1	1
151	Salway	r	l	f	11	12	13	25
152	Schumacher						1	1
153	Sellers Cling			c	5	1		1
154	Sellers Free			f	1	1	2	3
155	Sener	r	e	f	1			
156	Shinns Rareripe				1			
157	Shipleys (late red)	g	l	f			2	2
158	Silver Twig						1	1
159	Smocks Free, *St. George*	r	l	f	2	1		1
160	Smocks Late	r	l	f	7	8	3	11
161	Snow	r	l	f	3			
162	Snows Orange	r	e	f	2	4		4
163	St. John	g	e	f	5	4	3	7
164	Steadly	r	l	f			2	2
165	Stevens Rareripe	r	l	f	2			
166	Stilsons		l	f		1		1
167	Strawberry Cling			c		2	4	4
168	Stump the World, *Jersey Stump*	g	l	f	7	10	6	16
169	Sturtevant	g	e	f		1		1
170	Summer Snow	g	l	c	1			
171	Susquehanna	r	l	f			6	6
172	Susquehanna No. 2				5	4	1	5
173	Switzerland	g	l	f			1	1
174	Tillotson (early)	g	e	f	3	2		2

TABLE 43.—*Relations of peach varieties to peach leaf curl, with records of glands, time of ripening, and adhesion of pit*—Continued.

No.	Peach varieties.	Character of glands.	Season of ripening.	Adhesion.	Little susceptible.	Medium susceptible.	Very susceptible.	Total medium and very susceptible.
175	Thissells White	.....	.....	.....	.....	.....	4	4
176	Troths (early)	g	e	f	1	1	4	5
177	Tuskena, *Tuscan Cling*	.....	.....	c	2	2	.....	2
178	Ulatis	r	e	f	.....	2	.....	2
179	Wager	r	l	f	2	2	1	3
180	Wards Late Free	r	l	f	2	1	2	3
181	Waterloo	r	e	f	2	2	1	3
182	Wheatland (early)	g	e	c	1	2	2	4
183	White English	.....	.....	.....	1	.....	.....	.....
184	White Melocoton	.....	.....	.....	1	1	2	3
185	Wilcox Cling	.....	.....	c	.....	.....	1	1
186	Wiley	.....	.....	.....	2	.....	.....	.....
187	Wilkins Cling	.....	.....	c	1	4	7	11
188	Willow (peach)	.....	.....	.....	1	.....	.....	.....
189	Winters	.....	.....	.....	.....	.....	1	1
190	Wonderful	r	l	f	1	2	3	5
191	Yellow Rareripe	g	e	f	.....	.....	1	1
	NECTARINES.							
192	Boston	g	l	f	2	.....	.....	.....
193	Early Newington	s	e	c	1	1	.....	1
194	Hardwicks Seedling	g	e	f	3	.....	.....	.....
195	Lord Napier	r	e	f	2	2	.....	2
196	Rivers Orange	r	l	f	.....	.....	1	1
197	Victoria	r	e	f	.....	.....	1	1

A digest of 98 reports on peach varieties in respect to the form of glands, earliness or lateness of ripening, and adhesion or nonadhesion of the pits, as these characters may or may not be related to susceptibility to curl, is given in the following table.

TABLE 44.—*Comparative susceptibility of 98 peach varieties in relation to form of glands, earliness or lateness of ripening, and adhesion or nonadhesion of pit.*

Character of glands.	Period of ripening and adhesion of pit.	Number of varieties—		Total varieties—	
		Very susceptible.	Little susceptible.	Very susceptible.	Little susceptible.
Reniform, 50 varieties	Early	8	12	24	26
	Late	16	14		
	Free	20	23		
	Cling	4	3		
Globose, 42 varieties	Early	9	12	21	21
	Late	12	9		
	Free	19	18		
	Cling	2	3		
Serrate, 6 varieties	Early	.....	5	.....	6
	Late	.....	1		
	Free	.....	4		
	Cling	.....	2		

In the above table a most striking correlation appears between peach varieties with serrate leaves and susceptibility to curl. All the six varieties for which full information could be obtained are little susceptible, which is all the more interesting from the fact that the varieties with serrate leaves have long been known to be very subject to mildew. A list of seven such varieties for which the characters of the leaves have been obtainable is here given in contrast to the above.

TABLE 45.—*List of peaches subject to mildew.*

Name.	Characteristics.		
	Glands or leaves.	Ripens.	Adhesion.
Briggs May	Serrate	Early	Free.
Downing	do	do	Do.
Early Anne	do	do	
Early York	do	do	Free.
Red Rareripe	do	do	Do.
Royal George	do	do	Do.
Tillotson	do	do	Do.

Some correlations of the shape and absence of leaf glands with the time of maturity of the fruit and the adhesiveness of the pit have been compiled from over 400 varieties, and these correlations are shown in the table which follows.

TABLE 46.—*Correlation of shape or absence of the leaf glands of the peach with the period of maturity of the fruit and the adhesiveness or nonadhesiveness of the pit.*

	Reniform glands.	Globose glands.	Serrate leaves, or without glands.
Early	46	130	32
Late	140	50	4
Free	124	166	32
Cling	62	14	4
Early free	35	120	28
Late free	89	46	3
Early cling	14	10	4
Late cling	48	4	1

This table shows that of 208 early-fruiting varieties, 46 have reniform glands, 130 globose glands, and 32 serrate leaves; while of 194 late varieties, 140 have reniform glands, 50 globose glands, and 4 serrate leaves. In other words, of the early varieties given there are nearly three times as many with globose glands as with reniform glands. On the other hand, of the late varieties, there are nearly three times as many with reniform glands as with globose glands. The table also shows that there are 120 early free globose to 35 early free reniform varieties, while there are 89 late free reniform to 46 late free globose varieties. This table is given as a step in the direction of future investigations along this line, which appear warranted by the correlations found to exist between the form of glands, the date of maturity, the date of bloom, etc., and the little or great susceptibility of varieties to curl and mildew. Such facts may prove of much importance when taken in connection with future work in originating hardy or otherwise desirable varieties by cross breeding.

The preceding records, showing the comparative susceptibility to curl of nearly 200 varieties of peaches, will enable the grower who contemplates setting an orchard to make his choice of varieties advisedly. As already said, however, many superior varieties are very subject to curl, hence the practical methods of preventing it as detailed in this bulletin make it possible to successfully grow the most susceptible varieties in the most unfavorable situations, so far as this disease is concerned. Such varieties are in fact saved to the peach industry of large sections of the country by means of this preventive treatment. The Elberta, a favorite in both the East and the West, and the Lovell, a favorite in California, may now be cultivated to any desired extent in regions from which they have heretofore been practically excluded by curl—advantages that are certainly not the least of those arising from the recent work in the treatment of that disease.

As a striking illustration of what has just been said, the following, contained in a letter recently received by the writer from a gentleman in northern California, is given: He states that the Lovell variety will curl in his locality so as to be of little use, if not sprayed. One of his neighbors, who had a small orchard of that variety, stated that he intended grafting the trees to some other peach, as they did so badly on account of curl, but our correspondent advised the winter use of Bordeaux mixture, cautioning the grower to spray his trees thoroughly. This was done, and the trees bore a fine crop of fruit. The work was so satisfactory that instead of grafting over the Lovell variety a block of Fosters was grafted to the Lovell, the variety with which the detailed experiments of the writer were conducted in the Sacramento Valley in 1894 and 1895.

TREATMENT OF NURSERY STOCK.

The nursery is not only the source of the orchard, but also very largely the source of orchard diseases, and its health is therefore of common interest to the orchardist and nurseryman. Could a nursery be freed from curl, many orchards planted from it would not suffer from the disease for years, especially if isolated. There is little doubt that curl has been largely disseminated throughout the world by means of nursery trees.

It has been supposed that the main source of spring infection of trees was from the perennial mycelium already in the buds, and were this hypothesis true nurserymen could scarcely hope to procure buds for their seedlings which were free from this disease. The spray work upon curl has shown, however, that the single external application of a fungicide is sufficient to prevent 95 to 98 per cent of curl when the treatment has been thoroughly made. This appears to indorse the view that at least 98 per cent of the spring infections are, as elsewhere claimed in this bulletin, from spores upon the tree, probably largely resting upon or within the bud scales themselves.

The facts given are sufficient to warrant some general considerations and recommendations:

(1) The trees from which buds are to be selected should be thoroughly sprayed with strong copper sprays before the buds are removed. (2) Where the last year's branches are removed as a whole, the buds to be cut out while budding is in progress in the nursery, the bud-bearing shoots should be thoroughly dipped once or twice in a well-made Bordeaux mixture before being taken to the nursery.[1] (3) After the nursery trees are budded they should be sprayed with Bordeaux mixture, no portion of the tree or newly inserted bud being omitted. This treatment should be repeated as often as found advisable, and the more thorough the better, especially after the removal of the seedling top.

The writer feels that these recommendations are for the best interests of the nurseryman, as well as the prospective purchaser. The Bordeaux mixture will not only prevent the injurious action of the disease, but will increase the diameter and height of the trees more than sufficient to warrant the outlay, and will make them in every way more valuable to the nurseryman and orchardist.[2]

Messrs. Dressel Bros., proprietors of the Hart Nurseries, Hart, Mich., sprayed their peach nursery in the spring of 1894 with Bordeaux mixture. They reported good success from this work in the control of curl. In the spring of 1895 they undertook an experiment with the use of 5 pounds of copper sulphate, 10 pounds of lime, and 45 gallons of water, this experiment including 110,000 nursery peach trees one year old and of several varieties. The sprayed trees were treated twice, the first spraying being done April 1 and the second April 16. On July 21 the foliage of sprayed and unsprayed trees was estimated, and it was found that while none of the leaves had fallen from the sprayed trees, 15 per cent had fallen from those unsprayed. There were 100,000 sprayed trees and 10,000 unsprayed trees in this experiment.

Dressel Bros. state respecting this experiment that they considered the work very successful, that their nursery stock showed good results, and that the work would be continued. The sprayed stock showed an increase in height. In 1897 they again treated their trees,

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[1] This is a matter calling for careful and detailed experiments. It should be comparatively easy to dip such shoots one, two, three, or four times, and to have the buds from such shoots inserted in seedling trees of separate nursery rows. By such method a record could be kept of the number of trees showing curl upon the pushing of the first leaves. In this manner much could be learned about the disease, and a standard could be determined for the treatment of the shoots to be used as the source of buds.

[2] In relation to the added size and weight of sprayed over unsprayed nursery trees, the reader is referred to Bull. No. 7, Division of Vegetable Pathology, U. S. Dept. of Agr., 1894. This bulletin relates to the effect of spraying with fungicides on the growth of nursery stock.

leaving unsprayed trees for comparison. The trees of the sprayed block, it is stated, were very nice and straight and made a good growth, and there was no curl, it being hard to find a leaf affected, while growth started well and continued thrifty throughout the season. The unsprayed trees on the other hand curled so badly that many were crooked and stunted, not attaining the height of the sprayed trees within a foot, and a good many were worthless. The treated trees were sprayed twice in the month of March, 1897. They note that Bordeaux mixture, to do its work properly, should be on the trees for seven or eight days without rain.

SUMMARY.

(1) Peach leaf curl has a world-wide distribution, occurring in every region in which the peach is grown. In humid localities it is a leading hindrance to peach culture, and in portions of the Pacific coast States it has greatly limited the extent of the industry.

(2) The orchard losses from peach leaf curl vary from a small amount of fruit to the entire crop, while in many instances young trees are killed. The national losses from this disease will amount to $3,000,000 annually.

(3) Curl is caused by a parasitic fungus known as *Exoascus deformans*, the ravages of which are largely dependent upon the atmospheric conditions prevailing while the trees are leafing out. Rains and cold weather at that time tend to increase the severity of the trouble by favoring the growth of the parasite and interfering with the proper functions of the host. For these reasons orchards near large bodies of water and in low or damp situations are more subject to curl than those in dry regions or in elevated situations.

(4) Most of the spring infections of peach leaves are due to the spores of the fungus and not to a perennial mycelium, as formerly held, hence the efficacy of sprays.

(5) Curl was first successfully treated in California during the period from 1880 to 1885, the success depending upon the application of fungicides to the dormant trees. The disease was not successfully treated in Europe for ten years after its prevention in the United States.

(6) The copper sprays are now found to be more effective than the sulphur or other sprays first used. Of the various sprays experimented with, Bordeaux mixture, in the proportion of 5 pounds copper sulphate, 5 pounds lime, and 45 gallons of water, gave the best results, the equal weights of the copper sulphate and lime being most effective when the mixture is applied shortly before the opening of the blossom buds. When it is desired to increase the durability of a spray by increasing the proportion of lime, the application should be made earlier or equal proportions of copper and lime should be maintained.

The total saving of foliage increases with the increase of copper sulphate when the amount of lime remains constant, but the average saving per pound of copper sulphate decreases with the increase of copper used.

(7) In the treatment of peach leaf curl, from 95 to 98 per cent of the spring foliage was saved by spraying. A net gain of 600 per cent in foliage over that retained by adjoining unsprayed trees resulted in the case of several different sprays. Bordeaux mixture when applied to the dormant tree increased the weight and starch-producing power of the leaves, and the sprayed trees showed a great gain over the unsprayed in the number and quality of the fruit buds they produced for the following year, the gain in the number of spur buds being over 100 per cent in some cases. The lower limbs of sprayed trees showed a marked gain over those of unsprayed trees as compared with the upper limbs in both the number of fruit buds and lateral shoots they produced.

(8) The average value of the fruit per tree in rows treated with the most effective Bordeaux mixture ranged as high as \$6.20 above that per tree in adjoining untreated rows, or the equivalent of a net gain of \$427.80 per acre where trees are planted 25 by 25 feet. Over 1,000 per cent net gain in the fruit set has resulted in the use of some of the more effective sprays.

(9) The trees should be sprayed each season, as the experiments proved that treatment one season will not prevent the disease the following year. Spraying should also be done even though the trees may not be expected to bear, as the loss of the crop of leaves is shown to result in as great a drain upon the trees as does the maturing of one-half to two-thirds of a crop of fruit.

(10) The work demonstrates that peach leaf curl may be cheaply and easily prevented in California, in western Oregon and Washington, and along the east shore of Lake Michigan, where curl causes great loss, as well as in all other peach-growing sections of the United States.

(11) The copper and lime sprays are less injurious to the trees than those composed of sulphur and lime. The use of lime in winter sprays has proven an advantage in enabling the workmen to see their work and complete it with greater thoroughness than would otherwise be possible. A proportional increase of both lime and copper sulphate is recommended for wet regions, and for very wet localities a second winter spraying is advised.

(12) Cyclone nozzles with lateral or diagonal discharge are best adapted to the work.

(13) The proper time for winter spraying and the number of applications depend to some extent on the locality, season, etc., but active sprays are likely to do most good if applied from one to three weeks before the opening of the blossoms in spring. The proper time to

apply sprays for the prevention of curl is in dry, calm weather, and during the middle of the day, in order to avoid dew or frost upon the limbs as much as possible.

(14) Of nearly 200 peach and nectarine varieties considered with a view of determining their comparative susceptibility to curl, it was found that very few were wholly free from the disease and that some were very subject to it. Some of the choicest varieties, as the Elberta and Lovell, are seriously affected, but it has been demonstrated that a single winter treatment will prevent the disease upon even these varieties. It may be thus fairly claimed that the spraying methods recommended will save to the peach industry some of its finest varieties, as well as result in the saving of foliage and crops already indicated.

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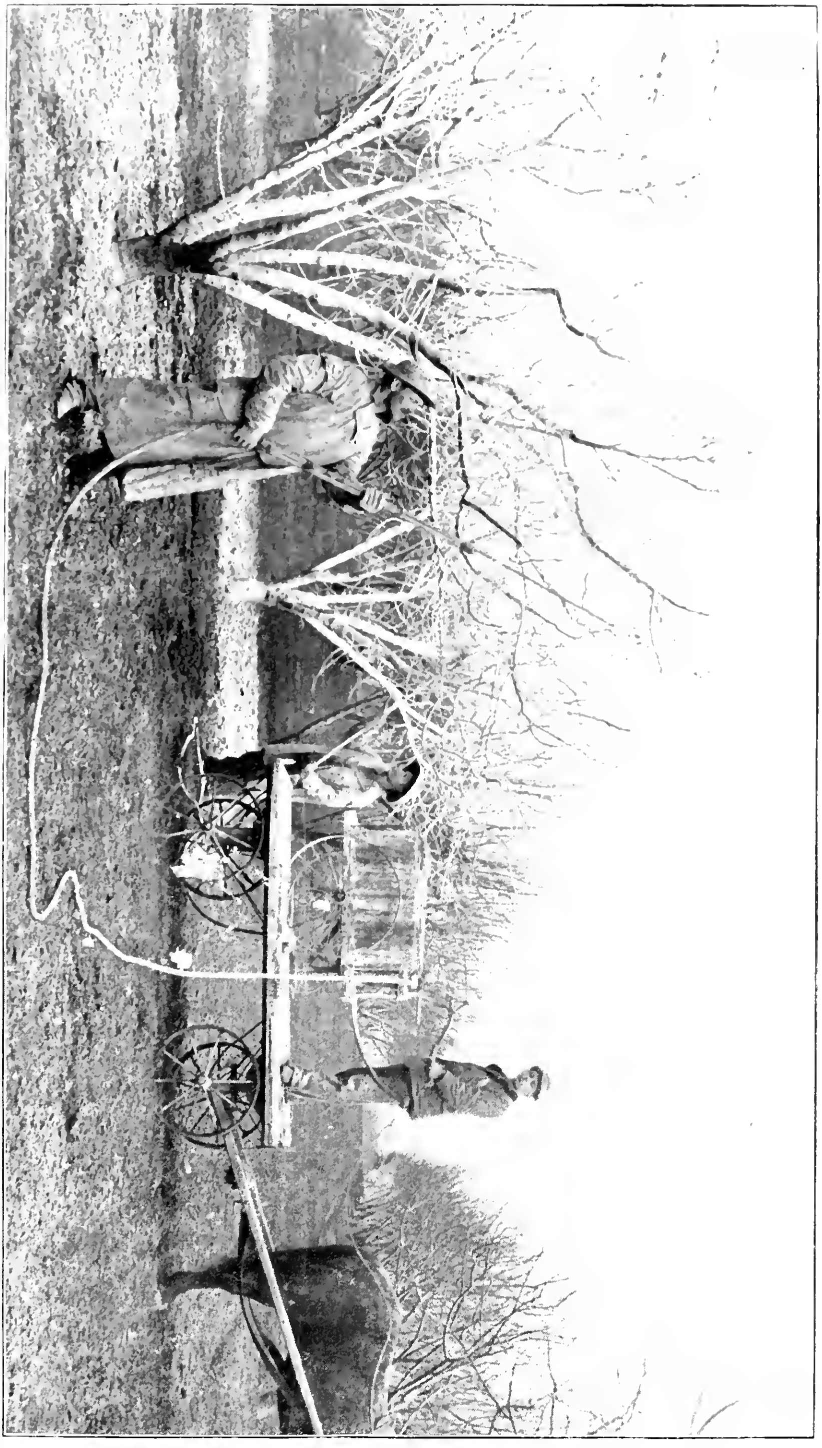
DESCRIPTION OF PLATE XXVI.

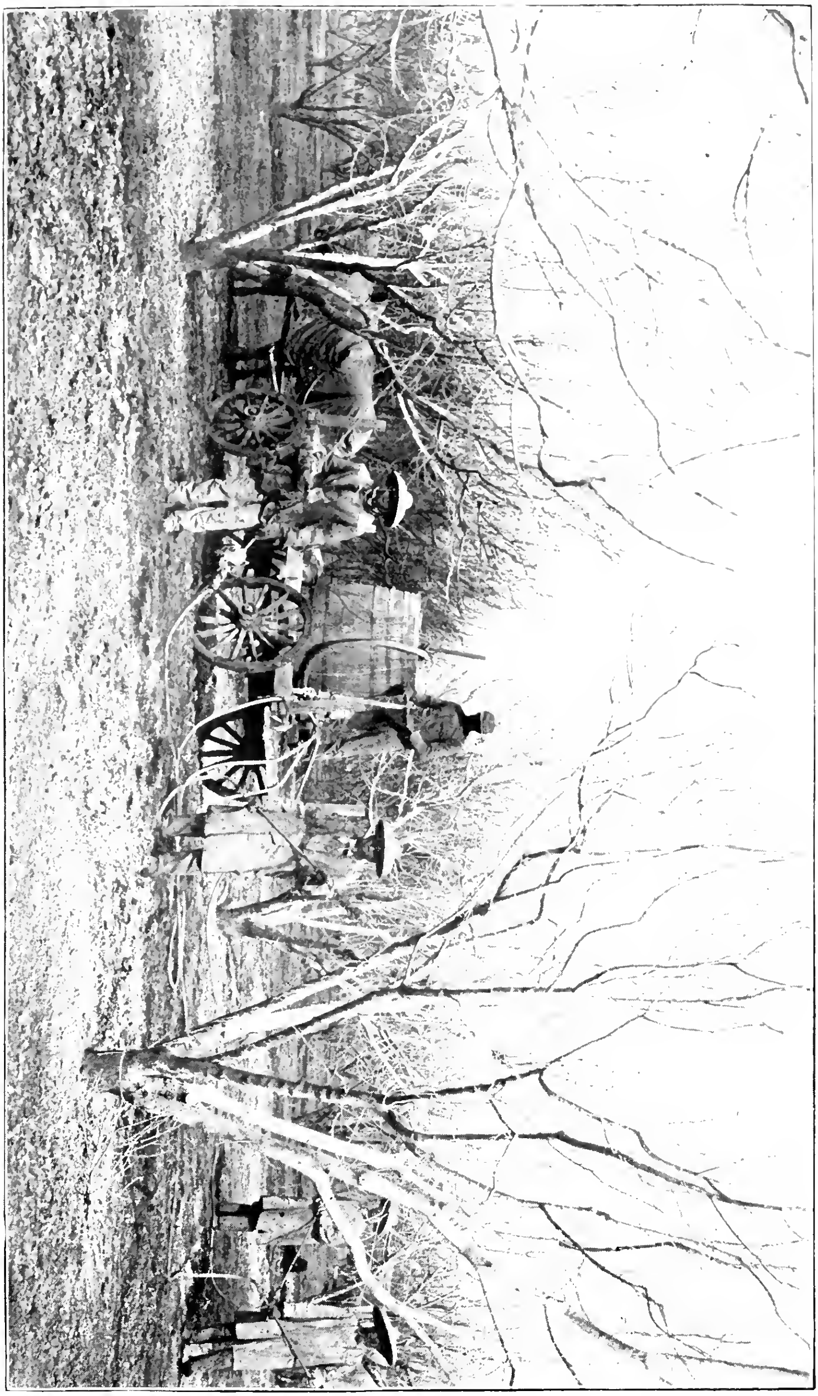
A suitable outfit for spraying small orchards. One horse, two men, and a boy spray two trees at a time. This scene represents the experimental spraying outfit used by the writer in the Rio Bonito orchard.



OUTFIT FOR SPRAYING SMALL ORCHARDS.

DESCRIPTION OF PLATE XXVII.

Spraying 4 trees at a time, with 5 men and 2 horses. There is here used a 300-gallon spray tank and long-lever (Gould), brass-lined piston pump, which has sufficient capacity to supply 4 nozzles, 1 man pumping. The horses are protected by means of gunny sack covers. The Chinese hats in use furnish good protection to the eyes and neck, but are too stiff for the most convenient work under limbs.

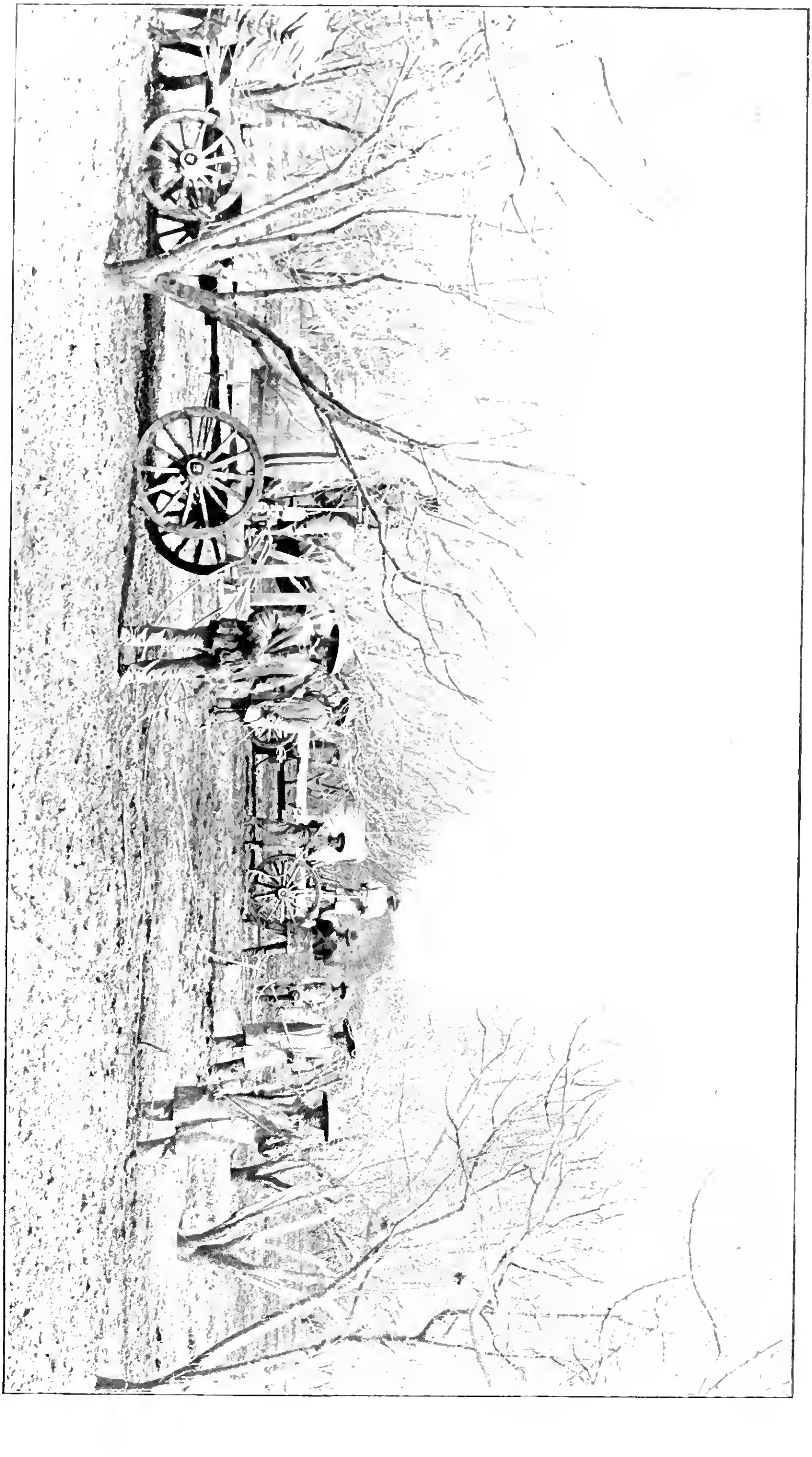


OUTFIT FOR SPRAYING MEDIUM-SIZED ORCHARDS.

Treating four trees at a time.

DESCRIPTION OF PLATE XXVIII.

Regular winter spray work in the Rio Bonito orchard. Eight trees are here being sprayed at one time, with 10 men and 4 horses. The trees being treated are well advanced, the buds being much swollen, although not yet open. If work is thoroughly done at this stage of bud development the results will commonly prove satisfactory; but an active spray should be used, such as the eau celeste, or Bordeaux mixture with a low percentage of lime and high percentage of copper sulphate. Such sprays should not be applied, however, after the opening of the blossoms. Earlier spraying is better, the chemicals in such cases doing less harm to the tree and having a longer time to reach all spores that endanger the new growth.



SPRAYING IN LARGE ORCHARDS.

Treating eight trees at a time.

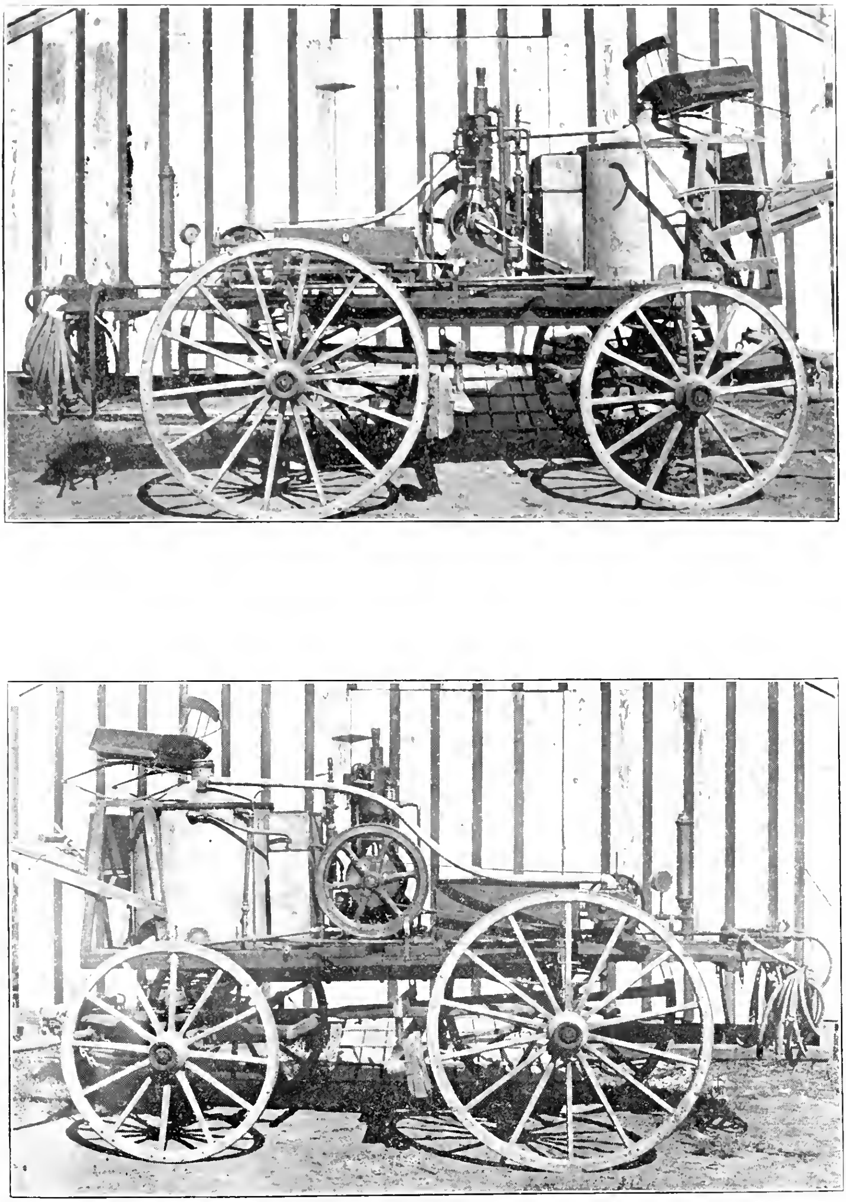
DESCRIPTION OF PLATE XXIX.

A power sprayer in use in a young orchard at Santa Barbara, Cal. This sprayer was built by the Union Gas Engine Company, San Francisco.

POWER SPRAYER IN USE AT SANTA BARBARA, CAL.

DESCRIPTION OF PLATE XXX.

Views of the right and left sides of the Gunnis power sprayer of San Diego, Cal. This sprayer is one of the lightest, most compact, and most practical power sprayers in use for general orchard work. It supplies 2 or 4 lines of hose, as may be desired. A tender is commonly used to carry the spraying materials to the orchard, where an extra rotary pump, worked by the same power as the spray pump, rapidly transfers the spray to the tank of the spray wagon. Such an outfit is adapted to extensive orchard work. Mr. H. R. Gunnis, San Diego, Cal., is the owner and operator of this machine.



RIGHT AND LEFT VIEWS OF POWER SPRAYER, SAN DIEGO, CAL.

BULLETIN No. 21. V. P. P.—74.

U. S. DEPARTMENT OF AGRICULTURE.

DIVISION OF VEGETABLE PHYSIOLOGY AND PATHOLOGY.

B. T. GALLOWAY, Chief.

TWO DISEASES OF RED CEDAR, CAUSED BY POLYPORUS JUNIPERINUS N. Sp. AND POLYPORUS CARNEUS Nees.

A PRELIMINARY REPORT.

BY

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WASHINGTON:

GOVERNMENT PRINTING OFFICE.

1900.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
DIVISION OF VEGETABLE PHYSIOLOGY AND PATHOLOGY,
Washington, D. C., April 6, 1900.

SIR: I respectfully transmit herewith a paper on two diseases of red cedar, giving the results of investigations by Dr. Hermann von Schrenk, of the Shaw School of Botany, St. Louis, Mo., and special agent of this Division. The growing interest in forestry and forestry problems has brought about a demand for more information on the many diseases to which timber is subject. In order to obtain a better understanding of the diseases Dr. von Schrenk was engaged the 1st of July last to extend a series of investigations which had been inaugurated at the Shaw School of Botany. Through the kindness of Dr. William Trelease, director of the school named, a plan of cooperation has been effected, which it is believed will result in much benefit to the Department.

This paper is the first of a number on timber diseases that we hope to issue, and I respectfully recommend that it be published as Bulletin No. 21 of this Division.

Respectfully,

B. T. GALLOWAY,
Chief of Division.

Hon. JAMES WILSON,
Secretary of Agriculture.

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TWO DISEASES OF RED CEDAR, CAUSED BY POLYPORUS JUNIPERINUS N. Sp. AND POLYPORUS CARNEUS NEES.—A PRELIMINARY REPORT.

INTRODUCTION.

Of the eight or more species of Juniperus in the United States, only two, the red cedar (*Juniperus virginiana*) and Southern red cedar (*J. barbadensis*), are of general commercial importance. The former is of quite general distribution throughout the northeastern United States,[1] its habitat extending from southern Nova Scotia and New Brunswick south to Florida, and west to the Dakotas, central Nebraska, Kansas, and Oklahoma. The Southern species occurs in the South Atlantic and Gulf Coast regions, extending southward through Florida.

Red cedar has long been valued because of its beautiful, aromatic, and durable wood. It is used to a considerable extent for interior finishing of houses, for sills, in the manufacture of lead pencils, and for cabinetwork, and is admirably adapted for chests and wardrobes. The wood is very resistant to the ordinary agents of decay, and on this account is much used for fence posts, and for other purposes where wood which is durable is desirable. The trees are slow growers and do not live to be very old. They are liable to be attacked by fungi after they have reached the age of fifty to seventy-five years, and these weaken the trunk and destroy the wood.

An investigation of the nature of the diseases of forest trees must necessarily extend through many years, for, to establish the absolute connection between one of the higher fungi and the effects which its mycelium produces in a tree, it is imperative that the disease be first produced in a healthy tree. This requires a long period, owing to the slow growth of the fungi, and for this reason, therefore, the investigations from a pathological standpoint are as yet far from complete. The following data are drawn largely from observations, and, owing to the conditions under which the work was necessarily carried on, many

[1] Bull. No. 17, Division of Forestry, U. S. Dept. of Agr., and Sargent, C. S., North American Silva, 1896, Vol. X, p. 94.

of the observations are also incomplete. Owing to the large area over which the trees grow, the conditions are very varied. Moreover, the opportunities for obtaining material are restricted to localities where the timber is cut for commercial purposes, and these localities and the manner in which the trees are cut are often unfavorable to research.

The writer is under obligations to Mr. W. B. Earthman, of Murfreesboro, Tenn., and Mr. Fred Heim, of St. Louis, for courtesies which they extended to him while pursuing his studies in their localities, and also to Dr. W. G. Farlow and Prof. L. M. Underwood for their courtesy in allowing him to examine their herbaria of Polypori.

WOOD OF THE RED CEDAR.

The wood of red cedar is rather light and soft and its tensile strength is not great. The heartwood is a deep red; the sapwood is very narrow and very white, contrasting markedly with the dark heartwood; the annual rings are very narrow, owing to the slow growth of the tree (the trunk shown in Pl. III has 65 rings, of which 16 belong to the sapwood). There are no resin ducts, as in the wood of the pine, but numerous isolated resin cells are scattered throughout the annual rings, and in the heartwood these are generally filled with a hardened resin.

GENERAL REMARKS ON THE DISEASES OF THE RED CEDAR.

Comparatively few diseases of the red cedar have heretofore been described. The most important fungi attacking this tree cause the so-called cedar apples, these being due to species of Gymnosporangium. The mycelia of these fungi flourish in the wood of the youngest branches and stimulate the cambial cells, causing them to grow very rapidly and form swellings or tumors,[1] and in one case they have been known to cause a witches' broom. The influence of these fungi on their host is not marked. They deform a few branches, but unless very plentiful do but little damage.

The mycelia of two fungi grow in the heartwood of many of these trees and bring about characteristic changes which render the wood unfit for lumber. In some cases entire car loads of cedar posts shipped from Tennessee and Missouri have been found to be so badly rotted by one or the other of these forms as to be of little value. One dealer in cedar lumber estimates that at least 60 per cent of the trees in his locality are defective owing to these fungi. A careful study of the trees in the neighborhood of Murfreesboro, in central Tennessee, and also of those in southern Missouri showed that both forms of decay were present in each region. Very few insects bore into the heart-

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[1] Wörnle, Paul. Anatomische Untersuchung der durch Gymnosporangium-Arten hervorgerufenen missbildungen (Forst. Naturwiss. Zeitsch., 1894, Vol. III, p. 68).

wood, the only one found in the investigations here described being a large carpenter bee, which made long tunnels through the entire length of the trunk. Here and there a few borers get in after the tree dies, as shown in Pls. V and VI.

WHITE ROT OF THE RED CEDAR (POLYPORUS JUNIPERINUS N. SP.).

Of the two forms of fungi attacking the red cedar the most striking is the one which ultimately causes long holes in the heartwood. These holes often unite and thus make a tube through the entire trunk. The trees attacked by this disease are seldom less than 25 years old and generally are much older. When a diseased tree is cut down several holes are found in the heartwood, the size of these varying according to the stage of decay. (Fig. 1 and Pl. III.) At first the holes are separated by long stretches of wood, which is apparently unchanged. A close examination, however, shows that this wood is not as deep a red as is the sound wood, but has become somewhat of a red brown. The holes themselves are coated with a brilliant white lining (Pl. II), which presents a striking contrast to the deep red of the heartwood. The layer of sound wood immediately outside the white lining has the same red brown color as the wood between the holes, and the successive rings outward from the hole show all shades of color from the red brown to the pure red of the sound wood. The holes are from 3 to 6 inches long and of variable width. They are partially filled with a velvety mass of reddish yellow mycelium, which glistens with many drops of a colorless liquid, apparently exuded by the hyphæ, and with masses of wood fibers of a reddish brown color in the last stages of disintegration. From the ends of the holes long, glistening white fibers project into the cavity, and on the longitudinal walls these fibers extend from end to end. (Pl. II.) The fibers consist of almost pure cellulose of the original wood elements, the encrusting lignin substances having been removed. In

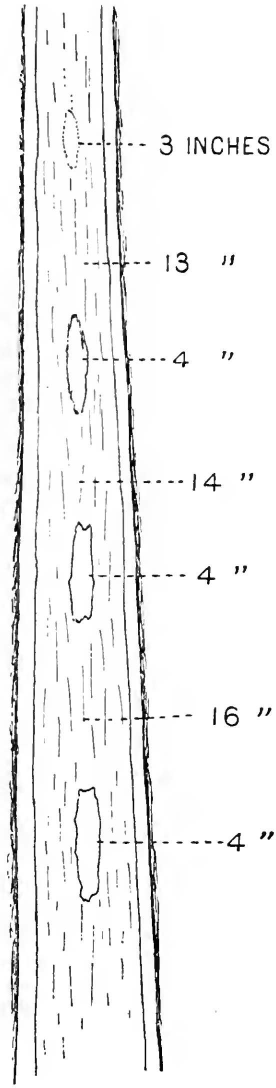

FIG. 1.—Longitudinal section of a cedar log showing position of holes caused by *Polyporus juniperinus*.

large holes the amount of wood fiber which has been reduced to cellulose is very considerable (often as much as 300 grams of this cellulose is present). The masses of cellulose consist of individual wood cells, which can be pulled out with a needle. The whole mass is very soft and can be squeezed between the fingers much like the wood pulp in a paper mill after treatment with zinc chloride. In older holes the white lining is almost absent (see largest hole, Pl. III), the walls being covered with a felt of soft brown mycelium, which often assumes very fantastic shapes. This is especially true where the proximal end of a branch projects into a hole, the wood of the trunk surrounding the branch having been destroyed and the more resinous end piece of the branch resisting the attacks of the fungus. Around this end piece the mycelium forms spherical masses of the size of a small marble. These felts are dry and elastic, and sometimes there are 20 or 30 of them together.

The holes are generally in the center of the trunk and extend longitudinally through it, one above the other, with partitions of sound wood between. (Fig. 1.) In the larger trees there are frequently several holes in the same cross section. (Pl. III.)

These holes may ultimately join here and there by the absorption of the intervening walls. They are largest at the base of the trunk, the size diminishing from the base upward, as shown in fig. 1. The distance between the holes varies from 6 inches to 3 feet.

CHANGES WHICH THE FUNGUS CAUSES IN THE WOOD.

The changes which occur in the wood after the entrance of the mycelium are of two kinds. In the first kind the original red color fades somewhat, the change being barely noticeable when the light is reflected at an angle. Very soon, however, the wood fibers in a given region turn white, showing that the lignin is being destroyed. Such a stage is shown in Pl. I. In this case the wood fibers of about eight annual rings are affected, the change being almost uniform throughout the whole mass. With the increased growth of the mycelium the wood fibers of the adjoining annual rings are attacked and are changed to cellulose. At a later stage the central mass is entirely absorbed and leaves a small hole, which gradually increases in size until it becomes 6 to 8 inches long and 2 to 3 inches wide. (Pl. II.) Around this cavity wood fibers in various stages of decomposition occur, some just beginning to change and others entirely reduced to cellulose.

In the second form of decay the red color disappears very slowly and the wood fibers gradually become brittle and finally fall apart in tangential layers. In Pl. II a wide ribbon of such wood fibers is shown extending from the left of the white area downward. The cavity is partially filled with wood fibers such as these, together with the mycelium. The cellulose fibers are never found loose in the cavity, being invariably attached to the margins of the hole. The red of the heartwood, the white of the cellulose fibers, and the intermediate color stages, together with the red brown of some of the fibers and the yellowish tint of the mycelium, make a combination of color rarely equaled. Unfortunately much of the brilliancy of the original is lost in the photograph.

The destruction of the wood fibers laterally takes place within well-defined limits, as is well shown in Pl. II. The disintegration has taken place up to one annual ring, everything toward the middle of the trunk being changed and every part outside of this one ring remaining unchanged, which indicates that the agent which brings about the change in the wood fibers permeates one ring and changes it before attacking another.

The upper and lower ends of the hole are by no means as sharply bounded. The penetration of the destroying agent seems to take place unevenly, eating more rapidly at some points than at others. This localized disintegration shows that the ferment, for such the active agent probably is, is able to pass longitudinally along the annual rings more readily than across them.

The first form of decay.—Structural changes in the wood fibers become visible shortly after the hyphæ have entered their lumen. In this form of decay[1] the primary lamella begins to have a granular appearance and very soon after is dissolved. At the same time the color of the secondary lamella becomes lighter, and then perfectly white. With chlor-iodide of zinc these lamellæ give the characteristic blue color, indicating that they are cellulose. After the solution of the primary lamella the individual cells fall apart. The cellulose fibers are perfectly smooth and there are regular perforations on their radial walls, indicating the former position of the bordered pits. (Pl. VII, fig. 5.) This mode of delignification agrees with that described by Hartig[2] for wood of the pine delignified by mycelium of *Trametes pini*. The character of the resulting cellulose fiber is very different from that of *Pinus echinata* or *P. palustris* when delignified by *Trametes pini*. The change in the red cedar from wood substance to cellulose is very complete and takes place over large areas.

The chemical nature of wood substance is as yet a matter of much discussion. Substances called lignin compounds, coniferin, etc., to which the characteristic properties of wood were attributed, have been isolated from wood fiber. Czapek[3] has recently announced the discovery of a compound, which he calls "hadromal," that is supposed to

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[1] The word decay is used to indicate changes in which substances that are not normal wood are formed.

[2] Hartig, R., Zersetzungserscheinungen des Holzes, p. 36.

[3] Czapek, Fr., Über die sogenannten Ligninreactionen des Holzes (Hoppe Seyler's Zeitschr. f. Phys. Chem., 1899, Vol. XXVII, p. 141).

give the reactions so characteristic for wood fiber—that is, red coloration with phloroglucin and hydrochloric acid, and has also obtained an enzym[1] from the mycelium of *Merulius lachrymans*, which acts on wood fiber, destroying the hadromal and leaving pure cellulose fiber. Czapek obtained this enzym by grinding the mycelium with emery powder and making an aqueous extract, precipitating the enzym with excess of alcohol. He was able to demonstrate the gradual destruction of the hadromal, beginning with the tenth day. Owing to lack of fresh material no attempt has so far been made to obtain such an enzym from cedar wood. The enzym, however, has been extracted by the writer from the mycelium of *Polyporus subacidus* growing in spruce wood. If it be assumed that such an enzym brings about the above-described changes in the cedar wood, it must necessarily be regarded as very potent.

The formation of the diastase ferment by the mycelium of wood-destroying fungi is very insignificant when compared with this lignin-splitting enzym, which in a single cavity may convert several hundred grams of wood into cellulose. It is hoped that the enzym itself will be obtained before long.

The second form of decay.—The second and less common form of disintegration begins after much of the wood has been changed to cellulose, but as to whether it has any connection with the first form it is impossible to say as yet. It is very much like the transformation of cypress wood, where it is the common form of decay, while the reduction to cellulose is the second or exceptional form. The first noticeable symptom of the second form of decay is the failure of the inner portion of the thickened ring of the bordered pits to stain as deep a red as in sound wood. Soon after this the edges of the small circle of the pit appear to be corroded and the size of the hole increases. A tangential section through the pits shows that the secondary lamella is being gradually dissolved, thus increasing the size of the cavity. The tertiary lamella and the torus are as yet unaffected. The latter is sometimes torn away by the knife and may be seen hanging out on one side. At this stage a thin, veil-like membrane, consisting of the tertiary lamella, may be seen extending into the larger circle of the pit. Pl. VII, fig. 4, shows the same in dotted lines. Finally this membrane is entirely absorbed, leaving a clear, round hole, as large as the original pit (Pl. VII, fig. 7). The torus likewise disappears, and the solution of the secondary lamella has progressed. Pl. VII, fig. 4, shows a radial view of several tracheids. A stage with the round holes is shown in Pl. VII, fig. 2, and fig. 3 represents a piece of wood at a later stage which has become detached and is lying free in one of the cavities.

The solution of the primary lamella causes adjoining tracheids to

[1] Czapek, Fr., Zur Biologie der holzbewohnenden Pilze (Ber. d. Deut. Bot. Ges., 1899, Vol. XVII, p. 166).

separate, except here and there where small portions of the undissolved primary lamella still unite them. In the illustrations (Pl. VII, fig. 3) these parts are black. When they disappear the halves become free—the stage shown in Pl. VII, fig. 4. The dotted lines in this figure represent in perspective the margins of the hole, and two large holes in the tangential wall, where some of the hyphæ had passed through, are also shown. The holes are exceedingly numerous, puncturing the cell in all directions.

In the first stages of corrosion of the pits a change in the medullary rays becomes evident. The walls are very rapidly disintegrated, and even before there is much indication of change in the tracheids the medullary rays have disappeared entirely, leaving long holes, which extend in all directions from the original center of attack (Pl. VII, fig. 1). By the time the pits of the tracheids are gone the piece of wood has turned yellowish brown and has become very brittle. The numerous holes made by the hyphæ and the absence of the medullary rays and the primary lamella readily explain why such wood crumbles into a fine powder at the slightest touch. The parts that exist longest are held together by only the infinite number of fine hyphæ which surround them. In certain portions of the wood there are holes which show no disintegration whatever into cellulose. The small hole shown at the bottom of Pl. III is one of this kind.

THE MYCELIUM.

The mycelium of the fungus is found in the wood between the holes, as well as in the sound (?) wood around the cavities. In the newly invaded portions of the trunk it is almost colorless. The hyphæ are of various sizes, and the larger ones extend longitudinally within the tracheids, giving off branches which penetrate the walls in all directions. The hyphæ never fill a tracheid completely. Within the holes the mycelium forms large sheets and webs, the latter looking very much like ground spiders' webs. When first found in the holes, the mycelium of the sheets is composed of thick-walled hyphæ of a tawny yellow color. During the later stages of decomposition the tangential plates above referred to are found completely interwoven with the hyphæ. These plates hold the ultimate pieces of the wood fibers in position, surrounding them on all sides, and finally absorb them entirely.

PROGRESS OF THE DISEASE.

The condition in which the holes are found makes it possible to describe their formation. The fungus apparently enters the trunk through a dead branch, and when the hyphæ reach the heartwood they grow both upward and downward. What factors determine the spot where disintegration of the wood begins is as yet unknown. At one point, generally a distance from the place of entrance, some of the darkened fibers change in color and very soon have a snow-white appearance. At first this point is a mere spot, but it gradually expands and in a short time attains a length of several inches (Pl. I), the longitudinal growth being more rapid than the lateral. Around this point an area of several inches of wood is changed to cellulose, and now the total absorption of some of this cellulose begins and a small cavity starts and gradually increases in size. About this time white spots, similar to the first one, appear in the heartwood at a point from 3 to 5 feet on either side of the first hole—that is, the mycelium of the fungus has grown longitudinally and set up two new centers of destruction. A vigorous growth of the hyphæ takes place at these centers, and this growth invades the wood in all directions and brings about the characteristic changes very rapidly. In due time other centers arise farther up and down the trunk. The older holes continue to increase in size until they attain their greatest proportions, reaching the lateral limit very soon, as they are rarely more than 2 to 3 inches wide. The cavities extend up and down and frequently unite. The absorption of the cellulose goes on until none is left. The walls of the cavities then become coated with the brown felt of hyphæ before mentioned, or the second form of decay may have set in, leaving fine plates of wood hanging from the surfaces.

The setting up of these centers at which the destruction of the wood takes place is very difficult to account for, and at this time no explanation can be given of the singular mode of action. It was at first thought that the centers might be due to separate infections, but it was soon proved that this was not the case, as the hyphæ were absent from the outer layers of wood. A case which to some extent resembles the one under consideration is that of a recently described disease of Taxodium,[1] in which there is similar local action of the mycelium. The cavities in this case are very close to each other, and it seems probable that a product formed from the wood by the fungus might play an active rôle in limiting the growth of the mycelium to certain areas. Further work on this part of the subject is in progress.

THE FRUITING BODY.

After decomposition has advanced sufficiently the fruiting body forms on the outside of the trunk. This body does not appear to be common, for as far as known it has been collected only twice, once in 1895, by Miss Sadie F. Price, at Bowling Green, Ky., this specimen being now in Prof. L. M. Underwood's herbarium, and once by the writer near Murfreesboro, Tenn.[2] Nothing is known of its develop-

[1] von Schrenk, H., A disease of *Taxodium distichum* known as peckiness, etc. (Eleventh Annual Report Missouri Botanical Garden, 1899).

[2] The description here given is based on these two specimens and may have to be modified when more specimens are studied.

ment. The specimen found at Murfreesboro grew about 40 feet from the ground, and proved to be one of the Basidiomycetes belonging to the genus Polyporus. The mycelium had grown out through the wood of a dead branch, as shown in fig. 2 and Pl. IV, and had spread around this branch, forming a more or less hoof-shaped sporophore. The latter was several years old when examined, as shown by successive layers, which are plainly visible in the figure referred to. It is very hard and woody, and its upper surface is rough, irregular, and yellow brown at the margin (which is the youngest layer), soon becoming deeper brown, and finally much cracked and overgrown with mosses so that no color is distinguishable. The hymenial layer is almost horizontal, and is yellow brown in color, the yellow predominating. It extends to the very edge of the pileus and even somewhat over the edge. Each year when a new layer is added several rows of

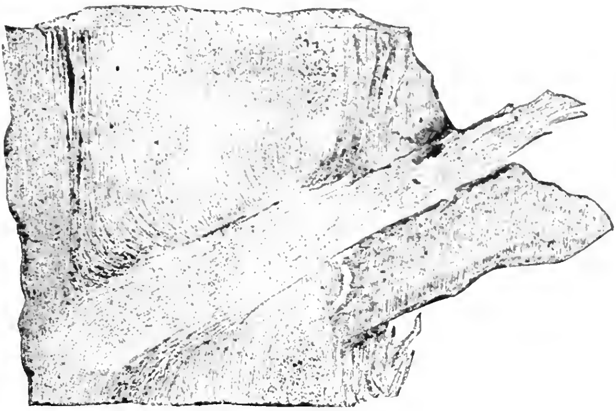

FIG. 2.—*Polyporus juniperinus* growing out from cedar trunk (x⅔).

tubes of the hymenium may be seen on the edge of the ridge, indicating where the edge of last year's pileus was. This feature is very characteristic, being well marked in both specimens mentioned, and readily distinguishes this form from *Polyporus fomentarius* and *P. igniarius*, its nearest allies. The pores of the hymenium are small and very numerous. Many of them are irregular, but the majority are quite round. The hymenium is almost smooth, for there are no hairs and the blunt cystidia project but little over the surface. The basidia are numerous, and each has four short sterigmata bearing four red-brown spores, which are more or less flat on one side. (Pl. VII, fig. 2.)

This Polyporus is one of the fomentarius type, differing from that species (a typical form of which occurs on birches in New England) in being flatter, in the character of its pores, in the color of its hymenium, and in its physiological behavior. It differs still more from *P. igniarius*, and for this reason it is proposed to call the species *Polyporus juniperinus* n. sp., to be characterized as follows: A Polyporus of the fomentarius type, flat, hoof-shaped, very hard, upper surface at first yellow brown, then becoming fissured and black; hymenium yellow brown, with numerous small, round pores, which extend out over the edge and partially onto the top of the pileus; found on *Juniperus virginiana* in Kentucky and Tennessee.[1] A study of other specimens, only two of this Polyporus having yet been seen, may prove that these characters are not constant, in which case the form should be considered a form of *Polyporus fomentarius*.

RED ROT, OR PECKY CEDAR (*Polyporus carneus*).

General characteristics.—This disease is perhaps more common than the white rot. It has been found in Missouri, Arkansas, Kentucky, Tennessee, Virginia, and New York; has been reported from Mississippi; and has been received from Bermuda on the wood of *Juniperus bermudiana*, which shows the disease in marked form. It doubtless exists in other States in which the cedar grows in quantity. The wood of arbor vitæ (*Thuya occidentalis*) found in Maine by the writer often had the characteristic brown pockets. Wood affected with this disease is full of pockets. (Pl. V.) In the early stages these are free from one another and are more or less filled with a brown metamorphosed wood substance which has cracked so as to form small cubes adhering to the walls of the pockets. The pockets are of different sizes, varying in length from 1 inch to several feet. In cross section they are nearly circular when small, but become very irregular when old. (Pl. VI.) Frequently a number join and make large, irregular holes, full of the brown wood. The latter has the appearance and properties of brown charcoal. It is very brittle and can be ground into an impalpable powder in a mortar. When boiled in water it acquires the consistency of cheese and can be cut with ease and readily compressed into a small volume. A mass of wood thus changed has the appearance of clay suddenly dried, which has split in the center and laterally into more or less regular pieces. The line of demarcation between the brown wood and the normal heartwood is very sharp. If the brittle wood is broken away the remnants of it can be scraped off, so as to leave the surface perfectly smooth. A very slight downward pressure on one of the cubical pieces will cause it to break off entirely. The specific gravity of the material is very much less than that of the cedar wood, and it absorbs water with great ease.

CHANGES WHICH THE FUNGUS CAUSES IN THE WOOD.

The structural changes caused by the fungus in the wood are but slight, but the chemical changes are very great. When cut into sec-

[1] A fungus has been reported from the Devonshire swamp, Bermuda, which may prove to be this form on *J. bermudiana*.

tions the walls of the wood cells are found to be very much thinner. They are badly curved and twisted by the knife and have lost all stiffness and elasticity. A thin section can be pushed about with a needle as if the cells were made of pieces of flexible wire jointed at the points of union. Here and there the walls are perforated, showing where the hyphæ of the fungus passed through. The chemical behavior of the walls shows that the cellulose has been removed almost entirely. When dilute KOH is added they swell to several times their normal size and dissolve in part. Acids precipitate a brown flocculent substance from such a solution, hot nitric acid dissolves the wood completely, and the addition of excess of water produces a deep orange precipitate, all of which reactions indicate great chemical changes. The three lamellæ of the cell wall may be seen, but they have shrunk, and the pits in the tracheids show four cracks, about 45 degrees apart, apparently brought about by shrinkage due to drying. Cellulose stains do not react even after treatment with KOH. With phloroglucin and HCl the wood turns red, and with thallin yellow. In certain cells red brown masses of a substance are found which are unaffected by acids or alkalies. They turn black with osmic acid or iron salts, indicating that they are probably one of the tannins. As these cells correspond somewhat with the position of the resin cells, it is possible that the brown substance is a derivative of the resin.

Continuous extraction of finely rasped cedar wood was made with absolute alcohol for six hours, using a Soxhlet's extractor, and finely powdered charred wood was similarly treated. The resulting yellow liquid was distilled until a sirupy liquid was obtained, and from this the alcohol was allowed to evaporate slowly. The substance that remained was red brown and could be readily broken into small pieces with bright fracture. It was insoluble in water, readily soluble in alcohol, and with phloroglucin and hydrochloric acid gave a red color identical with that obtained when wood fiber is treated with these reagents. The quantities of this substance obtained from charred wood and from normal wood were about equal. It was believed that the substance obtained was probably the bearer of the properties which had heretofore been vaguely regarded as lignin substance, but it proved to be identical with Czapek's hadromal.[1] Czapek obtained the same by boiling with zinc chloride and extracting the wood fiber thus treated with benzol. In the experiments here discussed the alcohol extraction proved sufficient.

It is evident that if the hadromal be the substance which gives the wood character to cellulose fiber, all fungi attacking wood do not destroy this compound, for in the brown disease of the cedar the hadromal is as abundant as in the normal wood. The same may be

[1] Czapek, l. c.

said of the charred wood of *Libocedrus decurrens*,[1] recently described. So little is known of the chemical nature of the wood fiber that it would be hazardous to attempt any discussion as to the rôle of any of the compounds found in decomposition processes. Charred wood, such as above referred to, is composed of a very small quantity of hadromal and a large part of some substance that is not cellulose, but possibly a derivative of it.

In view of the fact that for some wood the changes induced by fungi have been found to be due to enzyms secreted by their mycelia, it seems probable that the change in the wood of the cedar is brought about by an enzym. This enzym is probably distinct from any yet found, because of the very different products found as a result of its action. Many attempts have been made to secure it, but so far these have failed because of the very small quantity of mycelium which it was possible to get.

An aqueous extract of the charred wood when treated with an excess of alcohol gives a gray flocculent precipitate, which is soluble in water. Wood fibers have been immersed in such a solution, but they did not, even after standing several months, show any change.

As in the case of white rot, little is known of the life history of the fungus causing red rot. The changes which it induces have been studied in many trees, and were as follows: The first symptom noted in the heartwood was a slight change from red to brown over a considerable area. As the brown deepened, fissures began to appear and soon became very numerous. The wood shrank until pockets, such as above described, were formed. These pockets are most common near the base of the trees, where they become very large. They occur one above another, and often two unite. After a certain period no further increase in the number of pockets takes place, and the cessation of growth, as shown by this fact, is one of the problems which remains for solution, as does also the question why all growth of the mycelium should cease in the heartwood of a tree after it dies or is cut down. It seems to be a fact that many dead cedar trees are found which are partially decayed, and apparently have been in such a condition for many years. In southwestern Missouri, where the cedar grows on the rocky hillsides, many trees die after they have reached a certain age, apparently because of lack of food and water supply. Many of these trees are full of brown pockets, especially near the base.

THE MYCELIUM.

The mycelium of this fungus is very scanty, being found in quantity only here and there. The younger hyphæ are pale and have numerous clamps. They extend horizontally through the tracheids

[1] von Schrenk, H., A disease of *Taxodium distichum* known as peckiness; also a similar one of *Libocedrus decurrens*.

and give off lateral branches. No mycelium is found in the sapwood. The wood between the pockets has many hyphæ, which pass from one pocket to another.

The brown humous compound found in Taxodium[1] is entirely absent in the tracheids of this intermediate wood. In Taxodium this substance was supposed to be active in restricting the growth of the mycelium to certain areas, protecting, as it were, the wood in which it was contained. As a result holes were formed which rarely joined. In the cedar the holes join as a rule, forming very large, irregular cavities, and this would seem to bear out what has been claimed for Taxodium. There being no restraining factor, the enzym of the fungus acted in the surrounding wood, making the cavities larger and larger. There is practically no limit to the carbonization of the wood (Pl. VI), for very old trees may be almost hollow at the base, and it is no uncommon thing for such trees to be blown over when the hollow becomes so great that the sapwood is not strong enough to keep them standing.

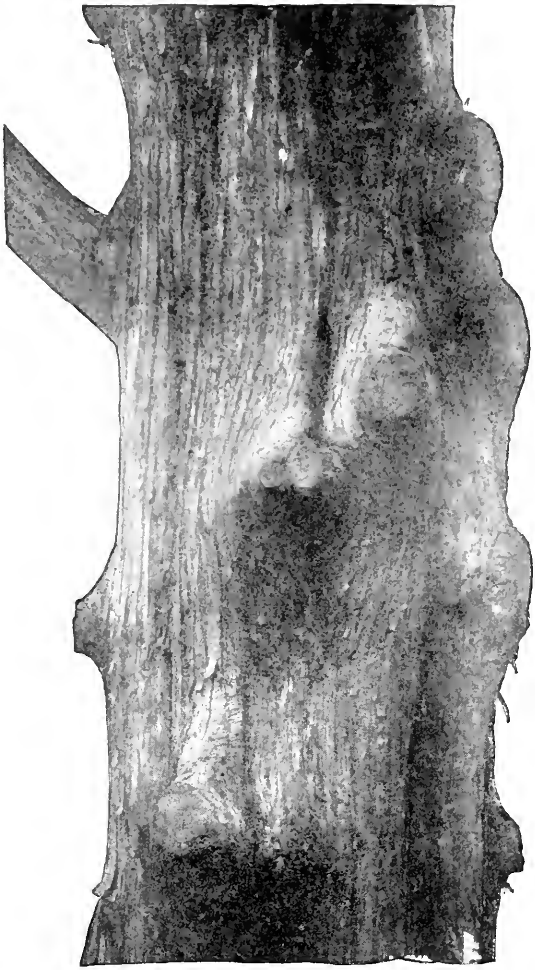

FIG. 3.—Trunk of a red cedar showing hole under an old branch.

THE FRUITING BODY.

The fruiting body of the fungus, which was long sought for, forms in the holes so common on the trunk of the cedar and which are brought about by the manner in which the dead branches seem to recede into the trunk (fig. 3). The cedar belongs to that class of trees in which the base of a dead branch does not grow

[1] von Schrenk, l. c., p. 14.

after the branch has fallen away. In many trees, such as spruce, fir, and some pines, several inches of the base of a branch remain alive and are supplied with nutriment by the parent branch. These keep pace with the increase in the diameter of the trunk until they are healed over. In other trees the pressure of the callus causes the branches to break off, and the wound is soon healed. A dead cedar branch remains visible on the outside for many years. The addition of annual layers of wood on both sides of a branch is such that after some years the stump lies in a hole which has a lens-shaped opening toward the outside, and it is in these holes that the fruiting body of the fungus is found.

The sporophores are often small and are difficult to remove, the shredded bark hiding them. The form of the hole determines the shape of the pileus, the latter being sessile, wedge-shaped, and from $\frac{1}{4}$ to $1\frac{1}{2}$ inches long and about $\frac{1}{2}$ an inch in width (Pl. VII, fig. 8). If there is sufficient room in the hole the upper part of the pileus is arched forward, so as to form a distinct bracket. The hymenium is flesh-colored and has numerous very minute spores. Sometimes the fruiting organs form in the holes within the tree when the holes become exposed to the air. They are then very irregular in shape, adjusting themselves to the form of the hole. In Pl. VII, fig. 9, one of the largest found is shown, as are also a number of smaller ones. In two cases the fungus was found fruiting in holes in logs which had been cut and piled.

The mature spores have not been found, and therefore the systematic position of this form is somewhat in doubt. On account of its flesh-colored hymenium it is regarded as a form of *Polyporus carneus* Nees—a form found on dead cedar wood, as well as on spruce and fir, in which cases, however, it never brings about the brown rot. Its deformed nature is undoubtedly due to its method of growth, which is not of sufficient value as a distinct specific character, and it is therefore proposed to consider this fungus as a form of *Polyporus carneus*.

GENERAL CONSIDERATIONS.

The fungi causing the two diseases described may be considered wound parasites, which grow in the heartwood of the living trees and thus render the wood unfit for commercial purposes. Frequently the diseased trees are cut and sold for use as an inferior grade of fence posts, although they apparently last almost as long as the sound posts. The natural supply of red cedar still available is very small, hence any remedies which might be suggested in connection with the two diseases must be applicable to trees growing under modern methods of forestry for lumber or for ornament. After a tree has once become affected with either disease, remedies will not avail.

As infection occurs through the entrance of the spores into exposed places in the heartwood of a tree, where they germinate and bring about the changes described, the treatment should be preventive, not curative. All sporophores which form on the trees should be destroyed and diseased trees should be removed, as they may give rise to sporophores which may escape notice. The retention of such diseased trees as seed bearers does not seem desirable in the case of the red cedar, as there are so many healthy trees which could serve the same purpose. It is also advisable to cut trees after they have reached a certain age, as old trees are more liable to attack than younger ones, the liability increasing with age. The best age for cutting varies with locality. In very favorable situations, where the trees grow very rapidly, they may be cut with profit when but half the age at which it would be best to cut trees growing on mountains or in exposed situations, where growth is very slow. A good age at which to cut the trees in Tennessee is from 65 to 70 years—in other words, when the trunk is about 1 foot in diameter.

EXPLANATION OF PLATES.

Plate I.—A slab of red cedar, showing the first stage of decay induced by *Polyporus juniperinus.* The white spot shows the cellulose fibers (x $\frac{3}{4}$).

Plate II.—A piece of the trunk of red cedar split open to show large hole caused by *Polyporus juniperinus.* The white masses are cellulose fibers, the flocculent gray masses in the hole are disintegrated wood fibers, while above and below the ends of branches are seen (x $\frac{1}{2}$).

Plate III.—Cross section of a red cedar trunk, showing five holes caused by *Polyporus juniperinus.* Two of these are early stages and show the white lining of cellulose fibers. The cracks in the block were made when the trunk was split (x $\frac{1}{2}$).

Plate IV.—*Polyporus juniperinus* growing on *Juniperus virginiana,* showing how the pileus forms around a dead branch (x $\frac{1}{2}$).

Plate V.—Upper figure, radial view of a block of red cedar, shows the early stages of decay (pecky cedar) due to *Polyporus carneus;* lower figure shows end view of several pockets uniting to form a larger area. The change from sound wood to brown wood is very abrupt.

Plate VI.—A cedar log showing large pocket, filled with brown wood, formed by *Polyporus carneus* (x $\frac{1}{2}$).

Plate VII.—*Fig. 1,* tangential view of wood from a large cavity caused by *Polyporus juniperinus,* showing how the medullary rays are first absorbed. The small holes in the cell walls show where hyphæ have bored through (x —). *Fig. 2,* tangential view of walls from same wood at a later stage. The torus is shown at *t*. The primary lamella and part of the secondary lamellæ have been dissolved. In two bordered pits the torus is still in position. *Fig. 3,* another wall, taken from spring wood, the stage of decomposition being the same as in fig. 2. *Fig. 4,* radial view of several tracheids from the same wood as shown in fig. 3: *a*, bordered pits, showing the initial stage of decay, the central opening widening; *b*, *c*, and *d*, tracheids in various stages of dissolution. The dotted lines indicate the margins of thin membranes of the tertiary lamella. *Fig. 5,* a single wood cell as it appears when changed to cellulose, from a cavity such as shown in Pl. II. *Fig. 6,* a stage in wood destruction later than that shown in figs. 2 and 3 of this plate. The dotted lines indicate the deeper margins of the holes. *Fig. 7,* a piece of badly decomposed wood lying free in a large cavity (Pl. II), the bordered pits having been entirely destroyed. *Fig. 8,* sporophore of *Polyporus carneus* Nees: *a*, lateral view; *b*, top view. The triangular shape shows how it has adapted itself to the shape of the hole in the cedar trunk. *Figs. 9* and *10,* sporophores growing in holes within the trunk. *Fig. 11,* spores of *Polyporus juniperinus* n. sp.

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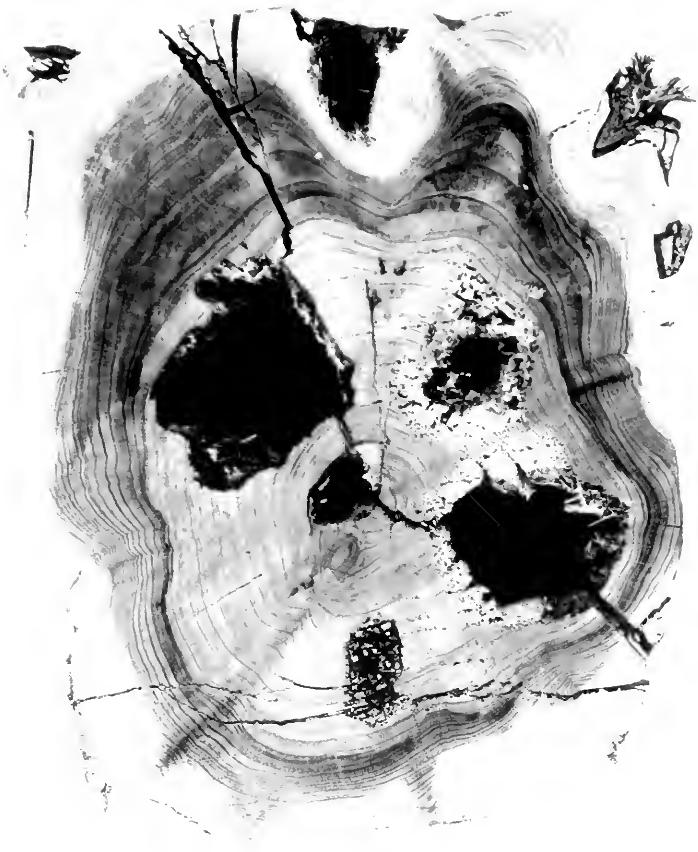
A RED CEDAR SLAB SHOWING THE FIRST STAGE OF POLYPORUS JUNIPERINUS.

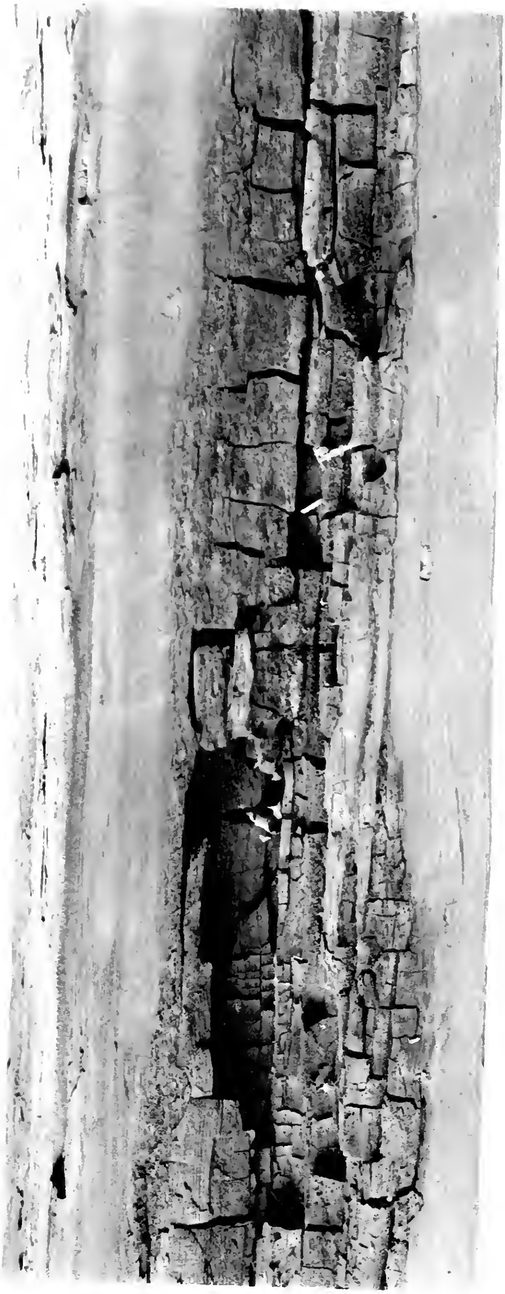
A PIECE OF THE TRUNK OF A RED CEDAR, SPLIT OPEN TO SHOW LARGE HOLE CAUSED BY POLYPORUS JUNIPERINUS.



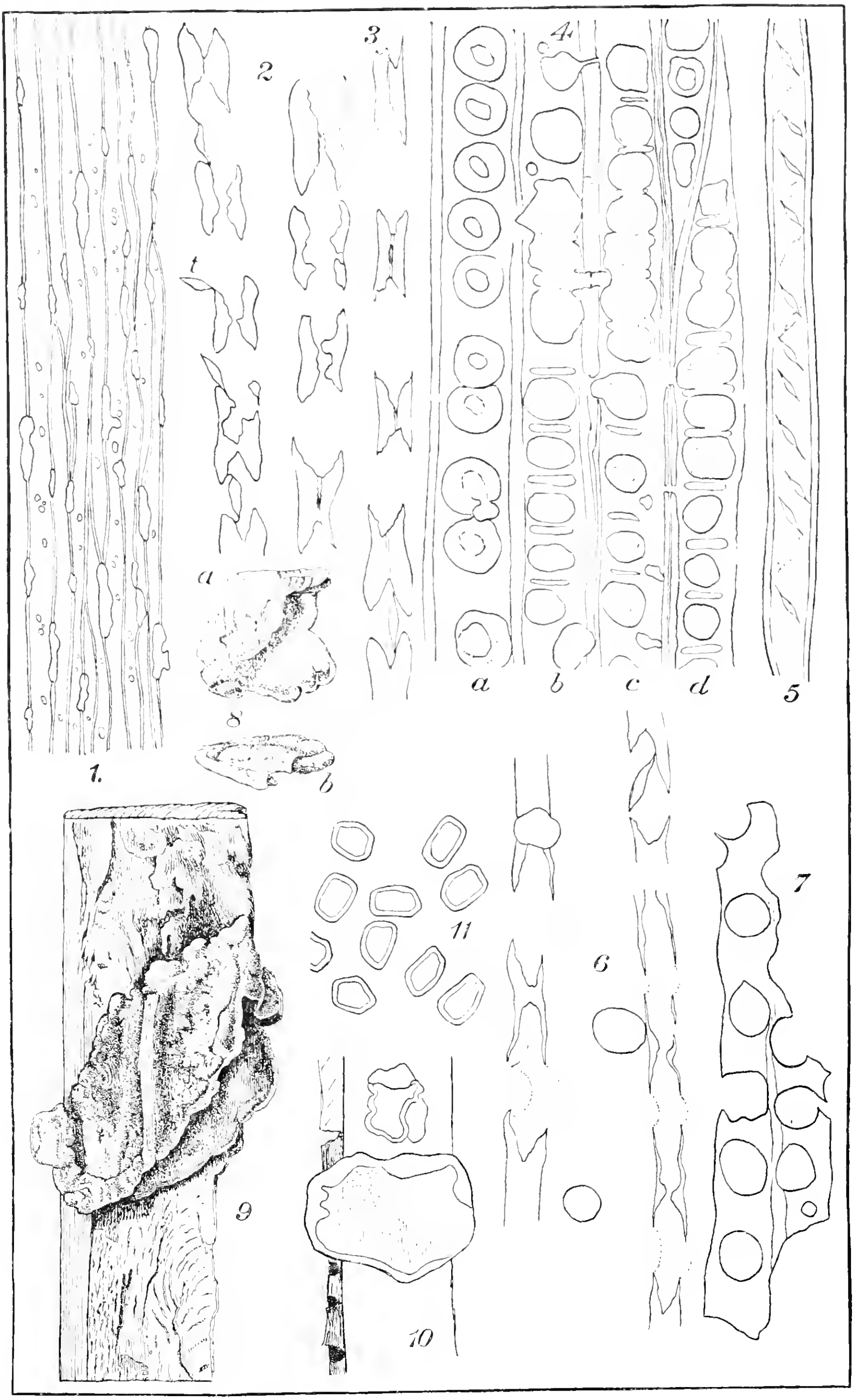
CROSS SECTION OF A RED CEDAR TRUNK SHOWING HOLES CAUSED BY POLYPORUS JUNIPERINUS.

POLYPORUS JUNIPERINUS. V. SCHRENK ON JUNIPERUS VIRGINIANA.

UPPER FIGURE SHOWS RADIAL VIEW OF BLOCK OF CEDAR IN EARLY STAGES OF DECAY; LOWER FIGURE SHOWS END VIEW OF SEVERAL POCKETS UNITING



CEDAR LOG SHOWING LARGE POCKET, FILLED WITH BROWN WOOD, FORMED BY POLYPORUS CARNEUS.



DIFFERENT STAGES OF DESTRUCTION OF CEDAR WOOD.

Bulletin No. 22. V. P. P. 75.

U. S. DEPARTMENT OF AGRICULTURE.

DIVISION OF VEGETABLE PHYSIOLOGY AND PATHOLOGY.

B. T. GALLOWAY, Chief.

XENIA,

OR THE IMMEDIATE EFFECT OF POLLEN, IN MAIZE.

BY

HERBERT J. WEBBER,

In Charge of Plant Breeding Laboratory.

Issued September 12, 1900.

WASHINGTON:

GOVERNMENT PRINTING OFFICE.

1900.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Division of Vegetable Physiology and Pathology,
Washington, D. C., June 12, 1900.

Sir: I respectfully transmit herewith the manuscript of a paper on xenia, or the immediate effect of pollen, in maize, by Mr. Herbert J. Webber, of this division. The paper is technical, but the subject discussed has a broad practical application in the work on plant breeding now under way. I respectfully recommend the publication of the paper as Bulletin No. 22 of this division.

Respectfully,

B. T. Galloway,
Chief of Division.

Hon. James Wilson,
Secretary of Agriculture.

CONTENTS.

ILLUSTRATIONS.

XENIA, OR THE IMMEDIATE EFFECT OF POLLEN, IN MAIZE.

INTRODUCTION.

The supposed immediate or direct effect of pollen on the character of seeds and fruits, which was termed xenia by Focke,[1] is a phenomenon which for years has puzzled botanists and plant breeders. Until recently no satisfactory theory had been advanced to explain how the influence of hybridization could pass outside of the fecundated embryo and cause changes in other portions of the seed or fruit. However, in a recent preliminary article "On the hybrid fecundation of the albumen," De Vries[2] calls attention to the discovery of double fecundation as probably furnishing an explanation of the phenomenon of xenia. Almost simultaneously with the appearance of De Vries's paper, Correns[3] published a summary of his studies on xenia in maize in which the same conclusion is reached.

In discussing the bearing of double fecundation on the problems of hybridization with Prof. De Vries in July, 1899, this probable explanation of xenia occurred to the writer independently, and during that summer quite a number of experiments were conducted with a view to obtaining evidence on this question. These experiments, while not complete, have already yielded suggestive results, and it is thought best to publish them now while the matter is under discussion rather than to wait until the completion of the work.

Double fecundation was first observed in *Lilium martagon* and *Fritillaria tenella* by Nawaschin[4] and reported at the meeting of the Botanical Section of the Russian Society of Naturalists, August 24, 1898.

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[1] Focke, W. O. Die Pflanzen-Mischlinge, p. 511. 1881.

[2] De Vries, Hugo. Sur la fécondation hybride de l'albumen. Comptes rendus d. séances d. l'Acad. d. Sci., T. 129, pp. 973–975. 4 Dec., 1899.

[3] Correns, C. Untersuchungen über die Xenien bei Zea Mays. Berichte d. Deut. Bot. Gesellsch., Bd. 17, pp. 410–417. December, 1899.

[4] Nawaschin, S. Resultate einer Revision des Befruchtungsvorgangs bei Lilium Martagon und Fritillaria tenella. Bul. d. l'Acad. Imp. d. Sciences de St. Petersbourg, T. 9, No. 4, 1898. Also Botanisches Centralblatt, Bd. 77, p. 62, 1899.

Shortly after this Guignard[1] described the same phenomenon more in detail. Previous to these discoveries it had been supposed that in fecundation only one of the two generative nuclei which are formed in the pollen tube of seed plants passed over into the embryo sac and united with the egg cell proper. Nawaschin and Guignard have shown, however, that both of the nuclei enter the embryo sac, one fusing with the nucleus of the egg cell and the other with the two polar nuclei to form the embryo sac nucleus, the division of which gives rise to the endosperm. If this double fecundation occurs in hybridization, it will be seen that the endosperm developed from the nucleus of the embryo sac must be of hybrid origin. Guignard also called attention to the more or less spiral form of the male generative nuclei and designated them antherozoids. This form of the nucleus which is suggested as being similar to the motile male cells of the higher cryptogams and cycads is very peculiar and suggestive.

No very recent researches on the embryology of corn or any of the cereals or grasses have been made, and no direct observations are thus extant to show that double fecundation takes place here. In 1893, Golinski,[2] in an article on the development of the andrœcium and gynœcium in grasses, described the elongated spiral form of the generative nuclei in wheat and rye. In this case the two nuclei are formed in the pollen grain before its germination. Golinski describes them as not unlike the antherozoids of the *Characeæ* and ferns. In a recent article Merrell[3] describes the occurrence of similar elongated spiral nuclei in the case of *Silphium*, where also they are formed in the pollen grain before germination. This form of the male generative cell probably is not correlated with double fecundation; but, in the present state of our knowledge, it is at least suggestive, as this is the peculiar form of the generative nuclei in *Lilium* and other plants where double fecundation has been observed. Since the publication of Guignard's paper the spiral antherozoids of *Lilium martagon* and the union of one of them with the embryo sac nucleus have also been observed by other investigators.[4] Last summer Dr. Scott, Director of the Jodrell Laboratory, Kew, England, kindly showed the writer slides prepared by Miss Sargant, plainly illustrating this phenomenon, and later the writer also had the pleasure of examining the preparations of Guignard which very plainly showed the stages which the latter figured. It would seem thus that double fecundation undoubt-

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[1] Guignard, L. Sur les anthérozoïdes et la double copulation sexuelle chez les végétaux angiospermes. Rev. génér. d. Bot., T. 11, pp. 129–135, 1899, and Comptes rendus d. séances d. l'Acad. d. Sci., T. 128, p. 869, 4 avril, 1899.

[2] Golinski, St. J. Ein Beitrag zur Entwicklungsgeschichte des Andrœceums und des Gynœceums der Gräser. Bot. Centralblatt, Bd. 55, Nos. 1–6. 1893.

[3] Merrell, William Dayton. A Contribution to the Life History of Silphium. Botanical Gazette, Vol. 29, p. 113. Feb., 1900.

[4] Sargant, Ethel. Proceedings Royal Soc., Vol. 65, p. 163. 1899.

edly occurs, in some plants at least, no matter what its interpretation may be.

While it has been claimed that xenia is a somewhat common phenomenon in many plants, there are very few cases on record that are not open to some doubt; but in no plant is its occurrence so well substantiated as in maize. Indeed, the entire belief in the existence of xenia may be said to depend upon its occurring in this plant. That corn crosses readily in the field and shows the effect the first year is a generally recognized fact among agriculturists in this country. The majority of the cases reported, however, are open to the criticism that the seed planted was not definitely known to be pure, and thus the supposed immediate effect of crossing might be explained as due to hybridization which occurred the previous year, or might possibly be interpreted as cases of reversion.

As early as 1724 Dudley[1] said:

> Indian corn is of several colours, as blue, white, red, and yellow; if these sorts are planted by themselves, so that no other sort be near them, they will keep to their own colour, i. e., the blue will produce blue, the white, white, etc. But if in the same field you plant blue corn in one row of hills (as we term them) and the white, or yellow, in the next row, they will mix and interchange their colours; that is, some of the ears of corn in the blue-corn rows shall be white, or yellow; and some in the white or yellow rows shall be of the blue colour.

In 1816 Dr. Savi, according to Darwin,[2] "sowed yellow and black seeded maize together, and on the same ears some of the grains were yellow, some black, and some mottled, the differently colored seeds being arranged irregularly or in rows." Probably the most convincing series of experiments which have been carried out were those conducted in 1866, by the famous French plant breeder, the late Henry L. de Vilmorin.[3] In the spring of that year he planted a dozen varieties of maize from 1,000 to 1,300 feet apart, which distance had been found sufficient to prevent intercrossing by wind-blown pollen. The ears to be crossed were enveloped in thin flannel, which excluded pollen perfectly. Such ears, unless artificially pollinated, never yielded a single kernel. To have a standard for comparison an inclosed ear from each sort was artificially pollinated with pollen from the same sort. The ears thus obtained were imperfectly filled, but the kernels were all true to the type of the race. On the other hand, when inclosed ears were artificially crossed "with pollen from another sort * * * the ears often, but not always, contained kernels showing the characters of their male parent. The proportion of

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[1] Dudley, P. An Observation on Indian Corn. Philosophical Transactions, Abridgement. Vol. 6, pt. 2, pp. 204, 205. Oct., 1724.

[2] Darwin, Chas. Animals and Plants under Domestication. Vol. 1. Second edition, pp. 430, 431.

[3] Vilmorin, Henry L. de. Bul. de la Soc. Bot. de France, T. 14, p. 246, Séance du 29 Nov., 1867.

such grains when they existed was very inconstant, being liable to vary from 1 to 60 per cent." The effect was limited to changes in color of the kernels, in most cases the pollen used being from a black corn in which this color existed in the substance of the kernel. No conclusions were drawn except from experiments upon plats of maize which when left exposed or fertilized with their own pollen reproduced the sort planted without change, thus showing the purity of the races used. In 1867 Hildebrandt gave the results of an experiment in crossing corn, using a yellow race for the female and a dark brown race as the male. In order to prove that the plants of the yellow race, which he used as the female, had not been affected by previous crossings, he pollinated some of the plants with their own pollen and obtained ears on which all of the kernels were exactly like the mother sort. Two ears which he obtained by fertilizing the yellow race with pollen of the dark brown sort "had about half the kernels like those of the mother sort or a little lighter, while the other half, scattered about among them, were a dirty violet color. On these latter, therefore, the pollen of the brown-kerneled sort had exercised a direct transforming influence." In 1872 Professor Körnicke,[1] in describing his experiments, came to the conclusion that xenia is shown in those varieties of maize in which the color is in the aleurone layer of the endosperm, and that the influence of xenia does not pass out of the endosperm and show in any other part of the seed.

In 1870 Körnicke grew a bed of Early Yellow Baden corn which came entirely true to seed. In 1871 two beds of this seed were sown. One bed was left open, to be pollinated by its own pollen, and all of the ears of this came true to seed. In the second bed some of the ears were pollinated with pollen of a reddish-black maize, the color of which was in the pericarp and in the aleurone layer. The cross-pollinated ears developed yellowish-red and dark-red kernels, and also kernels like those of the mother race. All of the ears of the red sort from which the pollen was taken bore seed typical of the race, thus demonstrating its purity. Körnicke criticised Hildebrandt's work, above referred to, stating that the color in the variety which he used was in the pericarp and thus could not be shown as xenia. He also claimed that the seed used by Hildebrandt must have been impure, and the results therefore faulty.

Many American investigators have given some attention to the immediate effect of pollen in corn; but few of the experiments are conclusive, as in most cases no attention was given to the purity of the seed planted, so that the results may have been due to previous crossings or to reversion. Sturtevant observed the occurrence of xenia

[1] Körnicke, Friedr. Vorläufige Mittheilungen über den Mais. Sitzungsberichte d. niederrheinischen Gessells. f. Nat. u. Heilkunde in Bonn, 1872, pp. 63–76.

at the New York Experiment Station in 1883, and Burrill reported instances of this influence in 1887; Tracy in 1887; Kellerman and Swingle in 1888; and Hays in 1889. In 1892 McCluer published the results of experiments conducted at the Illinois Experiment Station, with photographic plates showing the extraordinary effect which Black Mexican sweet corn used as the pollen parent exerted on kernels of a white dent race.

While many of the experiments are faulty on account of doubt as to the purity of the seed used, it will be seen from the above review that in the experiments of Vilmorin, Körnicke, and possibly Hildebrandt, careful attention was given to such features, and the work of these experimenters is thus not open to this objection. While the majority or all of the American experiments are open to this criticism, yet the fact that an immediate influence does seem to occur has been observed so often and so widely in America that, even considering the possibility of error in some instances, it is nevertheless probable that in many cases the effect observed must have been due to xenia. With all this weight of evidence favoring the occurrence of xenia, it was, nevertheless, doubted by very many botanists because of its apparent contradiction of well-established laws of reproduction and embryology and because of the great possibility of error in experiments of this kind. Under these conditions it was highly desirable that some interpretation of the phenomenon be obtained, and happily the discovery of double fecundation seems to furnish a reasonable explanation of a majority or possibly all of the cases in which xenia has been proved to occur.

In the preliminary note by Prof. De Vries, above referred to, he describes an experiment conducted in the summers of 1898 and 1899 in crossing a pure race of sugar corn known as "Blanche" with an ordinary starch corn. The tassels of the majority of the plants of the sweet corn were removed, and the ears were then dusted from time to time with pollen from a variety of starch corn. In this way De Vries obtained ten mixed ears bearing grains ridged and furrowed, resembling pure sweet corn, together with others which were smooth and filled with starch, like the kernels of the male parent. These kernels resembling the male parent were cultivated in the summer of 1899 and found to be true hybrids. The sweet corn which was used in this experiment as the mother parent was found to remain pure and true to seed in the summers of both 1898 and 1899. In such cases where the direct influence of the pollen occurs, De Vries concludes that the change is simply a case of the development of a hybrid endosperm, and that we have here an experimental proof in favor of the occurrence of double fecundation, as described by Nawaschin and Guignard in Lilium and Fritillaria.

Shortly after the appearance of De Vries's paper, Correns's article was published, which referred to the same phenomenon. In this very interesting and suggestive article a number of premises or propositions regarding the immediate influence of pollen in maize were given, but without an account of the experimental evidence on which they were based. From his experience Correns concludes that almost all races of *Zea mays* are capable of being modified in at least one character by fecundation with pollen from another race, and conversely that almost all races are in condition to be directly modified by at least one other race in at least one character. The most important features of Correns's conclusions are the following:

1. The influence of the foreign pollen exhibits itself only in the endosperm, all parts which are outside of this remaining entirely uninfluenced.

2. The influence extends only to the color of the endosperm and the chemical composition of the reserve materials—the starch or dextrin therein. In all cases the size and form of the kernels remain unchanged.

Previous to the discovery of the process of double fecundation by Nawaschin and Guignard, Correns came to the conclusion that either the secondary nucleus of the embryo sac must fuse with one of the generative nuclei from the pollen tube or that the effect was due to an enzymatic influence from the hybrid embryo. The former view, he decides, is proved to be correct by the actual discovery of double fecundation.

The supposed immediate effect of pollen in other plants than maize has been frequently reported, the influence extending not only to the endosperm, but apparently to the seed coats and pericarp. The effect of foreign pollen on the color of the seed coats of peas was inferred as early as 1729 and repeatedly since then, being reported by such experimenters as Gaertner and Berkeley. Laxton stated that he had observed an effect of foreign pollen not only on the color of the seed coats, but also on the pod in some instances, and his observations were confirmed by Darwin so far as the color of the seed coats was concerned. In 1893 Dr. Giltay[1] published an account of the results obtained by him from quite numerous experiments in crossing different varieties of peas which had been selected particularly to demonstrate whether xenia occurs in these plants. He made crosses of fifteen different combinations, obtaining from ten to twenty-five seeds of each, and also grew numerous control plants to demonstrate that the seed used was pure. From his experiments he concludes that the influence of the pollen is not shown outside of the embryo. The influence of the cross, however, was plainly manifested in the color of the cotyledons, which in numerous instances showed very plainly through the colorless coats of the seed, so that unless carefully examined it might be assumed that the seed coats themselves were

[1] Giltay, E. Ueber den directen Einfluss des Pollens auf Frucht und Samenbildung. Jahrb. f. wissensch. Bot., Bd. 25, p. 489. 1893.

influenced. Giltay also brought forward very satisfactory evidence of the immediate effect of foreign pollen on the color of the kernels of rye, in which case the color caused by xenia was found to be in the aleurone layer of the endosperm.

A phenomenon quite similar to xenia in its results, though probably due to very different causes, occasionally occurs in the animal kingdom. In a review of Professor Ewart's Penycuik Experiments, in Popular Science Monthly,[1] it is stated that "A hen which has been crossed with a cock of another breed often lays eggs whose shell is no longer like that of its own breed, but in color, and frequently in texture, resembles that of the breed with which it has been crossed." When we recall that the shell is deposited by a special shell gland which is in no way connected with the ovary, but is a part of the quite distinct oviduct, and that the change in the color of the eggshell must be caused by some change brought about in this gland by the cross fertilization, we see that in some ways the phenomenon closely resembles that of xenia in plants.

METHODS AND RACES USED.

The experiments on which this article is based were conducted in Washington, D. C., and at the Nebraska Agricultural Experiment Station. In 1898, plants of Hickory King, Gilman Flint, Leaming Yellow, and Peruvian, or Cuzco, were grown in the greenhouse at Washington for the purpose of crossing the first three with the Cuzco. The seed of the latter was imported from Peru, and being a subtropical race, was grown in the greenhouse because the season at Washington is not long enough to permit the plants to mature. Ears of each of the varieties used in these experiments were also inbred to determine whether they were true to seed. In the summer of 1899 the hybrids obtained in 1898, together with inbred ears of the other varieties grown that season, and twelve other sorts, were grown under the writer's direction at the Nebraska Experiment Station. In the experiments described below the crosses made in 1898 are so indicated and the resulting hybrids grown in 1899 are described. The majority of the experiments were made in 1899, however, and in these cases no statement is made as to when and where the cross was made. In these instances it is to be understood that the crosses were made with plants grown at Lincoln, Nebr., in the summer of 1899.

The work done at Lincoln was in cooperation with the Agricultural Experiment Station, and the writer is greatly indebted to Professor Emerson, Mr. Benedict, and others at that institution for their kindness in furnishing facilities for the work and for aid in the course of the experiments. In all the crossing and inbreeding experiments very careful methods were used. The ears operated upon were inclosed in

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[1] Vol. 57, p. 134. June, 1900.

manila paper bags before any of the silks had appeared, and were opened and pollinated four or five days later, when the pistils had matured. After pollination they were immediately rebagged, the bags not being finally removed until some ten or fifteen days later, when all the silks were dried up. The pollen in every case was collected by inclosing the tassel in a large paper sack, which was removed after the pollen had been discharged. It was found in the course of the work that the pollen retained its vitality for at least two weeks, but no experiments were made to determine the length of time it could be retained in good condition. As an indication of the thoroughness of the methods used, the fact may be cited that in at least seven or eight instances, where ears were bagged and not hand pollinated, no kernels set, showing that impurity is not likely to result from other pollen accidentally getting in when ears were bagged.

The following is a list of the varieties grown, with notes on their characters, etc.:

Cuzco or Peruvian No. 759.—A soft corn (*Zea amylacea* Sturt.) imported directly from Peru by the Section of Seed and Plant Introduction of this Department. The seeds for the writer's experiments were kindly placed at his disposal by Mr. D. G. Fairchild, special agent, then in charge of that Section. As obtained from Peru, the kernels were of mixed colors, apparently belonging to the same but very unstable and variable race. The majority were dark bluish-black or plumbeous (Pl. I, figs. 3–4), while some were mottled with dark purple and white (Pl. I, fig. 5), and others mottled in the same way and with a fuscous or ferruginous pericarp. (Pl. I, fig. 6.)

Cuzco No. 760.—In the Cuzco as imported from Peru there were many opaque white or whitish-yellow grains mixed with the plumbeous and variegated kernels described under the preceding number, and these, as they appeared to be distinct from the others, were selected out and given the number 760, under which they were distributed by the Section of Seed and Plant Introduction. (Pl. I, figs. 7–8.) A plant from one of these kernels, inbred as described in the following number, gave variously colored grains, showing that Cuzco No. 759 and 760 are apparently simply different-colored kernels of the same variable race.

Cuzco 7a.—One ear of Cuzco No. 760 was inbred in the greenhouse at Washington, D. C., in the summer of 1898 (Experiment 7a), and matured thirty-five good kernels, of which eighteen were pure yellowish-white, the same as the original kernel planted (Pl. I, figs. 7–8), and seventeen purplish, most of them being dark purple. These seeds were planted at Lincoln, Nebr., in 1899, and the pollen from some of them was used in crossing experiments that year. Such plants are distinguished in the writer's notes and in this paper as Cuzco 7a.

Hickory King (*Zea indentata* Sturt.).—A white dent race with very broad, deep kernels and a small white cob. It is the largest-kerneled race commonly grown in the United States (Pl. I, figs. 1–2). The seeds were purchased from Wood & Co., of Virginia, and were supposed to have been produced under control conditions. One ear was carefully inbred in the greenhouse in 1898 and came true to the type of the race. The seed of this inbred ear was grown at Lincoln in 1899, and one ear again inbred, which came true to type. In neither of the inbred ears was there any suggestion of impurity, and in none of the ears pollinated naturally in the field was any effect visible suggesting previous crossing with a plumbeous-kerneled race like the Cuzco. This peculiar color is shown as xenia on Hickory King (grown from this seed), × Cuzco No. 759, in the writer's experiments, 1a and 1b, 10a, etc.

Some seed of Hickory King purchased from Burpee & Co., of Pennsylvania, and claimed to have been bred true to type, was also grown at Lincoln, Nebr., in the summer of 1899 and used in a few of the crossing experiments. Two ears carefully inbred produced fair-sized ears which were apparently true to the type.

GILMAN FLINT (*Zea indurata* Sturt.).—A light orange-yellow flint race with white cob. The seed was obtained through the Seed Laboratory of this Department and it is believed was pure. One ear of this race inbred at Washington in 1898 reproduced the parent true, and the seed of this inbred ear was planted at Lincoln in 1899. One ear inbred in 1899 again reproduced true to type, and the majority of the ears from the plat of this race showed no effect of any mixture except in two ears, one of which showed wrinkled kernels like sweet corn, evidently being a case of xenia due to crossing with sweet corn pollen, and the other a few blue-black kernels, evidently being due to xenia from crossing with pollen from Black Mexican sweet corn which grew in an adjoining row.

LEAMING YELLOW (*Zea indentata* Sturt.).—An orange-yellow dent with long, rather slender kernels and red cob. The seed was obtained through the Seed Laboratory of this Department and it is believed was pure. None of the plants of this race were inbred, but the ears produced on the plants grown and naturally fertilized gave indication of being from a pure race, showing no evidence of mixed origin other than the xenia shown in a few ears from crossing with a white race grown next to it in the field.

CHAMPION WHITE PEARL (*Zea indentata* Sturt.).—A white dent race with white cob. The seed was grown by Mr. J. C. Suffern, of Voorhees, Ill., and was claimed to have been carefully bred under control conditions. One ear inbred in 1899 came true to type.

BOONE COUNTY WHITE (*Zea indentata* Sturt.).—A white dent race with white cob. The seed was grown under careful control conditions by Mr. James Riley, of Thorntown, Ind., the originator of the race. One ear inbred in 1899 came true to type.

BURR'S WHITE (*Zea indentata* Sturt.).—A white dent race with white cob. The seed was grown under careful control conditions by Mr. F. E. Burr, of Philo., Ill., the originator of the race. Two ears carefully inbred in 1899 came entirely true to type.

WHITECAP DENT (*Zea indentata* Sturt.).—A race of dent corn with comparatively small yellowish kernels with white apexes. The seed was grown by Burpee & Co., and was claimed to have been produced under control conditions. One ear carefully inbred in 1899 came true to type.

PEDRICK'S PERFECTED GOLDEN BEAUTY (*Zea indentata* Sturt.).—An orange yellow dent with red cob and broad kernels. The seed was grown by Burpee & Co. under control conditions. One ear carefully inbred in 1899 came true to type.

IOWA KING (*Zea indentata* Sturt.).—A white dent race with long kernels and white cob. The seed was furnished by the Seed Laboratory of this Department.

STOWELL'S EVERGREEN (*Zea saccharata* Sturt.).—A clear white race of sweet corn with long wrinkled kernels and white cob. The seed was grown by Burpee & Co. under control conditions. One ear inbred in 1899 came true to type.

BLACK MEXICAN (*Zea saccharata* Sturt.).—A race of sweet corn with blue-black more or less wrinkled kernels and white cob. The seed was furnished by the Seed Laboratory of this Department. It is believed to have been bred under control conditions.

RECORD OF EXPERIMENTS AND RESULTS.

DENT CORN CROSSED WITH SOFT CORN.

Experiment 1a,[1] *Hickory King* ♀ × *Cuzco No. 759* ♂.—The cross was made on plants grown at Washington in 1898. A small ear

[1] The numbers given here are those originally used in the writer's experiments. All of the experiments of a certain combination will be series 1 or series 2, etc., and

yielding ninety-nine kernels resulted, only four of which showed any indications of xenia. The other kernels were white, exactly like the ordinary Hickory King. (Pl. I, figs. 13 and 14.) On the four kernels which showed xenia the change consisted simply in irregular spots of the characteristic dark plumbeous color of the Cuzco. Some of the kernels showing this effect are illustrated in Pl. I, figs. 9–12. It will be seen by comparing these figures with the plumbeous-colored kernels, typical of the Cuzco (Pl. I, figs. 3 and 4), that the dark-colored spots in the kernels resulting from the cross show this color practically the same as in the Cuzco.

In the summer of 1899 the ninety-nine kernels resulting from this cross were planted at Lincoln, Nebr., one kernel in a hill, and produced seventy-four plants. Forty-four of these, judging from their characters, proved to be true hybrids, while thirty were either hybrids entirely resembling the mother plant or the results of accidental self-fertilization. The original cross was made in the greenhouse, but while the ear which was crossed was carefully inclosed, as in all other experiments, before the silk had pushed out considerable pollen had already fallen on the bracts of the ear, and this, in spite of the precautions taken, would render possible the introduction of foreign pollen; so that it is quite probable that some of the grains were self-pollinated. The forty-four which the writer takes to be true hybrids were very markedly influenced by the male parent, so that there can be no doubt of their being genuine hybrids. Indeed, the characters of the male parent seemed to predominate. Hickory King, the mother parent, has normally a rather slender stalk which is light green in color and has very few anchor or brace roots, which do not appear much above the surface of the soil, and very broad leaves. The hybrids differ from the typical Hickory King in having narrow leaves and much taller and thicker stems, which are purplish, particularly at the base, and fade to green above. They also have several circles of anchor roots, usually 3 to 6, which are very prominent, as in the Cuzco, and extend as high as 2 or 3 feet above the ground. The forty-four true hybrids ranged in height between 8 feet and 12 feet 4 inches, averaging 9 feet 7 inches; while the thirty plants showing no signs of having been hybridized ranged between 7 feet and 9 feet 3 inches in height, averaging 7 feet 10 inches. A number of plants of the typical Cuzco grown in the same patch averaged about 8 feet in height, while the Hickory King, grown under exactly the same conditions, averaged

the individual crosses under a series are referred to by letter as 1a, 1b, etc., or 2a, 2b, etc. In numbering the experiments when they were made there was no effort to group related crosses together and number them in sequence, and thus, when the crosses of dent corn with soft corn, etc., are grouped together as in this paper, the numbers of the experiments are not in sequence. The hybrids when grown are numbered in sequence from No. 1 upward, the same number never being given to more than one hybrid.

about 8 feet 6 inches. It should be stated, however, that the Cuzco grown and used for comparison, owing to the long season required for its development, was planted in the greenhouse earlier than the other races and transplanted to the field when the other corn was planted. It appeared to have been stunted somewhat in this process of transplanting and probably did not grow as large as it otherwise would have done. It will be seen from these figures that the hybrids greatly exceeded either parent in size and vigor, being taller than either parent by an average of about 1½ feet.

An exceedingly interesting feature of the hybrids was their lateness. Those which resembled the female parent, Hickory King, entirely, and were probably the results of accidental self-fertilization and not true hybrids, pushed out their silks ready for pollination the latter part of July and first of August. Quite a number of these were inbred, the work being done between August 1 and 15. Of those inbred seventeen matured, and the ears, while in some cases small and poorly filled, in all cases resembled typical Hickory King, and the writer thinks it can be definitely concluded that they were the results of self-fertilized kernels. The true hybrids were very late in showing their silks, the great majority of them not being ready for crossing before the 1st of September. The first of these to be ready for crossing were inbred August 14. Quite a number were inbred, but only a very few matured seed.

The following are notes on the individual hybrids which were inbred and produced ears. The number of the hybrid in each case is the number given to it in my series of experiments.

No. 5: Plant grown from one of the four kernels which showed xenia in the plumbeous-colored spots derived from the male parent. (Pl. I, fig. 9.) Ear inclosed August 12, 1899; inbred August 21, 1899, with pollen of another hybrid of the same character and parentage. Plants robust, 10 feet high, with several whorls of anchor roots; stem purplish. The small ear which matured contained only sixty kernels. Cob pinkish or fuscous. Kernels between coral red and rufous (Pl. I, figs. 15 and 16), about half of them being variously mottled or variegated with irregular dark-brown or plumbeous spots. The coloring matter forming these spots was limited to the aleurone cells of the endosperm, showing through the translucent coral-red pericarp. The color of the spots is the typical plumbeous of the endosperm of the Cuzco, which was the male parent, and is the same as the xenia spots shown in the original seed planted. The coral-red or rufous color is in the pericarp and was apparently derived from the Cuzco, some of the kernels of which show this peculiar color. (Pl. I, fig. 6.) It seems to be a color limited entirely to the pericarp, and in no instance of the writer's crosses with the Cuzco has it been shown as xenia.

No. 23: Grown from kernel showing no indication of xenia. Plant quite similar to Hickory King, 10 feet 2 inches high, with two whorls of anchor roots, only slightly purplish. Two ears were inbred, being inclosed August 8, and inbred August 14, 1899. Each of these matured only a small number of kernels. One of the ears, which had a light pinkish colored cob, matured about 300 kernels, all having a peculiar ferruginous color which was limited to the pericarp, and which resembled the color of the pericarp in the preceding hybrid, though somewhat lighter. (Pl. I, figs. 17 and 18.) The color was most dense at the apex, and faded to yellowish-white below at the base of the grain. In none of the kernels was there any trace of the plumbeous color commonly occurring in the aleurone layer of the male parent. The other ear, which had a nearly white cob, matured about sixty-seven kernels, all uniformly colored about the same as in the preceding ear. Here also there was no indication of color in the aleurone layer.

No. 39: Grown from kernel showing no indication of xenia. Plant 9 feet in height; purplish green at base and with four circles of anchor roots, in these characters plainly showing the effect of the male parent. The ear was inclosed August 10, and inbred August 29, 1899, with pollen of a different hybrid, but of the same parentage and characters. Only a very few kernels developed on a small whitish cob, all having the pericarp ferruginous colored on the sides and becoming whitish at the apexes. One of the kernels had a few irregular plumbeous-colored spots due to color in the aleurone layer.

No. 46: Grown from a kernel which showed no evidence of xenia. Plant 9 feet high; base purplish green, with three circles of anchor roots. The ear was inclosed August 10, and inbred August 14, 1899, with pollen of the same stalk. Only five kernels matured on a small white cob, all being ferruginous or fuscous, as in the preceding hybrid, with color limited to the pericarp. No plumbeous or other colored spots showed in the endosperm.

No. 68: Grown from a kernel which showed no xenia. Stalk 10 feet 4 inches in height; robust, purplish green at base with six circles of anchor roots and slender tassel similar to Cuzco. The ear was inclosed August 16, and inbred August 22, 1899, with pollen from the same stalk. Nineteen kernels matured on a small white cob. All were ferruginous or fuscous, fading into white at apex as in the preceding, the color being limited to the pericarp. No plumbeous-colored spots showed in the endosperm.

In the above experiment the seed of the Hickory King, used as the mother parent, had not been cultivated by the writer previous to the experiment and may not have been pure, though plants from the same batch of seed showed no impurity the same season or the following year. The plumbeous color of the Cuzco 759, which was shown as xenia in spots on four of the kernels, is an uncommon color in corn, and the Cuzco is not grown in the United States; so that it is hardly probable that the color here could have been due to the use of impure seed. Again the fact that the four kernels which exhibited these spots proved to be undoubted hybrids, showing plainly their Cuzco parentage, seems to the writer to prove conclusively that this is a true case of xenia. It is also interesting to note that of the forty-four true hybrids only four of the original crossed kernels showed xenia, so that in this case absence of xenia could not be taken as an indication that the kernels had not been hybridized.

Experiment 1c, Hickory King ♀ × *Cuzco 759* ♂.—The cross was made on plants grown at Washington in 1898. One small ear was harvested December 3, 1898. None of the kernels showed any indication of xenia, being pure white like the mother parent. These kernels were planted in the summer of 1899, but only one plant developed. This showed the characters of Cuzco, the male parent, in being very robust, reaching a height of 11 feet 4 inches, and having a purplish green stem with three circles of anchor roots. The ear on this plant was inbred August 19, 1899, but did not mature seed.

Experiment 1d, Hickory King ♀ × *Cuzco 759* ♂.—The plants used in this experiment were grown at Washington in 1898. The small ear which matured was harvested December 3, 1898. Only twenty kernels resulted, of which four were heliotrope-purple (Pl. I, figs. 19 and 20), and three had purplish-black spots similar to the kernels of experiment 1a, figured in Pl. I, figs. 9–12. All of the other kernels were pure white. No examination was made of the colored and spotted kernels to determine where the color was located. The plumbeous color of the Cuzco, however, is located in the aleurone layer of the endosperm, and in these cases also it was probably limited to that portion of the endosperm. There would seem to be no doubt that the coloration in this instance, as in the variegated kernels described under 1a, is a true case of xenia or the immediate effect of pollen.

In 1899, 20 seeds resulting from this cross were planted at Lincoln, Nebr., and produced eighteen plants, all of which were shown to be true hybrids from their characters: (1) from the color of the stem, which was purplish-green similar to the father parent, instead of green like the Hickory King; (2) from the larger number of whorls of anchor roots, which varied from three to six in the hybrids, the peculiarity, characteristic of the Cuzco, of producing numerous anchor roots being accentuated in the hybrids; (3) in the lateness of the flowering and maturing; (4) in the increased size due to the hybridization. (Pl. III, figs. 1 and 2.)

All of the eighteen true hybrids resulting from this series of experiments, when compared with the sixteen varieties grown in the same experimental field and with sorts grown in adjoining fields, were of very large size. The shortest was 11 feet in height, while the tallest was 13 feet 4 inches, the average height being 12 feet 4 inches. The average height of Hickory King grown in an adjoining row was about 8 feet 6 inches, while the average height of the Cuzco in the same field was about 8 feet. Thus the hybrids on an average exceeded the female parent in height by about 3 feet 10 inches and the male parent by 4 feet 4 inches. As stated under 1a, however, the Cuzco plants used for this comparison were probably somewhat below normal height, as the result of their having been grown in pots in the greenhouses for a time and then transplanted. Some of the hybrids of this series were inbred about the 1st of September, when the first silks appeared, but in all cases were too late to mature. The hybrids in most cases started to develop three to four ears, and these in all instances were very high, the lowest on the several stalks varying from 7½ to 8½ feet from the ground.

In this experiment, as in experiment 1a, the Hickory King used as the mother parent had not been cultivated previously under the writer's direction, and was not definitely known to be pure, but as in that case, and for the reason there given, the writer thinks there can be no doubt that the four purplish kernels and the three kernels with purplish-black spots produced on the original crossed ear, and which were shown to be hybrid kernels by growing them the next year, must be interpreted as cases of undoubted xenia. In this experiment also, as in 1a, many pure white kernels showing no indication of xenia proved to be hybrids.

Experiment 10a, Hickory King ♀ × *Cuzco No. 759* ♂.—The plant of Cuzco No. 759 from which the pollen was taken was grown from a dark plumbeous-colored kernel like that shown in Pl. I, figs. 3 and 4. A small well-filled ear resulted, the kernels of which almost all showed xenia in the plumbeous or heliotrope-purple color imparted to the seeds, the color being limited to the aleurone layer of the endosperm, as in Pl. I, fig. 32. The color varied greatly in density and distribution in the different kernels. Some were dark plumbeous or heliotrope-purple at the apex and extending down to the middle of the sides, but fading to nearly white below. Others were nearly white at the apex, but plumbeous below on the sides. A very few were white throughout like the mother parent. The character of the starchy endosperm was also much modified, xenia showing as plainly in this regard as in the color. Such kernels contained much more of the soft, opaque, white, starchy matter, and less of the hard, horny, translucent matter, or corneous endosperm, than the typical kernels of Hickory King, this character being clearly derived from the male parent, the Cuzco, in which the endosperm is almost entirely lacking in hard corneous matter. A fibrous, striped surface-appearance is shown in many of the kernels, a character which, so far as the writer is informed, is not shown by either of the parent races. (Pl. I, fig.

22.) This was found to be a character of the pericarp, for when the latter is pulled off from such kernels and held up to the light it is seen to be marked with alternate opaque and hyaline stripes which are irregular and run longitudinally. In this experiment, made at Lincoln, Nebr., in the summer of 1899, the seed of Hickory King used as the female parent was from an ear inbred by the writer the previous season, and known to be pure.

Experiments 18a, 18b, and 18c, three ears of Leaming Yellow ♀ × *Cuzco 7a* ♂.—(The plant of Cuzco 7a furnishing the pollen in these three experiments was from a yellowish-white kernel produced by inbreeding Cuzco No. 760 the preceding year. See description, p. 14.) Three poorly filled ears resulted, which were apparently uniform in all important characters. The kernels were yellowish on the sides like typical Leaming Yellow, but with whitish apexes. This must probably be considered as a result of xenia, as the white color probably predominated in the male parent, though known to be of a variable race. A comparison of the endosperm of the kernels of the crossed ear with those of typical Leaming Yellow showed very little, if any, reduction of the corneous matter, which was very marked in experiment 10a.

Experiments 19a and 19b, two ears of Leaming Yellow ♀ × *Cuzco No. 759* ♂.—Only a few kernels developed on each ear, all resembling Leaming Yellow, no xenia being apparent.

Experiment 20a, Pedrick's Perfected Golden Beauty ♀ × *Cuzco 7a* ♂.—(The plant of Cuzco 7a furnishing the pollen in this experiment was from one of the dark purplish kernels produced by inbreeding Cuzco No. 760 the preceding year. See description, p. 14.) A small well-filled ear containing something over 300 kernels resulted. None of these were like the normal Pedrick. The great majority were of a heliotrope-purple or plumbeous color at the apex or various combinations of these two colors, gradually fading on the sides to yellowish-white. The base and lower half of the kernels in most cases were yellowish-white or yellow, suggesting the color of the female parent, but not so deep an orange. Some few kernels were whitish or yellowish-white throughout, there being three or four of this sort. Two kernels were curiously marked, being half white and half heliotrope-purple, exhibiting a sharp line of demarcation between them. (Pl. I, fig. 24.) In these cases when the pericarp was pulled off over the line of demarcation the color was found to be entirely in the aleurone layer. In quite a number of the dark-colored kernels also, which were examined, the color was found to be limited to the aleurone layer. Practically every kernel of this ear showed xenia very plainly. The seeds of the female parent, while not bred under the writer's direction, were grown by a careful seedsman under control conditions, and were probably free from impurity. Furthermore, the plants from this seed which were inbred came perfectly true to type, and the ears which were developed in the plat without inbreeding and without artificial crossing showed no indication of the plumbeous or heliotrope-purple color shown in the crossed ear. This color is rare in races commonly cultivated and is not commonly a source of impurity, so that the writer is convinced that the effect here is due to xenia.

Experiments 26c and 26d, two ears of Burr's White ♀ × *Cuzco 7a* ♂.—(The plant of Cuzco 7a furnishing the pollen in these experiments was from a yellowish-white kernel produced by inbreeding Cuzco No. 760 the preceding year.) Two fairly well-filled ears developed, all the kernels of which were pure white, apparently the same as the type of the female parent used. The corneous endosperm also appeared to be apparently the same as in the typical Burr's White, no effect being visible here either. The fact that the Cuzco used in this experiment grew from a yellowish-white kernel similar to the color and appearance of Burr's White probably prevents the recognition of any characters due to xenia.

Experiment 33b, Champion White Pearl ♀ × *Cuzco 7a* ♂.—(Plant of 7a grown from a yellowish-white kernel, as in the preceding experiment.) A partly-filled ear resulted, all the kernels of which were white and similar to the typical Champion White Pearl, showing no xenia.

Experiment 35a, Champion White Pearl ♀ × *Cuzco No. 759* ♂.—(The plant of Cuzco No. 759 furnishing the pollen in this experiment was from a plumbeous-colored kernel similar to those shown in Pl. I, figs. 3 and 4.) The pollen used in this experiment was somewhat wet and only a few kernels matured. Some of these were plumbeous in color, similar to the color of the male parent, the color here again being limited to the endosperm and doubtless due to xenia. The seed sown, however, was not definitely known to be pure.

Experiment 41a, Leaming Yellow ♀ × *Cuzco No. 759* ♂.—(Cross made under the writer's direction by Mr. E. C. Rittue, at Washington, in the summer of 1899.) A well-filled ear resulted, on which the great majority of the kernels resembled typical Leaming Yellow, showing no indication of xenia. Three kernels, however, exhibited a very peculiar purplish color, which apparently was derived from the male parent. These three kernels, furthermore, showed the effect of the cross very distinctly in having a much larger quantity of soft, starchy material in the endosperm, and consequently a smaller amount of corneous endosperm. The other kernels on the ear were apparently like the typical Leaming Yellow in this regard, the structure of the endosperm showing no effect of xenia. The seed of Leaming Yellow used was not definitely known to be pure.

DENT CORN CROSSED WITH SWEET CORN.

Experiment 11a. Hickory King ♀ × *Stowell's Evergreen* ♂.—A small ear developed, the kernels of which were all apparently pure Hickory King, showing no indication of xenia.

Experiment 16a. Leaming Yellow ♀ × *Stowell's Evergreen* ♂.—A fairly well-filled ear matured, all kernels of which were apparently true Leaming Yellow, showing no visible signs of xenia.

Experiments 31a and 31b, Champion White Pearl ♀ × *Stowell's Evergreen* ♂.—Two comparatively small ears developed, the kernels of which were all similar to the typical Champion White Pearl, showing no appearance of xenia.

The writer has frequently made examinations of sweet corn and dent corn grown in adjoining fields, and from observations made in such cases it would seem that the characters of sweet corn do not commonly show as xenia in dent races. Last year the writer had the opportunity to examine a field where about an acre of common sweet corn was growing in the corner of a comparatively large field of a pure yellow dent race. A careful examination was made of the adjoining rows of dent corn, and not a single instance was found where any influence of the sweet corn pollen could be observed, although numerous crosses probably existed. In the sweet corn patch, however, the effect of pollen from the dent race could be abundantly found, as will be explained later. In Kellerman and Swingle's[1] experiments also two instances of a dent race crossed with sweet corn failed to give any indication of xenia. These results would seem to correspond with the conclusions reached by Correns,[2] who says in his proposition 14 that xenia results in that a "more complicated chemical compound (starch) is laid down instead of a less complex one ('Schleim,' dextrin), never the opposite, whereby * * * a simpler substance is laid down instead of a more complex one." Correns, however, did not give an account of the experiments on which this conclusion was based.

SWEET CORN CROSSED WITH DENT CORN.

Experiments 13a and 13b, two ears of Stowell's Evergreen ♀ × *with Leaming Yellow* ♂.—The seed did not set well, and the kernels were pressed out of normal shape owing to the comparatively small number developed. They, however, clearly showed the effect of the cross, in every case being yellowish and smooth with a starchy endosperm similar to that of the male parent. The yellow color was here again limited to the endosperm, the pericarp being entirely hyaline. None of the kernels showed any indication of the typical wrinkling of the sweet corn. Xenia was thus shown here both in the color and composition of the endosperm, and it is further noteworthy that all of the kernels developed were plainly affected.

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[1] Kellerman, W. A., and Swingle, W. T. Experiments in the cross-fertilization of corn. First An. Rept. Kansas Agr. Exp. Sta., 1888, pp. 316–337.

[2] Correns, l. c., p. 413.

The above are the only hand-pollinated ears on which the writer has obtained the effect of dent pollen on a sweet corn race, but several very convincing instances have come under his observation. The case referred to above, under experiments 31a and 31b, of a patch of sweet corn grown by J. C. Bradt, of Marcellus, Mich., is very interesting and instructive. Here a patch of sweet corn of about an acre in extent produced from seed which had been grown for several years in an isolated locality and known to be pure, was planted in th corner of a large field of a yellow dent race. An examination of the sweet corn grown under these conditions and fertilized naturally showed a large number of mixed ears. In the rows which were immediately adjoining the rows of dent corn almost every ear contained many kernels which were smooth and yellowish like the dent corn, an effect doubtless due to xenia. (Pl. II, figs. 12–13, and Pl. IV, fig. 2.) In some instances the kernels showing xenia largely predominated so that a particular plant of sweet corn would be producing an ear composed largely of yellow dent kernels. In this instance, furthermore, the writer was able to notice the distance to which the pollen was carried, although this feature is of course governed by the prevailing winds, etc. Passing away from the dent corn farther and farther into the patch of sweet corn the number of ears showing xenia greatly diminished, until on the opposite side of the small patch of sweet corn, only about 200 feet from the dent corn, very few ears could be found showing kernels crossed with dent pollen.

The article by Professor De Vries above referred to, calling attention to double fecundation as being a probable explanation of xenia, is based on an experiment where sweet corn was crossed with pollen of a dent race and showed xenia the same as in the cases described here. In Kellerman and Swingle's[1] experiments two ears of Cory Sweet, a reddish sort, were crossed with Extra Early Adams Table, a white dent. One of the resulting ears clearly showed xenia in having smooth kernels mixed with the wrinkled ones, while the other, which matured but few kernels, gave no visible indication of having been crossed.

DENT CORN CROSSED WITH DENT CORN.

Experiment 2a, Leaming Yellow ♀ × *Hickory King* ♂.—The plants were grown and crossed at Washington in 1898. A small ear developed which matured only forty-six kernels, none of which showed any indication of xenia, being like the seed planted so far as could be observed.

These forty-six kernels were planted at Lincoln, Nebr., in the summer of 1899, and almost all of the plants grown from them proved to be true hybrids about intermediate between the two parents. Ears

[1] Kellerman and Swingle, l. c., p 335.

on seven different plants were carefully inbred with their own pollen and all of these, as well as some thirty ears developed without inbreeding, showed the same intermediate characters. The cobs were white, like Hickory King, the male parent, but intermediate in number of rows, having from twelve to fourteen, while the mother parent has ordinarily from twenty-four to twenty-six and the father parent from eight to ten rows. Some kernels were yellowish throughout and about an equal number white throughout, while some were yellowish on the sides with white apexes. The different colored kernels were irregularly mixed together on the same cob.

Experiment 34a, Champion White Pearl ♀ × *Hickory King* ♂. The ear which resulted was twelve-rowed, with a white cob. No effect of xenia was visible unless the rather shorter and broader kernels were caused by the pollen parent. This is doubtful, however, as the ear was smaller than normal.

Experiment 42a, Leaming Yellow ♀ × *Champion White Pearl* ♂.—The ear which resulted was eighteen-rowed, with a red cob. About half of the kernels are yellowish throughout, as in the normal Leaming Yellow (Pl. I, figs. 30 and 31), and the others are yellowish on the sides, with white apexes. This would seem to be a case of xenia, as both the orange yellow color of the mother parent and the opaque white of the father parent are in the endosperm, the pericarp and testa being hyaline. There is a possibility that the seed of the Leaming Yellow used in this experiment may have been impure, but some of the same seed grown at Washington in 1898 and in 1899 came true, though this is not positive evidence of the purity of the individual kernels sown at Lincoln. The writer's experiments have not been sufficiently extended in crossing the races of dent corn to determine how generally xenia is shown. In the experiments conducted by Kellerman and Swingle[1] at the Kansas Experiment Station nineteen ears of various white dent races were crossed with pollen of yellow dent races. Of these, ten ears showed xenia by a change of color on some of the kernels, while nine ears remained unaffected. Seventeen ears of yellow dent races were crossed with pollen of white dent races, and of these twelve ears showed xenia by a change in the color of some of the kernels, while five ears remained unaffected. In these experiments the seed of the various races used was not positively known to be pure, and it is assumable that in some instances the results obtained may have been due to previous crossing. It is hardly probable, however, that all of the cases were due to this cause. The mixing of white and yellow races of dent corn when they are grown in adjoining fields is a matter of common observation with

[1] Kellerman and Swingle, Experiments in cross fertilization of corn. l. c., and Experiments in crossing varieties of corn. Second An. Rep. Kansas Agr. Exp. Sta., 1889, pp. 288–346.

corn growers. In the experimental plats at Lincoln, Nebr., where a number of races were grown from seed obtained from careful seedsmen (see history of sorts grown, pp. 14, 15), several marked instances of change in color were noted which must probably be attributed to xenia. Hickory King, Champion White Pearl, Boone County White, and Burr's White, all pure white races, showed many yellow kernels, evidently from crossing with pollen of yellow races. Pedrick's Perfected Golden Beauty and Leaming Yellow, pure orange-yellow races, both produced many kernels having white apexes evidently from crossing with white sorts. It would seem to be a very common thing in crossing yellow and white dent races for the apexes of the kernels to be changed in color while the sides and bases of the kernels remain the same, or nearly the same, as in the mother parent. Whitecap Dent showed many kernels with orange or yellow apexes or caps instead of white as in the parent race, an effect probably due to crossing with a yellow dent pollen.

In all of the dent races considered above in this section (Dent × Dent) the color is in the endosperm, the pericarp and the testa being hyaline. The color, therefore, we should expect to be shown as xenia if the endosperm is developed from a hybrid nucleus, as would be the case if corn has double fecundation the same as the lily. What occurs in the case of those races, however, like the red dent, where the color is in the pericarp? The writer has made no experiments with races of this sort, and thus can not answer the question. Kellerman and Swingle in their experiments above referred to used a red dent in a number of combinations, and while no statement is made as to the location of the color in the race which they used, it was doubtless located in the pericarp, as this is the case with all red dent sorts which have come under the writer's observation. Nine ears of yellow dent races which they crossed with pollen of red dent showed no indication of xenia so far as color was concerned. Of ten ears of white dent crossed with pollen of red dent nine ears showed no indication of xenia in the transmission of color, while one case, that of Shannon's Big Tennessee White ♀ × red dent ♂, is recorded as showing evidence of the cross in the color of the kernels. Whether this is a true case of xenia or due to impurity of seed or other cause can not be determined. It should be noted that the ear resulting from the cross is described as "not sufficiently matured for complete description and comparison." Some races of white dent even when, comparatively speaking, of perfectly pure strains show a tendency to exhibit a red or scarlet flush when they dry up before maturity and become somewhat moldy. Kellerman and Swingle also describe a case where red dent ♀ × Riley's Favorite ♂, a yellow dent, produced light-yellow grains like the male parent. As in the last-mentioned case, it can not be determined whether this is a case of true xenia or due to other causes. In none of these experiments so far as recorded was the seed grown previously and proved to be pure. The number of cases in which the red dent was used and gave no indication of the red color as xenia strongly suggests that the other cases were errors or due to other causes, and that the rule that no character outside of the endosperm can be shown as xenia holds here as in other cases. Further evidence on this point is furnished by the experiments of McCluer, where Cranberry corn, in which the color is in the pericarp, was used in crossing with other varieties. He summarizes his results as follows:

Color, where it is a character of the kernel and not of the seed coat, tends very strongly to pass from one variety to another. The peculiar color of the Cranberry did not seem to affect the other white varieties to which the pollen was applied. The Cranberry owes its color to the seed coat entirely; the kernel is white, and the variety is classed as a white corn.[1]

SWEET CORN CROSSED WITH SWEET CORN.

Experiment 15b. Stowell's Evergreen ♀ × *Black Mexican* ♂.—A small, poorly filled ear resulted, on which about two-thirds of the kernels were bluish black like the male parent, the color being limited to the aleurone layer, and the pericarp in both races being uncolored and hyaline. The kernels developed were rounded and quite different from the normal Stowell's Evergreen, but this was doubtless due to the few which matured on the ear. (Pl. II, figs. 10 and 11.) The color imparted to the kernels in this case is probably due to xenia, though the seed of the mother parent had not been previously grown under the writer's control, and so can not definitely be claimed to have been pure. Dark blue-black corn is not commonly grown, however, and is not very liable to be found as an impurity in the common races sold by seedsmen in the United States.

Experiment 36a. Black Mexican ♀ × *Stowell's Evergreen* ♂.—A small ear resulted, on which almost all of the kernels were apparently typical Black Mexican. Eight kernels were whitish, as if possibly affected by the cross, the bluish-black or plumbeous color of the endosperm being absent. Whether this can be considered as a case of xenia can not be told without further experiments.

DENT CORN CROSSED WITH FLINT CORN.

Experiment 37a. Iowa King ♀ × *Gilman Flint* ♂.—A fair sized ear developed with yellowish-white kernels having a large proportion of very hard corneous endosperm similar to the Flint parent. All of these kernels seem to clearly show xenia, but the purity of the female parent was not definitely known.

In Kellerman and Swingle's experiments four ears of white dent races were crossed with pollen of yellow or brown races of flint. Two ears showed xenia in producing yellow kernels and two remained unaffected.

[1] McCluer, Corn crossing. Ill. Agr. Exp. Sta. Bul. 21 (1892), p. 84.

FLINT CORN CROSSED WITH DENT CORN.

Experiment 4a, Gilman Flint ♀ × *Leaming Yellow* ♂.—The plants were grown and crossed at Washington in the summer and fall of 1898. A small ear resulted, all of the kernels of which resembled the seed of the mother parent, showing no indication of xenia.

In the summer of 1899 these were grown at Lincoln, and the majority, if not all of them, proved to be true hybrids. The plants were intermediate in size between the two parents, in general being larger and less inclined to stool and branch than the Gilman Flint. In all ears the kernels were yellow, but varied somewhat in the intensity of the color, some being light-yellow and others orange-yellow. Some kernels showed a slight dent at the apex while others were filled out like the mother parent. The majority had an opaque, starchy area at the apex, evidently derived from the male parent. In an examination of a number of ears of this hybrid it was found that among those ears which had kernels resembling mainly the flint parent, but more orange yellow, there were 11 ears with red cobs and 5 ears with white cobs. Among those ears which had kernels more plainly dented and did not show the flint characters so plainly, there were 9 ears with red cobs and 3 ears with white cobs. The red cob thus predominated in the hybrids, though the mother parent had a white cob.

Experiment 5a, Gilman Flint ♀ × *Hickory King* ♂.—The plants were grown and crossed at Washington, D. C., in the summer of 1898. Only eight kernels matured, all of which were pure orange yellow like the seed of the mother parent, showing no signs of xenia.

In the season of 1899 these eight kernels were grown and all proved to be true hybrids. The hybrid plants were intermediate in size between the two parents and stooled from the base considerably, as in the mother parent (Pl. III, fig. 1), three or four stalks developing from each kernel. These grew much taller and less bushy than the Gilman Flint. The ears, of which six were inbred, matured considerably earlier than Hickory King, but not so early as the Gilman Flint. The cobs of all the ears examined were white. The kernels were all slightly dented, smaller than in the Hickory King, and more flinty and hard, with a much larger proportion of clear, horny, or corneous endosperm. In color they were yellow or white, kernels of the same color being irregularly mixed in the same ear.

In neither of the above cases was any indication of xenia shown, but the races used in experiment 4a were unfavorable for the recognition of any effect of this sort, and in experiment 5a only eight kernels were developed. In Kellerman and Swingle's experiments five ears of yellow or brownish races of flint crossed with white dent gave no indication of xenia, while one ear of a white flint crossed with yellow dent showed xenia in the production of yellow kernels.

FLINT CORN CROSSED WITH SWEET CORN.

Experiment 39a, Gilman Flint ♀ × *Black Mexican* ♂.—Only a few kernels set, and these showed no indication of xenia. No other artificial pollinations of this combination were made, but some of the ears of Gilman Flint grown at Lincoln in 1899, and naturally fertilized, showed wrinkled kernels resembling sweet corn (Pl. II, fig. 7) mixed on the same ear with the normal kernels (Pl. IV, fig. 3). The seed of the Gilman Flint planted had been inbred artificially the previous season and had shown no sign of impurity, so that the writer thinks this to be an undoubted case of xenia. A row of Stowell's Evergreen was growing near the Gilman Flint, about 100 feet away, and the two races were in bloom at the same time. It is interesting to note that the wrinkled kernels of the Gilman Flint showing xenia were yellow like the normal Gilman Flint instead of white and hyaline like the Stowell's Evergreen. So far as the writer is informed no race of yellow sweet corn was grown near by from which the pollen could have come. The wrinkled kernels were more translucent than the normal kernels, in this regard resembling the sweet corn. In a number of the kernels which were wrinkled like sweet corn the effect seemed to be limited to certain portions of the kernel, half of the kernel being smooth like normal flint and half wrinkled like the sweet corn parent. This may be similar to the occurrence of color in spots in the endosperm, when shown as xenia, as in several cases cited above. These differences in composition in different portions of the endosperm, however, are not so easily recognizable as in the case of color differences and not so marked when observed.

SWEET CORN CROSSED WITH FLINT CORN.

No experiments were made with this combination, but an interesting case of apparent xenia occurred in the Black Mexican sweet corn which was grown at Lincoln in the writer's experimental field. On two ears of the Black Mexican over half of the kernels were smooth instead of wrinkled, resembling in shape the kernels of Gilman Flint which was growing in the next row 6 feet away. They were, however, dark blue-black in color like the typical Black Mexican. The smooth kernels, while hard and containing an abundance of corneous matter, nevertheless contained in the interior much more white, starchy matter than the typical kernels of the Black Mexican. Aside from the blue-black coloration, the endosperm was very markedly similar throughout to that of the Gilman Flint. While it can not be positively affirmed that this change in the characters of the kernels is due to xenia, because the seed used was not definitely known to be pure, yet the evidence is in favor of this interpretation of the phenomenon.

In Kellerman and Swingle's experiments above referred to, three ears of different sweet corn races crossed with flint corn pollen showed xenia plainly in producing smooth kernels like the male parent, and in being changed in color.

DISCUSSION OF RESULTS.

The experiments of the writer are in many cases open to the common criticism that the seed used was not known to be pure. In a number of instances, however, practically all of the possibilities of error were eliminated. In experiment 10a, where marked xenia occurred in the color of the aleurone layer, the seed from which the mother plant grew was from an ear of a pure race artificially inbred the previous year and thus known to be true to type. The year in which the cross was made, furthermore, no variation from the type was observed in inbred ears, but some kernels on ears open to cross-fertilization with adjoining races showed xenia, as would be expected. In the case of Hickory King ♀ × Cuzco 759 ♂ (experiments 1a, 1b, and 1c), where xenia was shown in the color of the aleurone layer, the seed used, while not previously cultivated by the writer, was produced by a careful seedsman who is known generally to use considerable care to grow pure seed. Inbred ears the same season showed no variation, and all of the kernels which showed xenia were found to be true hybrids, so that the possibility of error in this case is reduced to a minimum. The production of kernels resembling sweet corn on ears of Gilman Flint, produced from seed which had been inbred the previous year and thus known to be pure, is also considered by the writer to be an undoubted case of xenia. (See p. 291.) The same is true of the crosses of sweet corn with dent corn occurring in a field of sweet corn grown from seed of known purity by Mr. J. C. Bradt and examined by the writer. (See p. 241.) The other cases in which xenia has apparently occurred in the experiments of the writer, while open to some doubt, are, it is thought, more reasonably to be explained as caused by xenia than in any other way. The conclusion has, therefore, been reached by the writer that xenia does occur in maize, whatever its interpretation may be.

In all of the cases observed by the writer no exception has been found to the rule first asserted by Körnicke, that xenia is shown only in the endosperm, the portions of the kernel outside of the endosperm remaining unaffected. "Nach meinen Beobachtungen halte ich es aber gleichwohl für wahrscheinlich, dass der Mais, welcher einen gefärbten Inhalt der Kleberzellen hat, sich theilweis direct vererbt, aber auch nur dieser."[1] Color in the endosperm is frequently transmitted as xenia, but color in the pericarp apparently can not be thus

[1] Körnicke, l. c., p. 70: "According to my observations I consider it, however, to be probable that only in that maize in which the contents of the cells of the aleurone layer are colored is there an immediate effect of pollen."

shown, as red dent corn, where the color is in the pericarp, does not appear to cause xenia. (See p. 261.)

In the writer's experiments it was found that the plumbeous or bluish-black color of the aleurone layer of the endosperm in the Cuzco and Black Mexican races was apparently shown in almost all cases as xenia when these races were used as the pollen parents in crossing with white or yellow races of dent, flint, or sweet corn. Where, however, the race having the dark-colored aleurone layer is used as the female parent and is crossed with pollen of yellow and white races it would seem that xenia is not so liable to show, but the writer's experiments have not been sufficiently extended to demonstrate this conclusively. According to one of Correns's[1] propositions it is impossible for xenia to show as change of color when a race with a yellow endosperm and blue violet aleurone layer is crossed with a race in which the endosperm and aleurone layer are white or colorless. If the writer's hypothesis in regard to the formation of mosaic or variegated kernels by xenia, discussed in detail later on, is true, it would seem probable that races with dark-colored aleurone layers could, at least in some cases, be influenced by crossing with races with colorless aleurone layers. This question, however, can not be settled without further experiments.

The chemical composition of the endosperm has been found to be greatly changed as a result of xenia. Sweet corn crossed with pollen of dent or flint races produces smooth kernels with starchy endosperm like the male parent, this feature being very noticeable. In this case the sweet corn, if a dark-colored race like the Black Mexican, may produce the smooth, starchy kernels of the male parent, but retain its original color unchanged, as in the case of Black Mexican × Gilman Flint (see p. 291). If, however, the race of sweet corn used is hyaline, the color as well as the chemical composition may be changed as in the case of Stowell's Evergreen × yellow dent (experiments 13a and 13b, p. 23) or white dent (Pl. II, fig. 4). Dent races, however, in which the endosperm is starchy, do not seem to show xenia by changing to the sweet corn type of endosperm (experiments 11a, 16a, 31a, and 31b, etc.).

Flint races crossed with sweet corn may show xenia in the wrinkled type of sweet-corn endosperm produced as in the case cited of Gilman Flint × Stowell's Evergreen (p. 29; also Pl. IV, fig. 3). In this case the kernels, while showing the wrinkled character of the male parent, retained the yellow color of the mother parent. This instance of the effect of pollen from a race with sugary endosperm on a race with starchy endosperm in producing wrinkled kernels apparently with sugary endosperms forms an exception to Correns's proposition 14, that xenia may result in that "a more complicated chemical compound

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[1] Correns, l. c., Propositions 1, 2, and 14.

(starch) is laid down instead of a less complex compound ('Schleim,' dextrin?); never the opposite, whereby * * * a simpler substance is laid down instead of a more complicated one."[1] By crossing a white dent race with pollen of Black Mexican, a race of sweet corn, McCluer[2] obtained ears showing xenia in having many of the kernels bluish-black and wrinkled like the male parent. The wrinkling of the kernels here would indicate that the starchy endosperm of the Dent race had been modified and become similar to the sugary endosperm of the sweet corn. In describing the xenia produced in this case, McCluer says:

Ears produced by crossing a White Dent with pollen of Black Mexican had kernels varying in color from white to black. More than half the kernels were wrinkled and had the taste characteristic of sweet corn, while the rest, though showing the black color as much as the wrinkled or sweet kernels, were only less dented than is characteristic of the variety. The taste was not modified.

In the writer's experiments, however, particularly in the case of dent races with starchy endosperm crossed with sweet corn with sugary endosperm, there has been no indication of a modification of the chemical constitution, and while it seems probable that there may be exceptions to Correns's proposition, it would nevertheless seem to hold true in the great majority of cases.

The experiments and observations of the writer all favor the theory that xenia in maize is caused by the fecundation of the embryo sac nucleus by one of the male nuclei, as suggested by De Vries and Correns, and the evidence now available would seem to indicate that those cases of supposed xenia where the pericarp is influenced must be due to other causes or be explained as errors of observation. Giltay's[3] work has done much to clear up this matter, as cited in the introduction, because in no case other than corn was the occurrence of xenia supposed to be so thoroughly established as in peas. In his extensive experiments, however, Giltay secured no instance where the effect of the cross showed in the portions of the seed outside of the embryo, and the influence on the embryo itself is of course readily understood. The changes in the color of the embryo were visible through the hyaline seed coats, and unless closely examined the color might be interpreted as being in the seed coats. It must be remembered, however, that both Gaertner[4] and Berkeley,[5] in describing instances of xenia in peas which they had observed, distinctly stated that the color is in the seed coats, and it is yet too early to conclude that cases may not occur where the influence is shown outside of the endosperm.

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[1] Correns, l. c., p. 413.

[2] McCluer, Corn Crossing. l. c., p. 84.

[3] Giltay, l. c.

[4] Gaertner, Versuche und Beobachtungen über die Bastarderzeugung im Pflanzenreich, pp. 81 and 499. 1848.

[5] Berkeley, Gard. Chron., 1854, p. 404.

The fact that the embryo itself may be changed in color by cross, fertilization, as observed by Gaertner, Laxton, Darwin, Giltay, and others, favors the conclusion that the color in the endosperm of corn may be due to the fecundation of the embryo sac nucleus. If the embryo, the immediate result of the union of the male and female pronuclei, can show the effect of changed color in the seed, it favors the interpretation that the endosperm, the immediate result of the union of the endosperm nucleus with one of the male nuclei, would probably be able to show similar changes of color.

In the writer's experiments all kernels showing xenia, which have been grown, have proved to be true hybrids, and there can be but little doubt that this is usually if not always the case. Correns makes the definite statement that "the plant growing from a kernel showing xenia is always a hybrid." In races which show xenia on crossing the change may be used as a handy index to demonstrate that a certain kernel has been hybridized and is thus a convenient check in practical hybridization work. The converse of this proposition, however, that all seeds which have been hybridized show xenia, is not true, even in cases where xenia commonly occurs. In quite a number of instances of crosses of different races which commonly show xenia, no evidence of the cross was visible, the kernels remaining the same as those of the mother parent. This was very noticeably the case in experiments 1a, 1b, and 1c, where some of the kernels showed xenia, but where fifty-one which showed no indication of xenia proved to be undoubted hybrids. It would seem probable that in these cases the embryo sac nucleus was not fecundated, but developed without fecundation taking place. So little is known about double fecundation that, while it seems undoubtedly to occur in some plants, we do not know whether it is a process necessary to development. While the egg cell, which is the important organ, must in almost all cases be fecundated, a few truly parthenogenetic cases are known where the egg cell develops without fecundation having taken place. It would thus not be surprising if the embryo sac nucleus should be capable of functioning even if it were not fertilized. The evidence from the non appearance of xenia in so many instances of true hybrids of varieties where xenia may occur favors this interpretation.

The peculiar feature of xenia showing in spots on the kernels, as in Hickory King × Cuzco (experiment 1a, Pl. I, figs. 9–12), and occasionally on one-half of a kernel, as in Pedrick's Perfected Golden Beauty × Cuzco (experiment 20a, Pl. I, fig. 24), and Gilman Flint × Stowell's Evergreen (p. 29), is interesting in this connection. A hypothesis has occurred to the writer which may explain such phenomena, but the evidence in its favor is yet very incomplete. As stated above, in very many cases of true hybrids of parents capable of showing xenia no effect is produced, and in such cases the fecundation of the embryo-sac nucleus probably did not take place.

It is not improbable that in some cases the second sperm nucleus enters the embryo sac, but fails to unite with the two polar nuclei. In such cases it may be able to form a spindle and divide separately, the unfecundated embryo sac nucleus formed by the union of the two polar nuclei also dividing separately. If this occurs, there would then be formed, in the protoplasm of the embryo sac, nuclei of two distinct characters, one group from the division of the embryo sac nucleus and the other from the division of the sperm nucleus.

The nuclei which form the endosperm reproduce free in the cytoplasm of the embryo sac, the cell walls which delimit them not forming for some time, probably not until nearly the ultimate number of nuclei have been formed. Before a very large number is formed they move out from the center of the embryo sac and usually come to lie near the wall, where the nuclear reproduction continues. In the delimitation of the nuclei later by the formation of walls about them the process of wall formation begins at the periphery of the embryo sac and gradually extends inward. This process of endosperm formation, which is common in seed plants and is known to occur in wheat, is doubtless the process occurring in corn. If, then, the union of the second sperm cell with the embryo sac nucleus fails to take place and they both divide separately, when the nuclei formed by their division move out to the surface of the embryo sac the nuclei of male and female origin would probably become more or less interspersed. In their further division we would then have groups of cells of male origin here and there, interspersed between those of female origin. It is probable that when the nuclei become dispersed around the outer portion of the embryo sac they largely retain their individual location and sphere of influence, so that the nuclei resulting from the division of one nucleus after it has assumed a location at the surface remain near together and, ultimately, when delimited by walls, form a group of cells derived from the same nucleus. If this is the case, wherever a nucleus derived from the division of the second sperm nucleus is located, after migration to the periphery of the embryo sac, there would be formed ultimately an island of tissue which, being derived entirely from the male parent so far as the nucleus is concerned, would probably exhibit almost entirely the characters of the male parent. This hypothesis would account for the occurrence of such variegated kernels as were produced in experiment 1a (Pl. I, figs. 9–12).

When the migration of the nuclei from the center of the embryo sac to the periphery occurs, if the nuclei derived from the male nucleus have remained grouped together, as would probably occur, while those derived from the division of the embryo sac nucleus have remained grouped together in a similar manner, it is probable that in their migration to positions near the periphery of the embryo sac those from one group would come to occupy mainly one portion of the embryo sac, while the others would occupy the other portion. This would lead to the production of kernels where approximately half of the endosperm resembles one parent and the other half the other parent, as was the case in some kernels produced in Pedrick's Perfected Golden Beauty ♀ × Cuzco 7a ♂ (p. 21, Pl. I, fig. 24) and (Gilman Flint × Stowell's Evergreen (p. 29).

As bearing on this hypothesis it should be remembered that it is well known that in the egg cell proper of both plants and animals the male and female pronuclei do not fuse together intimately, but remain more or less distinct until the reorganization of the daughter nuclei after the first division, and among certain animals the maternal and paternal elements have been traced through several cell generations. Häcker[1] first found that in *Cyclops strenuus* the two pronuclei do not fuse, but give rise to two separate groups of chromosomes, which lie side by side at the equator of the first cleavage spindle, and in the daughter cells resulting from this division each nucleus consisted of two distinct lobes, which Häcker thought to represent the maternal and paternal elements. The truth of this was later demonstrated by Rückert,[2] who was able to trace the distinct groups of chromosomes derived from each parent, from the bi-lobed nuclei of the two-celled stage through the second cleavage, and in many instances distinctly recognized the double character of the nuclei in a much later stage, when the germ layers were being formed. In the division of the bi-lobed nuclei of the two-celled stage a double spirem and double group of chromosomes are formed, the spindles being almost entirely distinct and resulting in the formation of bi-lobed nuclei. In *Ascaris* also, the maternal and paternal chromosomes remain distinct for some time, according to Herla,[3] who was able to distinguish them perfectly as far as the twelve-cell stage. The male nucleus, furthermore, has been found by a number of investigators to be capable of independent division. This was shown in the now classical researches of Boveri[4] in fertilizing enucleated fragments of the eggs of sea urchins. Boveri showed that spermatozoa will enter enucleated fragments of eggs and that such fragments divide and give rise to dwarf larvæ, differing only from the normal in size and in containing only half the ordinary

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[1] Häcker. Die Eibildung bei Cyclops und Canthocamptus. Zool. Jahrb. V., 1892.

[2] Rückert. Ueber das Selbständigbleiben der väterlichen und mütterlichen Kernsubstanz während der ersten Entwicklung des befruchteten Cyclops-Eies. Archiv. f. mikroscop. Anatomie, XLV, 3. 1895.

[3] Herla. Étude des variations de la mitose chez l'ascaride mégalocéphale. Archives de Biologie, XIII. 1893.

[4] Boveri. Über die Befruchtungs und Entwickelungsfähigkeit kernloser Seeigel-Eier, etc. Archiv. f. Entwickelungsmechanik, II, 3. 1895.

number of chromosomes. Boveri's results, so far as the division of the enucleated fragments of eggs when fertilized is concerned, have been confirmed by several investigators, and there would seem to be no doubt of the correctness of the observation.

The facts thus established that in some cases among animals the male and female elements remain separate and almost entirely distinct through several divisions, and that the male pronucleus may in some cases form a spindle and divide alone without fusing with the female pronucleus, would seem to strengthen the probability that the second male nucleus which enters the embryo sac in maize may divide without uniting with the embryo sac nucleus, and thus give rise to the variegated or mosaic endosperm, as suggested by the writer. Again, the very recent observations of Guignard[1] on double fecundation are suggestive in connection with this hypothesis, as in Endymion he finds that the two polar nuclei, the union of which produces the nucleus of the embryo sac, approach and touch each other long before the penetration of the pollen tube into the ovule. But, although flattened at the point of contact, they do not fuse, their contours remaining quite distinct. It would seem quite probable that in some plants these two nuclei may fuse, or even divide, before the male nuclei enter the embryo sac, or be so far advanced that the male nucleus would not fuse with them, and thus result in its remaining isolated and dividing without fusing with a nucleus of female origin. It is of course certain that the fecundation of the embryo sac nucleus is not necessary to the formation of the endosperm in all cases, as in some plants the endosperm is known to form before fecundation takes place. So far as the writer is informed it is not known when the polar nuclei in corn fuse, but it is interesting to note that in Triticum, a related plant, Koernicke found that the polar nuclei approach each other and apparently become thoroughly fused together before fecundation takes place. Koernicke wrote:

> Wir erinnern uns, dass vor der Befruchtung die beiden Polkerne des Embryosacks sich zum sekundären Embryosackkern vereinigt haben. Dieser Doppelkern beginnt nach einiger Zeit, wobei man noch immer einen zarten Streifen bemerken kann, der auf seine Entstehung durch Verschmelzung zweier Kerne hindeutet, sich zu theilen. Die erste Theilung tritt gewöhnlich schon dann ein, wenn der Pollenschlauch im Embryosack angekommen ist und sich an die Eizelle angelegt hat. Nachdem die Befruchtung durch die Vereinigung des Spermakerns mit dem Eikerne vollzogen ist, hat der Endospermkern sich schon mehrfach getheilt.[2]

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[1] Guignard. In report of the March 12, 1900, meeting of the Paris Academy of Sciences. Nature, Vol. 61, p. 507. 22 March, 1900.

[2] Koernicke, Max. Untersuchung über die Entstehung und Entwicklung der Sexualorgane von Triticum. Verhand. d. naturhist. Ver. d. preuss. Rheinlande Westf. u. d. Regierungsbezirks Osnabrück, Bd. 53, Jahrgang 1896, p. 174. "We must remember that before fecundation the two polar nuclei of the embryo sac have united to form the secondary embryo sac nucleus. This double nucleus begins to divide after

A second hypothesis which has some evidence in its support, and which should be considered in the investigation of the problem, is the possibility that the second sperm nucleus fuses with one of the polar nuclei and that after their fusion takes place the other nucleus is repelled and develops independently. This would give rise to two groups of cells, as in the first hypothesis, one from the division of the fecundated nucleus and containing both maternal and paternal elements, and the other from the division of the unfecundated polar nucleus containing only maternal matter. If this process of fusion and cleavage took place, the ultimate distribution of the two groups of nuclei at the periphery of the embryo sac and the formation of islands of tissue of different origin and characters would probably occur as suggested in the discussion of the first hypothesis.

The further investigation of the fecundation of the endosperm nucleus will doubtless throw light on many questions now in doubt, and the above hypotheses are suggested to direct the attention of investigators to the desirability of obtaining evidence supporting or contradicting them.

NOTE.—Since the above bulletin went to press a second important paper by Prof. Hugo de Vries has appeared, entitled "Sur la fécondation hybride de l'endosperme chez le maïs" (Rev. générale de Bot., Vol. 12, pp. 129–137, 15 avril, 1900). The experiments described in his preliminary paper above referred to (p. 7) are described more in detail and with illustrations; and the connection of double fecundation with the production of xenia is more fully discussed. No important new features are given, however, which were not mentioned in his preliminary paper, so that no further discussion of the article is necessary in connection with the features brought out in this bulletin.

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a time, during which a delicate line can always be observed, indicating its origin through the fusing of two nuclei. The first division is usually already beginning when the pollen tube reaches the embryo sac and applies itself to the egg cell. By the time fecundation is effected through the union of the sperm nucleus with the egg nucleus the endosperm nucleus has already divided many times."

DESCRIPTION OF PLATE I.

[Figs. 1–31, natural size; fig. 32, x 200 diam.]

Figs. 1 and 2.—Hickory King: Anterior and posterior view of kernel.

Figs. 3 and 4.—Cuzco 759: Anterior and posterior view of plumbeous-colored kernel.

Fig. 5.—Cuzco 759: Posterior view of a mottled kernel, the color of which is all in the aleurone layer of the endosperm.

Fig. 6.—Cuzco 759: Posterior view of a mottled kernel, the dark blotches being due to color in the aleurone layer of the endosperm, and the reddish ferruginous flush to color in the pericarp.

Figs. 7 and 8.—Cuzco 760: Two kernels showing anterior and posterior views.

(The kernels of Cuzco figured in 3–8 are all simply the different colored kernels of a single very mixed race.)

Figs. 9–12.—Kernels of 1a (Hickory King ♀ × Cuzco 759 ♂), showing xenia, the dark plumbeous color of the male parent appearing in irregular blotches.

Figs. 13 and 14.—Kernels of 1a (Hickory King ♀ × Cuzco ♂), showing no indication of xenia.

Figs. 15 and 16.—Two kernels of first generation hybrid No. 5 from experiment 1a (Hickory King ♀ × Cuzco 759 ♂). The general coral red or rufus color is limited to the pericarp, as in the Cuzco kernel shown in fig. 6, while the dark blotches shown in fig. 16 are caused by color in the aleurone layer of the endosperm, as in the case of the kernel in fig. 9, showing xenia, which is a painting of the original kernel from which hybrid No. 5 grew.

Figs. 17 and 18.—Two kernels of first generation hybrid No. 23 from experiment 1a (Hickory King ♀ × Cuzco 759 ♂). The ferruginous or fuscous color here is in the pericarp and is evidently derived from the male parent, being similar to that of the Cuzco kernel shown in fig. 6.

Figs. 19 and 20.—Kernels of 1d (Hickory King ♀ × Cuzco 759 ♂), showing xenia, the plumbeous or heliotrope-purple color, which is limited to the aleurone layer, coming from the male parent.

Figs. 21 and 22.—Kernels of 10a (Hickory King ♀ × Cuzco 759 ♂), showing xenia, the heliotrope-purple color derived from the male parent being located in the aleurone layer. (Compare cross section of one of these kernels, fig. 32.)

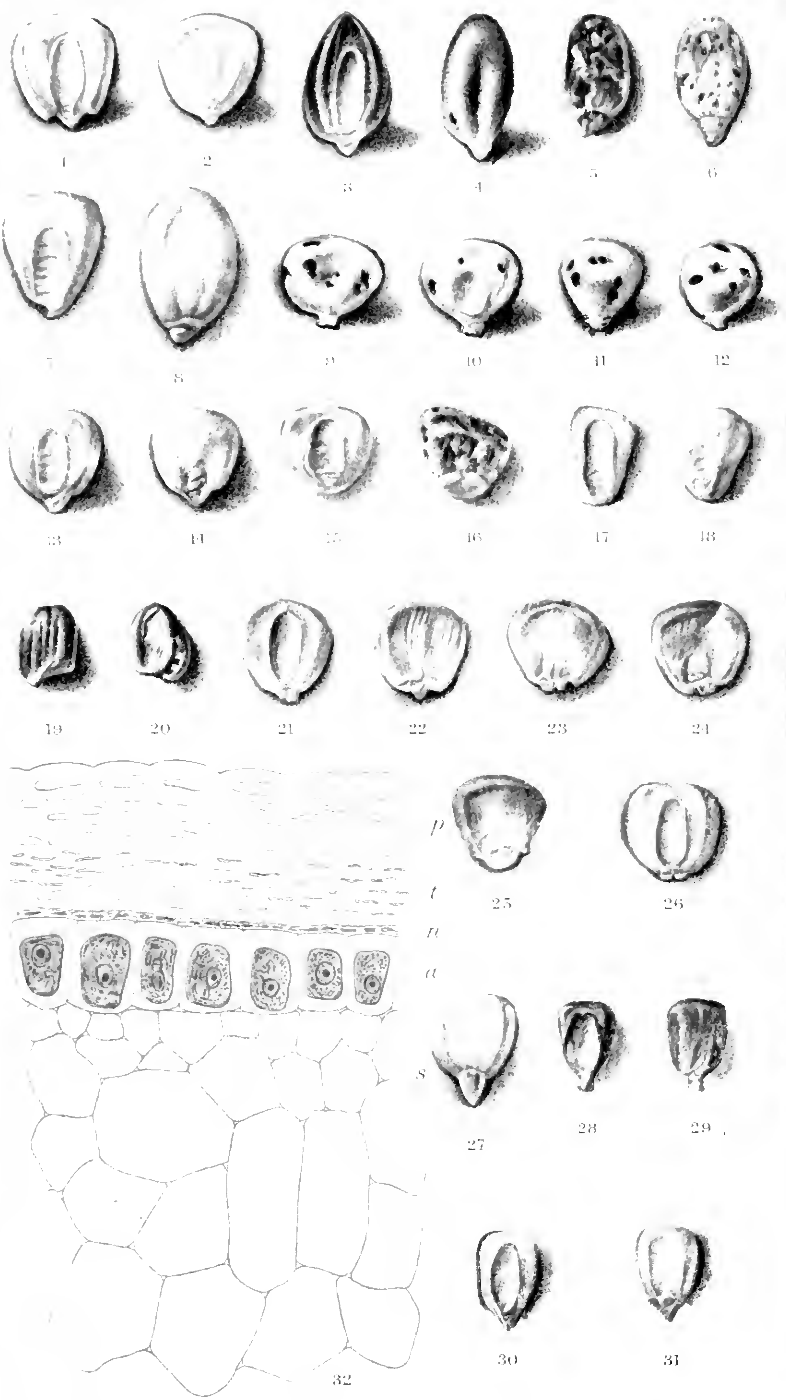
Figs. 23, 24, and 25.—Kernels of 20a (Pedrick's Perfected Golden Beauty ♀ × Cuzco 7a ♂), showing xenia, the plumbeous or heliotrope-purple color derived from the male parent being located in the aleurone layer. (Kernels of typical mother parent used in this experiment are shown in figs. 26 and 27, and those of father parent in figs. 3, 4, 5, and 6, as Cuzco 7a is simply seed from an inbred ear of the typical Cuzco.)

Figs. 26 and 27.—Kernels of typical Pedrick's Perfected Golden Beauty, which was used as the mother parent in experiment 20a. (Compare figs. 23, 24, and 25.)

Figs. 28 and 29.—Kernels of 41a (Leaming Yellow ♀ × Cuzco 759 ♂), showing xenia, the dark plumbeous color derived from the male parent being limited to the aleurone layer. (Typical kernels of the mother parent are shown in figs. 30 and 31.)

Figs. 30 and 31.—Kernels of Leaming Yellow, which was used as the mother parent in experiment 41a. (Compare figs. 28 and 29.)

Figs. 32.—Cross section of kernel of 10a (Hickory King ♀ × Cuzco 759 ♂), showing xenia, the heliotrope-purple color derived from the male parent being limited to the aleurone layer: p. pericarp; t, testa; n, nucellus; a, aleurone layer of endosperm; s, starchy endosperm.



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COLOR CHANGES IN KERNELS OF CORN, PRODUCED BY XENIA.

DESCRIPTION OF PLATE II.

[Figures all natural size.]

FIG. 1.—Leaming Yellow: Anterior and posterior views of kernels.

FIG. 2.—Champion White Pearl: Anterior and posterior views of kernels.

FIG. 3.—Stowell's Evergreen: Anterior and posterior views of kernels.

FIG. 4.—Kernels of Stowell's Evergreen, showing xenia from crossing with pollen of Champion White Pearl. (Compare with male parent, fig. 2, and female parent, fig. 3.)

FIG. 5.—Kernels of Stowell's Evergreen, showing xenia from crossing with pollen of Leaming Yellow. (Compare with male parent, fig. 1, and female parent, fig. 3.)

FIG. 6.—Gilman Flint: Anterior and posterior views of kernels.

FIG. 7.—Kernels of Gilman Flint, showing xenia from crossing with pollen of Stowell's Evergreen. (Compare with male parent, fig. 3, and female parent, fig. 6.)

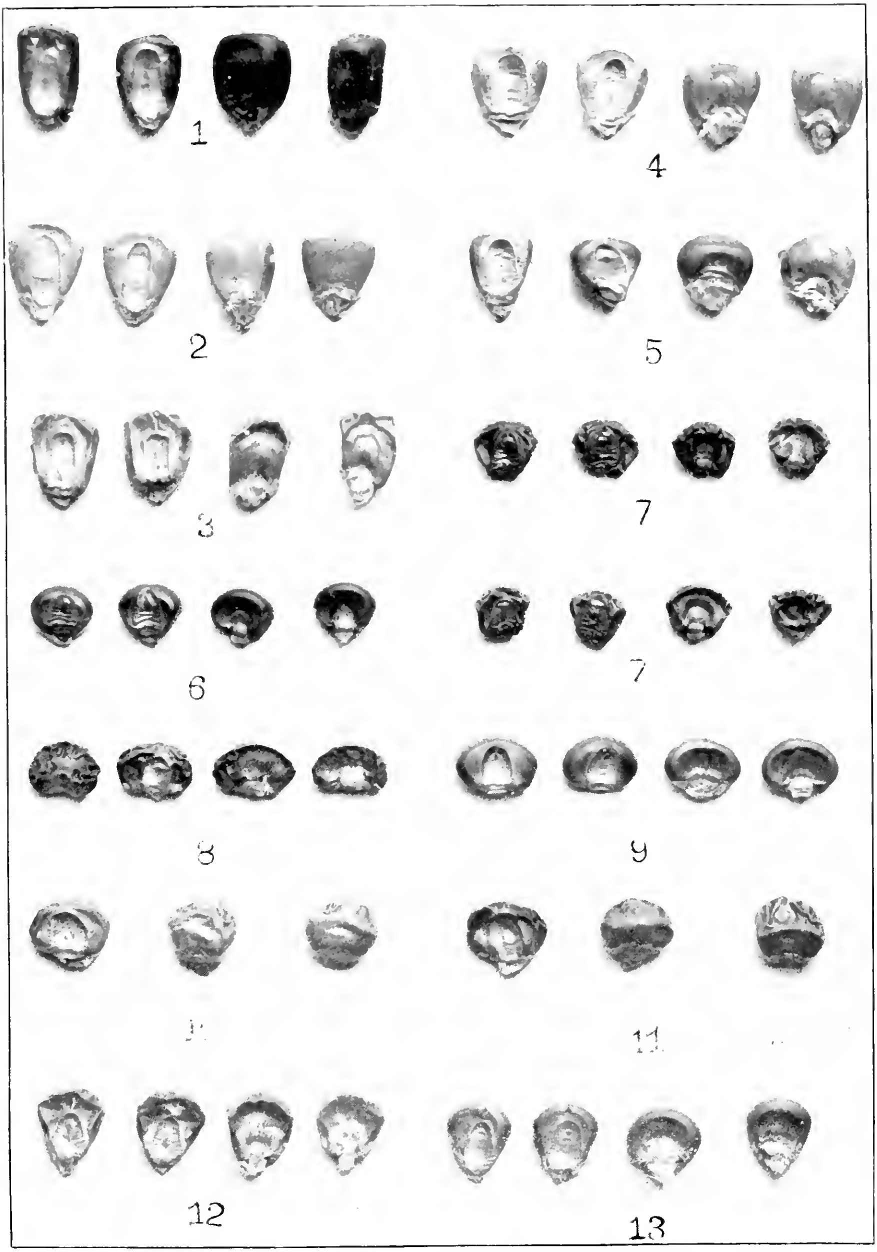
FIG. 8.—Black Mexican: Anterior and posterior views of kernels.

FIG. 9.—Kernels of Black Mexican, showing xenia from crossing with pollen of Gilman Flint. (Compare male parent, fig. 6, and female parent, fig. 8.)

FIG. 10.—Kernels of Stowell's Evergreen ♀ × Black Mexican ♂ (experiment 15b), which are white and transparent, resembling the mother parent.

FIG. 11.—Kernels of Stowell's Evergreen ♀ × Black Mexican ♂ (experiment 15b), showing xenia in the blue-black color imparted to the aleurone layer of the endosperm. (Compare unaffected kernels from same ear, which are shown in fig. 10, and also male parent, fig. 8, and female parent, fig. 3.)

FIGS. 12 and 13.—Kernels from an ear of a pure race of white sweet corn, some of which show xenia from crossing with pollen of a yellow dent race. Those of fig. 12 are normal, evidently having been self-fertilized, while those shown in fig. 13 show xenia.



CHANGES IN FORM AND COLOR OF KERNELS OF CORN, PRODUCED BY XENIA.

DESCRIPTION OF PLATE III.

Fig. 1.—Hybrids of Hickory King ♀ × Cuzco 759 ♂ (first-generation hybrid from experiment 1d), showing increased vigor. In order to show the size as compared with the parents the attendant held a stalk of Hickory King in his left hand and one of Cuzco in his right hand.

Fig. 2.—Central stalk a hybrid of Hickory King ♀ × Cuzco 759 ♂; stalk on left Hickory King, the mother parent; stalk on right Cuzco, the father parent. (Stalks in each case of maximum size, the largest that could be selected from the experimental plats.)

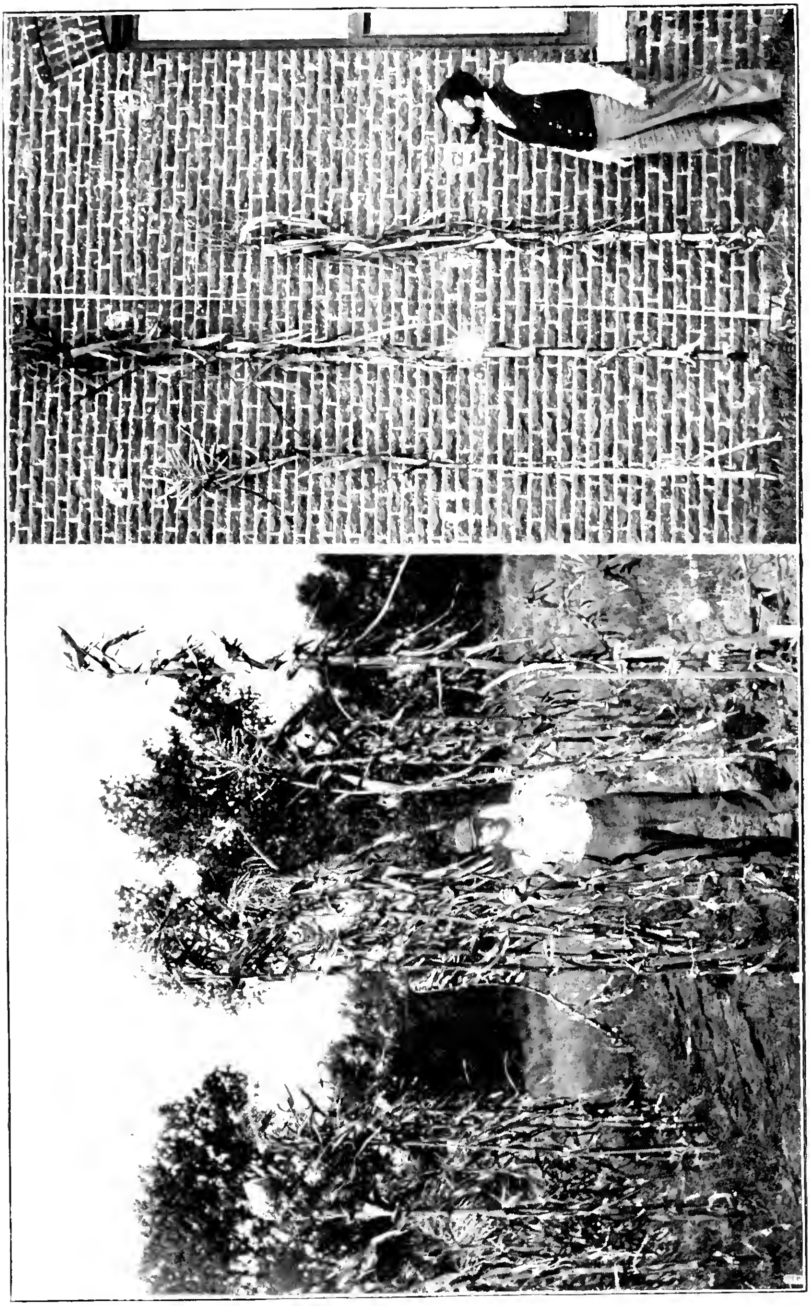


Fig. 1. Fig. 2.

FIRST GENERATION HYBRIDS OF HICKORY KING CORN ♀ × CUZCO CORN ♂, AND TYPES OF PARENT STALKS FOR COMPARISON.

DESCRIPTION OF PLATE IV.

Fig. 1.—Hybrid and parents: Hill in center, a first generation hybrid of Gilman Flint ♀ × Hickory King ♂, grown from one kernel (experiment 5a); hill on right, Gilman Flint, the mother parent; hill on left, Hickory King, the father parent.

Fig. 2.—Ear of sweet corn, the smooth kernels of which show xenia from crossing with pollen of a yellow dent race. Natural size. (See p. 24.)

Fig. 3.—Ear of Gilman Flint, the wrinkled kernels of which show xenia from crossing with Stowell's Evergreen. Natural size. (See p. 29.)

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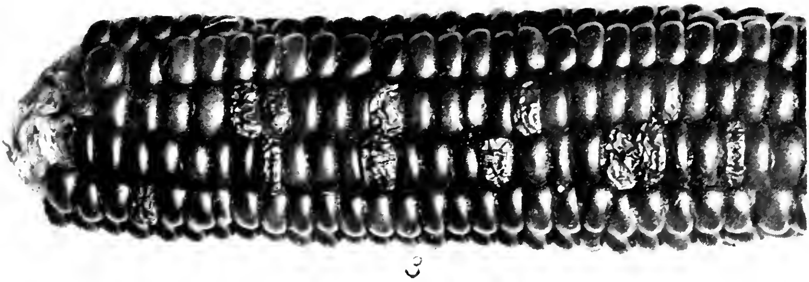

3

COMPARISON OF HYBRID OF GILMAN FLINT CORN ♀ · HICKORY KING CORN ♂ WITH PARENTS, AND EARS SHOWING CHANGE CAUSED BY XENIA IN COMPOSITION OF KERNELS.