UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 712

Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief

Washington, D. C. **PROFESSIONAL PAPER** **October 29, 1918**

APPLE POWDERY MILDEW AND ITS CONTROL IN THE ARID REGIONS OF THE PACIFIC NORTHWEST.[1]

By D. F. Fisher,
Assistant Pathologist, Fruit-Disease Investigations.

CONTENTS.

ECONOMIC IMPORTANCE OF POWDERY MILDEW.

Apple powdery mildew is usually considered as of only minor importance and principally affecting nursery stock in the eastern part of the United States, only becoming serious in restricted localities. Occasionally it is severe in Utah, Colorado, New Mexico, and the East on old trees, but in the apple-growing districts of the Pacific coast the conditions are such that it often becomes serious. The arid climate of the hot interior valleys of the Pacific Northwest has proved an effective safeguard against fungous diseases in general, but apple powdery mildew is endemic.

In these regions, where deciduous-fruit growing, and especially apple growing, has become such an important industry, orcharding is generally carried on under very intensive conditions and the in-

[1] Acknowledgment is due Dr. Charles Brooks, of the Office of Fruit-Disease Investigations, Bureau of Plant Industry, for many helpful suggestions during the course of the work, and to Messrs. E. J. Newcomer, of the Bureau of Entomology, and M. M. Brown and L. C. Carey, formerly assistants in spraying experiments, who actively assisted in the field work.

dustry is highly specialized. In the Wenatchee Valley, Washington, where the experimental work herein reported was carried on, the arable land is almost entirely taken up with apple orchards; and, having a high valuation, it is cut up into small holdings, the average orchard area being somewhat less than 10 acres for each owner. Great attention is given to every detail of the orchard operations; pests and diseases are vigorously combated, and every effort is made to produce a maximum amount of the perfect high-colored fruit which has made this region notable. Imperfections and markings affecting only the appearance of the apples cause a loss of grade and consequent financial loss to the grower. If, as in the case of apple powdery mildew, there is added to this effect a lessened production, every effort to remove the cause is justified.

The seriousness of apple powdery mildew is greatly modified by the character of the season in any given year. The spread of infection is greatly facilitated by a rainy spring. During seasons when conditions for spore germination are most favorable the disease assumes epidemic proportions and is the cause of serious loss. It not only attacks the foliage and tender wood growth, but also destroys fruit buds and directly attacks the fruit. In the Wenatchee Valley the russeting of the fruit is considered one of the most serious effects of the disease.

REVIEW OF THE LITERATURE.

The first mention of the disease in this country was made by Bessey (1)[1] in 1877. He reported a serious outbreak of powdery mildew (*Podosphaera kunzei*) on seedling apples and cherries in the college nursery in 1871.

The fungus was first described as *Sphaerotheca leucotricha* by Ellis and Everhart (2) in 1888.

Galloway (3) carried on the first extensive experimental work and published the first recommendations for control. In 1889 he reported that the disease occurred abundantly through all the region east of the Mississippi. He found that it was confined to attacks on young trees in the nursery, especially seedlings, the leaves becoming dry and brittle and of so little use that the trees were rendered worthless for budding. He stated that the disease is spread by wind dissemination of spores, aided by insects, rain, and other agents. He pointed out that the ascospores are of no practical importance and that the fungus winters over in mycelial form. In a later publication (4) he reported the successful use of ammoniacal copper-carbonate spray in controlling the disease.

---

[1] The serial numbers in parentheses refer to "Literature cited" at the end of this bulletin.

Burrill (5) in 1892 changed the name of the fungus to *Sphaerotheca mali* (Duby), identifying it with *Erysiphae mali* of that author, but this fungus was later identified as *Phyllactinia corylea* (Pers.) Karst.

Grout (7) accepted Burrill's identification. He found that the perithecia matured late in the season and were usually found on the shoots, seldom on the leaves, which he suggested might account for the rarity of their collection and the confusion in nomenclature.

In 1894 Pammel (6) called attention to the disease in Iowa, stating that it was of common occurrence. He recommended the use of Bordeaux mixture instead of ammoniacal copper carbonate as a spray, In a later publication (8) he discussed the confusion in nomenclature and suggested that it is doubtful whether perithecia of *Podosphaera oxyacanthae* were ever actually seen on the apple in this country.

The early confusion of the identity of the fungus was cleared up by Salmon (9) in 1900. He definitely referred the fungus to *Podosphaera leucotricha.*

The first report of the disease from the State of Washington was by Lawrence (10) in 1905. He described the different species of powdery mildews occurring in the State but did not recognize *Posdosphaera leucotricha.*

In 1910 Stewart (11, p. 318–321) reported that he had found no other species than *Podosphaera leucotricha* on apples in New York. He found the disease chiefly on water sprouts and nursery stock, but also found it on the terminal growth of trees 36 years old. He noted that the Chenango and Black Ben Davis varieties are particularly susceptible.

In 1914 Ballard and Volck (12) published a very complete description of the occurrence and control of the disease in the Pajaro Valley of California, where the climatic conditions are particularly favorable to the development of the disease in serious epidemic form. They found that fully 90 per cent of the foliage of susceptible varieties, such as Yellow Newtown and Yellow Bellflower, was frequently diseased. They found that Bordeaux mixture gave very poor mildew control. Copper acetate and copper oxychlorid were effective against the mildew, but caused injury to the fruit and foliage. Dilute lime-sulphur solution and solutions of sulphids in general were likewise injurious. About 125 different materials were tested for foliage spraying, and as a result it was found that sulphur in some finely divided form was the most efficient. Specific directions were given for the preparation of an "iron-sulphid" spray whereby the soluble sulphids so injurious to foliage in that climate were eliminated. Attention was called to the importance of pruning out diseased twigs as a supplemental aid in control. The important relation between tree vigor and susceptibility to mildew was shown and experiments were reported which demonstrated the possibility of foliage stimulation through spraying with various compounds.

THE CAUSAL ORGANISM.

The cause of apple powdery mildew is the fungus *Podosphaera leucotricha* (E. and E.) Salm. Another species of Podosphaera, *P. oxyacanthae* (DeC.) DeBary, has been reported as the cause of this mildew in some eastern localities, but the writer has never found it on the apple in the Pacific Northwest.

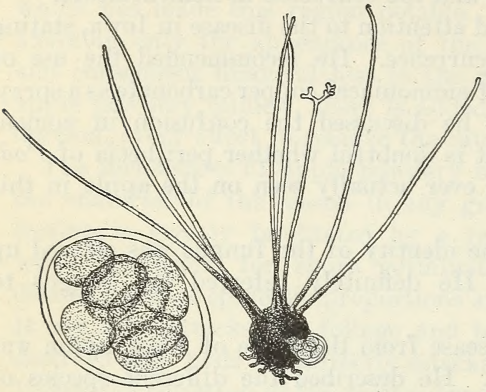

FIG. 1.—Perithecium and ascus of *Podosphaera leucotricha* (E. and E.) Salm. (The former is magnified 80 times and the latter 420 times.)

The two species can not be distinguished except in their perfect stage, when marked differences are observed. In the case of *Podosphaera leucotricha* there are two types of appendages on the perithecia. The basal appendages are short, twining, and rootlike, while the apical appendages are long, slender, stiff, and rarely divided at the tips. Perithecia of *P. oxyacanthae* have appendages placed more or less equatorially and all dichotomously branched at the tips. They are usually all of one type, but rootlike basal appendages are also sometimes found. The distinction between the two species is shown in figures 1 and 2.

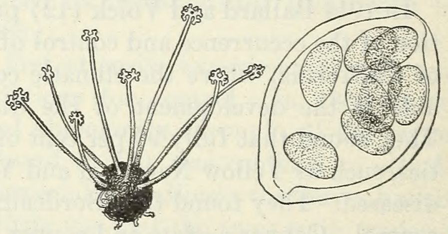

FIG. 2.—Perithecium and ascus of *Podosphaera oxycanthae* (DeC) DeBary. (The former is magnified 80 times and the latter 420 times.)

It is probable that much of the confusion which has arisen in regard to the identity of the species involved is due to the fact that in most localities the perfect stage is produced but sparingly. However, in the Wenatchee Valley this stage is abundant, and repeated examinations of perithecia have never revealed other than *Podosphaera leucotricha* on the apple. *P. oxyacanthae* has, however, frequently been found by the writer on the native bitter cherry (*Prunus emarginata* (Dougl.) Walpers) and on the western chokecherry (*Prunus demissa* (Nutt.) Walpers) growing in close proximity to apple trees.

DISSEMINATION OF THE FUNGUS.

In the Wenatchee Valley the spread of the fungus during the growing season is largely dependent on the prevalence of dews. Light rains occasionally occur, but moisture for most of the spore germination is found in the dews, which are of almost nightly occurrence. While the humidity of the air in the Wenatchee Valley is usually very low, it is much higher in the orchards which are being irrigated. The daily range of temperature varies between 25 and 30 degrees F. during most of the early part of the season, and often it is even greater; consequently, dews are frequent and occur in the orchards when other sections are free from them.

Spore dissemination is doubtless accomplished by the agency of the wind. During the early part of the season strong winds are of common occurrence and often blow steadily for days. The branches of the trees are whipped about, and the conidia are scattered around and lodged on tender young leaves and shoots. With the coming of nightfall and dews, favorable conditions for spore germination arise and infection proceeds.

Beetles were often found feeding on the mildew, and they may be responsible for some of the spread of the fungus; but they were never found in sufficient numbers to indicate that they were important agents in its dissemination.[1]

The perfect stage of *Podosphaera leucotricha* begins to appear as early as the middle of June, when black speckled patches of perithecia form in the felted mycelium on twigs, leaf petioles, and midribs (Pl. I, fig. 1), and occasionally on the fruit.

The perithecia have been observed from year to year in an attempt to determine definitely whether they play any appreciable part in the dissemination of the fungus. The dates of the earliest collection of perithecia in the Wenatchee Valley during the course of this investigation are as follows:

In 1915, on June 22, three months after the appearance of the first leaves.
In 1916, on June 13, two months after the appearance of the first leaves.
In 1917, on June 29, two months after the appearance of the first leaves.

Twigs bearing perithecia were brought into the laboratory at frequent intervals in the spring for examination to determine the date at which the spores were shed. None of the perithecia were found ruptured until fully a month after conidia had become abundant on the current season's growth. Frequently no ruptured perithecia could be found until after new perithecia had developed on the current season's growth. Early in the spring it was difficult to break

[1] Identification of the insects discovered feeding upon the mildew has been made by Mr. E. J. Newcomer, of the Bureau of Entomology, as follows: The most abundant, a ladybird (*Psyllobora borealis* Casey); the next common, a small, pointed, black and brown beetle (*Pentaria nubilia* Le Conte); and the rarest, *Anthicus nitudulus* Le Conte.

the perithecia under a cover glass for microscopic examination, but after soaking in water for 24 hours they were much more easily broken, indicating that rainfall would facilitate natural ascospore dispersal. However, rainfall adequate for this purpose is always lacking in the Wenatchee Valley at this season.

Repeated attempts were made to inoculate tender young foliage with ascospores obtained from perithecia of the previous season's growth. A suspension of spores was sprayed on Jonathan leaves with an atomizer. Some of the leaves were inclosed in glassine bags in order to increase the humidity, while others were left exposed. The work was done between the middle of May and the first of June, when the disease was actively spreading in the orchards. The results were always negative. It would appear from these studies that the ascospores play little, if any, part in spreading the disease and that they are unnecessary to the overwintering of the fungus. This conclusion is in agreement with the results of the investigations of Ballard and Volck (12) in the Pajaro Valley of California and the earlier work of Galloway (3).

DESCRIPTION OF THE DISEASE.

In the Wenatchee Valley the writer has found the disease in its conidial and perithecial stages on twigs, foliage, and fruit of the apple, and occasionally also on pear twigs and foliage. It sometimes attacks the blossoms, and in this case frequently the entire blossom cluster, with its attendant leaves, is involved. Affected flowers are dwarfed and hypertrophied and set no fruit. The petals are deformed, are of a greenish or yellow color, and soon become covered with a powdery coating of spores. (Pl. I, fig. 3.)

The first appearance of the disease is usually manifested in small grayish or white feltlike patches of mycelium on the under sides of the leaves, which become crinkled and curled. (Pl. II, fig. 1.) Often the presence of the fungus can be detected before the appearance of the felted mycelium by the mottled color of the infected leaves, accompanied by a corrugation of their surface. The patches covered by the fungus rapidly enlarge, and generally the entire leaf becomes covered with the felted mycelium and a powdery coating of spores. When very young leaves are attacked they have a tendency to increase in length but not in breadth and gradually become somewhat folded longitudinally. (Pl. I, fig. 1 and Pl. II, fig. 1.) Infected leaves become greasy and eventually so brittle and parched that they fall from the tree. The mildew spreads rapidly down the petiole of the leaf to the twig, which becomes covered with mycelium and spores. Twig growth is soon checked, and in severe infections the twig is killed outright. (Pl. II, fig. 2.) In the Wenatchee Valley, trees covered with terminals killed by powdery mildew are frequently seen after a season of severe infection.

A serious phase of the disease is found in the case of twigs stunted but not killed. New leaves are infected as rapidly as they appear. Buds formed on such twigs are infected by the overwintering mycelium, and in the spring the fungus resumes activity when the leaves unfold, thus performing a function vital to the spread of the disease in carrying the fungus over from season to season. On such twigs the internodes are much shortened and the lateral buds are crowded together. (Pl. II, figs. 3 and 4.) These buds are characterized by a purplish red color and an elongated shape, and they are always delayed in opening from a week to 10 days behind normal buds. (Pl. II, figs. 4 and 5, and Pl. III.)

In cases of severe infection the formation of new fruit buds is prevented and the following season is one of a light crop or no crop at all. Vegetative growth, however, is favored by the absence of a fruit crop; hence, during such a season the trees are given an opportunity to recuperate their vigor and resist the mildew for the time being. But the following year an increased crop is produced, and mildew, again being favored by reduced vegetative vigor, resumes virulent activity and so tends to produce a periodicity of crops that is very undesirable.

The effects of fruit infection are to dwarf the apple and produce a russeting of the skin beneath the mycelium. (Pl. I, fig. 2.) Fruit infection usually occurs early in the season. Active infections on apples after the skin has become hardened have not been observed, and it is therefore probable that danger of such injury is past before the apple is half grown. Infected apples often show elongated stems, while the basins are generally russeted.

SUSCEPTIBILITY OF VARIETIES.

The varieties of the apple found to be most susceptible to the disease in the Wenatchee Valley are Pryor Red, Jonathan, Newtown, Black Ben Davis, Grimes, Esopus (*Spitzenburg*), Fameuse (Snow), and Stayman. No variety appears to be immune, but among the least susceptible are Winesap and White Pearmain. Of these varieties the Pryor Red and Fameuse are not commercially important in the Wenatchee Valley.

IMPORTANCE OF THE DISEASE IN THE PACIFIC NORTHWEST.

Apple powdery mildew occurs in all of the apple-growing regions of the Pacific Northwest, but its economic importance in any of them varies from year to year. Investigations by the writer have shown that the disease is of little economic importance in the Willamette Valley of Oregon and the sections of Washington west of the Cascade Mountains. In these sections infection seems to be confined to watersprouts and terminals and has not been observed to be as severe as that often met with in the irrigated regions. Where apple scab is prevalent, as in these more humid sections of the Northwest, the ordinary sprayings with lime-sulphur solution for scab control are effective against mildew, and its control in these sections, therefore, presents no unusual difficulty. In such districts as the Spokane Valley, Wash., the Hood River valley, Oreg., and other sections where natural rainfall can be relied upon for part of the moisture necessary for tree growth and where spraying for apple scab is generally practiced, the growers and horticultural inspectors are agreed that apple powdery mildew is of little or no economic importance. However, in the hot interior valleys, where irrigation is entirely depended upon for moisture supply and where fungicidal spraying has been regarded as unnecessary, the disease has demanded serious attention, and the development of a safe and effective spraying schedule has been attended with peculiar difficulties. Reports of the State horticultural inspectors indicate that serious loss is often experienced. Mr. C. W. Gilbreath, State horticultural inspector in the Walla Walla (Wash.) district, is authority for the following statement regarding the disease:

> The damage from apple powdery mildew in this district grew heavier each succeeding year and reached its maximum in 1915. As a result many orchards showed a reduction in crop of 25 to 50 per cent. Jonathan and Newtown are the most susceptible varieties.

That the disease is equally serious in the Yakima Valley, Wash., where the largest acreage of apple orchards in the Northwest is found, is indicated by the following statement of Mr. H. E. Waterbury, State horiticultural inspector for the district:

> Mildew is prevalent all over the valley on certain varieties, such as Jonathan, Spitzenburg, Newtown, and Rome. The loss occasioned is chiefly loss in vitality, which can scarcely be measured. I do not know of any orchards that do not have some mildew. There has been considerable loss from the so-called mildew scratches (russeting) on the fruit, which has reduced the grade. In some places the Black Ben Davis was so badly marked that fully 25 per cent had to be culled.

Observations by the writer in the Wenatchee Valley indicate that orchards often have shown a reduction of fully 75 per cent of the crop as a result of mildew infection and that frequently nearly all of the new wood growth is attacked, while foliage infection may reach 75 to 90 per cent. Its damage was most severe in many parts of the valley in 1914 and 1915, but each year sees appreciable losses in some orchards due to mildew infection. In 1915 many crops of Jonathan and Black Ben Davis were complete failures, due to the severity of the 1914 infection, while many other varieties were seriously damaged through fruit russeting, foliage infection, and twig blighting. Alarm over impending damage became so general

APPLE POWDERY MILDEW—I.

FIG. 1.—A late stage of foliage infection on Pryor Red watersprouts. Note that many of the leaves have been shed and that those remaining are covered with conidia and are somewhat folded longitudinally. The twigs are covered with mycelium, embedded in which may be seen the dark patches of perithecia, usually located at the base of a leaf and extending up on the petiole. FIG. 2.—Mildew russeting of a Black Ben Davis apple, August, 1916. FIG. 3.—Mildewed blossom cluster from a Pryor Red tree. Note the abundance of conidia over leaves and blossoms and the deformity of the blossoms.

APPLE POWDERY MILDEW—II

FIG. 1.—Portion of the terminal growth of a Black Ben Davis tree, showing an early stage of foliage infection. FIG. 2.—Branch of a Jonathan tree, showing a terminal spur killed by an infection of the previous year and three spurs blighted during the current season. This branch had been sprayed with lime-sulphur solution and the mildewed leaves were severely burned, while the healthy foliage was unharmed. FIG. 3.—Branch of a Pryor Red tree, showing two years' growth, with lateral buds on the portion infected during the first year pushed out into spur growth. Note the shortened internodes. FIG. 4.—Terminal growth on a Pryor Red tree, showing shortened internodes on the infected portion. The noninfected buds are swelling, while those infected are still dormant. FIG. 5.—Portion of a branch of a Pryor Red tree, showing noninfected cluster buds opening and considerable expansion of healthy foliage, while infected leaf buds near the tip of the branch are still nearly dormant. FIG. 6.—An apple, showing injury resulting from the application of sulphur-dust sprays in the Yakima Valley in 1917. FIG. 7.—Pryor Red apple, showing sulphur injury, the type of injury which may be expected to follow applications of sulphur sprays after the advent of hot weather in the arid valleys of the Pacific Northwest.

APPLE POWDERY MILDEW—III.

Branch from a Jonathan tree, showing a terminal twig killed by the infection of the previous year. Note that the petals are beginning to fall from the healthy blossoms on the lower portion, while the blossoms from the infected buds near the terminal twig are not yet open.

in 1915 that for the first time in the Wenatchee Valley systematic spraying for a fungous disease was undertaken.

In general, the methods followed were based upon the recommendations of Ballard and Volck (12) for the Pajaro Valley of California; but since the climatic conditions under which they found soluble sulphids injurious to foliage were not prevalent in the Wenatchee Valley, the somewhat laborious process of removal of these compounds from the iron-sulphid spray was not attempted and a modified formula was used. (See formula 7, p. 11.) A considerable quantity of commercial spray preparations was also used. According to a report of Mr. O. T. Clawson, then State horticultural inspector for the Wenatchee district, the following quantities of spray materials were sold for mildew spraying in 1915:

Commercial sulphur pastes	17,850 pounds.
Lime-sulphur solution	11,600 gallons.
Iron sulphate (for making iron-sulphid spray)	31,000 pounds.

SPRAY INJURY.

It has not been difficult to control the mildew effectively with any one of several of the sulphur spray materials commonly employed for spraying, but their use during the intensely hot summer weather in the arid districts of the Northwest has invariably been attended with severe fruit burning and some foliage injury.

The importance of climatic factors on spray practices in mildew control has been pointed out by Ballard and Volck (12). However, the difficulty experienced in the Pajaro Valley of California, i. e., defoliation and the dropping of fruit caused by sulphur injury, is seldom met with in the irrigated regions of the Northwest, apparently because of the absence of the foggy weather which is so prevalent in the Pajaro Valley. Sulphur burning on the fruit is found to be the chief reaction induced by climatic conditions in the irrigated sections of the Northwest. Fruit dropping following sulphur injury is only occasionally met with, and foliage injury usually is of minor importance when it occurs at all. However, sulphur spotting of the apples has often resulted in more loss than the mildew would have caused. Growers have therefore largely abandoned attempts to spray for the disease until a safe spraying program could be developed.

Sulphur spotting is always confined to apples on the south and southwest sides of the trees and involves only those apples exposed to the direct rays of the sun during the hottest part of the day. Apples shaded by the foliage are never affected.

In the Wenatchee Valley no injury has resulted from sulphur sprays applied before the middle of May. Sprays applied after this date have generally resulted in the fruit burning as soon as hot weather starts, and sprays applied early in June have invariably resulted in injury. In some cases intense burning sunlight has not occurred until fully two weeks after the spraying was completed, but still severe burning of the fruit resulted.

The adoption of adequate spraying methods is largely dependent on the safety with which they may be used. The data secured on injury in connection with the use of various sprays during the course of the experiments reported below will therefore be of value in pointing out the weather conditions under which burning occurs, the type of injury resulting, and the time at which the sprays may be safely applied. These data are presented in connection with the experiments herein reported.

ORCHARD SPRAYING EXPERIMENTS.[1]

The orchards used were adjacent to each other and for the purposes of this work can be considered as one. The trees used were a solid block of the Pryor Red and Jonathan varieties, the experimental plats each consisting of adjacent rows of seven trees each, while the Black Ben Davis plats comprising a like number of trees were located in double rows extending across the orchard. The trees were 14 years old at the beginning of the experiments in 1915.

The Pryor Red trees have a very open habit of growth, and although they had been cut back severely to bring them into more workable shape they still had a spread of about 30 feet and were about 30 feet high. When in full foliage they required about 25 gallons of spray material per tree. The Black Ben Davis trees were not spread out as much, but were more compact and dense. They required about 20 gallons of spray material each. The Jonathan trees were smaller than those of the Black Ben Davis and more open, requiring about 10 to 15 gallons of spray material per tree. All had been infected with mildew for several years, the disease being especially severe in 1914, when the crop of the Pryor Red trees was reduced to an average of 2 bushels each, although the trees were otherwise capable of producing at least 30 bushels. The Black Ben Davis and Jonathan trees had produced a somewhat heavier crop than those of the Pryor Red, but in every case the foliage and twig growth had been seriously infected and many terminal branches had been killed.

The experiments were undertaken to determine—

(1) The most effective fungicides for use against apple powdery mildew.
(2) The most desirable dates for spraying.
(3) The possible toxic effects of the various spray materials tested.

A high-power spraying outfit of 200-gallons capacity was employed, a pressure of 200 to 250 pounds was maintained, and eddy-

[1] These experiments were carried out at Wenatchee, Wash., in the orchards of the V. & W. Land & Improvement Co. and of Mr. A. P. Kornbau, to whom acknowledgment is due for many courtesies extended during the course of the investigations and for active cooperation at all times.

chamber nozzles of the "driving-mist" type were always used. One line of hose was operated from the top of the sprayer, where special attention was directed toward covering the terminal branches in the tops of the trees and the outside parts of the trees. Another line of hose was operated from the ground and directed against the interior parts of the trees and upward against the under side of the leaves. In this manner an endeavor was made to cover completely all of the vegetative and fruit surface on each tree and obtain as complete protection as the different spray materials could afford. The details of the experiments are presented in Tables I to IV.

The materials tested are listed below, with a statement as to the manner of their preparation or dilution. In connection with each is given the formula number referred to in the spraying schedules.

List of the spray materials tested, showing the composition of the formulas used.

Formula 1.—Commercial lime-sulphur, 34° Baumé, diluted 1½ to 50.

Formula 2.—Commercial lime-sulphur, 34° Baumé, diluted 1 to 50.

Formula 3.—Commercial lime-sulphur, 34° Baumé, diluted 1 to 75.

Formula 4.—Commercial lime-sulphur, 34° Baumé, diluted 1 to 100.

Formula 5.—Self-boiled lime-sulphur, 8–8–50. Add 8 pounds of sifted sulphur to 8 pounds of stone lime, slaking in a barrel. Stir well, and add sufficient water from time to time to keep it from burning. After ebullition ceases, dilute to 50 gallons and strain into the spray tank, when it is ready for use. In practice it is best to make up enough for 150 to 200 gallons at once.

Formula 6.—Iron sulphid (Ballard's formula). Dissolve 10 pounds of iron sulphate in a barrel containing 50 gallons of water. Add lime-sulphur solution until no more precipitate forms. Allow the precipitate to settle and drain off the supernatant liquid. Again fill the barrel with water, stir up the precipitate, and allow to settle, and then drain off the clear liquid as before. Continue this washing process until the yellow color disappears from the clear liquid. Make up to 50 gallons for stock solution. For spraying, stir the stock solution well and dilute 10 gallons in 90 gallons of water to make 100 gallons of spray.

Formula 7.—Iron sulphid (Wenatchee formula). Slowly add 2 pounds of granulated iron sulphate to 100 gallons of water in the spray tank, keeping the liquid well agitated. The iron sulphate goes into solution very quickly. Add 3 quarts of lime-sulphur solution (at a strength of 34° Baumé) and use immediately.

Formula 8.—Colloidal sulphur.[1] Dissolve one-half pound of cheap glue in hot water and add to 50 gallons of water in the spray tank. With the agitator run-

---

[1] This formula was adapted from a rather meager description of a method for preparing colloidal sulphur contained in the Gardener's Chronicle, Aug. 7, 1915, by J. M. Hector and S. J. M. Auld, of University College, Reading, England. They employed this material against American gooseberry mildew at Heston, England, but a complete report of their work has not been published. In a letter to the writer, dated Mar. 10, 1916, Prof. Hector furnished the formula used by them. It differed from the one here described in that they employed gelatine instead of glue and hydrochloric acid instead of sulphuric acid, and they made up a stock solution, which was diluted for spraying. Prof. Hector stated that the chief objection to its general use was its expensiveness. However, by the substitution of glue and sulphuric acid, as employed in formula 8, its cost is greatly reduced. The formula as used at Wenatchee has been satisfactorily employed against apple scab in the Willamette Valley, Oreg., and against prune brown-rot in Clarke County, Wash., in experiments carried on by the Office of Fruit-Disease Investigations.

ning, add 1½ gallons of commercial lime-sulphur solution; then add commercial sulphuric acid until the yellow color is almost but not entirely replaced by white. It usually requires about 0.9 pint of sulphuric acid for 1½ gallons of lime-sulphur solution. When arsenate of lead is to be used in combination with this material it should be added after the acid. Colloidal sulphur spray made up in this manner analyzes approximately as follows, depending upon the composition of the lime-sulphur used: Polysulphid sulphur (calcium as sulphur), 0.09 per cent; thiosulphate sulphur (calcium as sulphur), 0.08 per cent; sulphate sulphur (calcium as sulphur), 0.08 per cent; free sulphur, 0.41 per cent; insoluble matter other than sulphur, 0.009 per cent.

Formula 9.—Finely ground sulphur material of the following composition: Water, 41.44 per cent; sulphur, 55.15 per cent; organic matter (in the form of glue), 1.94 per cent; ash, 1.47 per cent. Dilute to 7 pounds to 50 gallons of water.

Formula 10.—Finely ground sulphur material of the following composition: Water, 14.82 per cent; sulphur, 76.72 per cent; organic matter, 1.80 per cent; ash, 6.66 per cent. Dilute to 6 pounds to 200 gallons of water.

Formula 11.—Sodium-sulphur material of the following composition: Sodium polysulphid, 56.84 per cent; sodium thiosulphate, 36.56 per cent; sodium sulphate, 0.66 per cent; free sulphur, 3.38 per cent; iron and aluminum oxids, 0.14 per cent; water, 2.42 per cent. Dilute to three-quarters pound to 50 gallons of water.

Formula 11a.—Same as formula 11, but diluted to 1½ pounds to 50 gallons of water.

Formula 12.—Sodium-sulphur material of the following composition: Sodium polysulphid, 55.06 per cent; sodium thiosulphate, 40.80 per cent; sodium sulphate, 2.17 per cent; free sulphur, 1.56 per cent; water, 0.41 per cent. Dilute to 1 pound to 50 gallons of water.

Formula 12a.—Same as formula 12, but diluted to 1½ pounds to 50 gallons of water.

Formula 13.—Barium-sulphur material of the following composition: Barium polysulphid, 67.44 per cent; barium thiosulphate, 8.67 per cent; barium sulphate, 5.15 per cent; free sulphur, 17.28 per cent; water, 1.46 per cent. Dilute to 4 pounds to 50 gallons of water.

Formula 14.—Bordeaux mixture, 4–4–50.

Formula 15.—Ammoniacal copper carbonate prepared as follows: Dissolve 5 ounces of copper carbonate in 3 pints of ammonia (25 per cent solution, which should be diluted before using). Dilute to 50 gallons in spray tank.

Formula L.—Lead-arsenate paste, 2 pounds to 50 gallons of water, or powdered lead arsenate, 1 pound to 50 gallons. Where used in combination with fungicides, this designation appears in the spraying schedule, together with the number of the fungicidal formula.

Formula S.—Soap. The addition of 2 pounds of potash-fishoil soap to 50 gallons of spray for a spreader is indicated where this designation appears, together with the number of the fungicidal formula in the spray schedule.

SPRAYING EXPERIMENTS IN 1915.

The results of the spraying experiments conducted in 1915, together with the resulting spray injury and the control established, are shown in Table I.

Aside from the foliage injury shown in Table I, very severe burning of exposed fruits was noted on June 9 on the south and southwest sides of the trees. An estimate of this burning in the various plats was not attempted because of the almost entire absence of a crop. Stayman Winesap (*Stayman*) trees, bearing a heavy crop and situated alongside the Black Ben Davis used in this experiment and sprayed by the orchard owner with iron sulphid (formula 7), showed on this date about 30 per cent of exposed fruit on the south and southwest sides very severely burned. Besides this, defoliation to the extent of 50 per cent in many instances had taken place, and a heavy drop of fruit had been caused. Subsequent observations indicated that this variety is particularly subject to injury of this nature.

TABLE I.—*Results of spraying experiments for the control of apple powdery mildew at Wenatchee, Wash., in 1915.*

Variety and plat.	Spray formula.[a]	Dates of application.[b]	Foliage injury.[c]				Foliage infected.
			On Apr. 28.	On June 4.	On July 29.	Total.	
			Per cent.	*Per cent.*	*Per cent.*	*Per ct.*	*Per ct.*
Black Ben Davis:							
No. 1	6	Apr. 24, May 20, June 15, July 15.			2 [d]	2	1.4
No. 2	7	Apr. 24, May 20, June 15, July 15.		([e])	5 [f]	6	1.5
No. 3	1 1 L	Apr. 14, 24, May 20. June 15	3 [g]	No increase.	Slight increase.	4	.3
No. 4	1 1 L	Apr. 24, May 20. June 15	5 [g]	3 [h]	2 [h]	10	.3
No. 5	12a	Apr. 14, 24, May 20, June 15, July 15.	Slight	4 [h] 2 [i]	Slight increase.	6	.8
No. 6	11	Apr. 14, 24, May 20, June 15, July 15.	do	2 [h]	do	4	.9
No. 7	5 S	Apr. 24, May 20, June 15.					1.1
No. 8 (check)		Not sprayed.					35.1
Pryor Red:							
No. 9	1 1 L	May 20, June 15. Apr. 24	20 [j]	No increase.	No increase.	20	2.8
No. 10	9 9 L	May 20, June 15. Apr. 24					6.5
No. 11	13 L 13	Apr. 24, July 15. May 20, June 15.			2 [d]	2	6.1
No. 12	11 11 L	Apr. 24, May 20, June 15. July 15	Slight tip burning.	Less than 1 per cent.	Slight increase.	2	12.6
No. 13	12a 12a L	Apr. 24, May 20, June 15. July 15	do	2 [i] 5 [k]	8 [h]	16	14.9
No. 14	7	Apr. 24, May 20, June 15, July 15.			1	1	10.6
No. 15 (check)		Not sprayed					20.1

[a] For composition of sprays used, see pp. 11–12.
[b] Buds in the "pink" (just before full bloom), Apr. 14; petals fallen, calyx not yet closed, Apr. 24; other applications at the time of regular codling-moth sprayings.
[c] Foliage injury expressed in percentage of leaf-surface reduction.
[d] On southwest side of trees.
[e] Very slight leaf spotting.
[f] Increase on southwest side of trees.
[g] Leaf spotting and margin burning.
[h] Increase.
[i] Defoliation.
[j] Defoliation (consisting only of infected leaves).
[k] Leaf spotting.

Since climatic factors are known to play such an important part in the development of spray injury, the following data will be of interest in connection with the injury noted. The records of the

Washington section of the Weather Bureau show the following conditions prevailing at Wenatchee during the period when spray injury occurred:

Measurable precipitation.

April, none.
May, 1.77 inches, distributed over May 1, 2, 9, 10, 11, 14, 17, 23, 24, 27.
June, 0.21 inch, distributed over June 10, 11, 12, 23.
July, 0.28 inch, distributed over July 4, 8, 14, 26, 27.

Mean maximum and minimum temperatures.

Month, 1915.	Maximum.	Minimum.	Month, 1915.	Maximum.	Minimum.
	°*F.*	°*F.*		°*F.*	°*F.*
April	70.3	42.2	June	80.1	53.5
May	68.2	46.0	July	86.4	57.9

The maximum temperature was between 80° and 90° F. on April 16, 17, 18, and 19, on May 4, 6, 7, and 8, on June 3, 6, 7, 13, 14, 15, 20, and 21, on July 5, 7, 8, 17, 18, 26, 29, and 30; between 90° and 100° on June 4, 5, 22, 23, 29, and 30, and on July 1, 4, 19, 20, 24, 25, and 31; and above 100° on July 2, 3, 21, and 23.

The above temperatures are shade temperatures. The temperatures on fruits exposed to the direct rays of the sun were naturally much higher. Tests made to indicate what this difference might be showed that the temperature was 20 to 30 degrees higher in the sun. From this it appears that the sun temperature ranged well above 100° F. on five successive days (June 3–7) just before the appearance of the fruit burning. No other excessive temperatures were recorded between the date of the last spraying and the appearance of the injury. With the continuance of the hot weather the injury was observed to increase to some extent, but most of the fruit exposed to direct sunlight was injured at the start. There was no indication that the scanty precipitation had any effect on spray injury either to fruit or foliage. The foliage injury appeared to be the result of toxic action of the wet sprays, probably intensified by the bright sunlight, since it began to appear so shortly after the application.

It was a rather difficult matter to arrive at an accurate or representative measure of the control established, especially in the case of infected leaves and twigs, which constitute the principal manifestation of the disease. The variation in the crops of fruit was so great among the different plats that no data could be secured on fruit russeting; hence the results had to be measured by the condition of the vegetative parts. An empirical estimate of the degree of infection is largely influenced by the personal equation, and an inspection of all the foliage and twigs was manifestly impossible in an experiment of this magnitude. Actual counts were therefore made to show the amount of mildew on definite branches of each tree, thus presenting a fair average of conditions over the plat. This method removed the personal equation and allowed the results to be placed on a percentage basis for comparison. In detail the method employed was as follows: An equal number of representative branches were inspected in the tops and around the lower parts of the trees in each plat; each leaf cluster was taken as a unit, and if any of its leaves showed active mildew infection the unit was so counted. Several thousand such units were examined in each plat about a month after the last spraying. The results, as shown in Table I, indicate the effectiveness of the sulphur sprays, and particularly of lime-sulphur solution, in controlling apple powdery mildew. On trees sprayed with lime-sulphur solution the mildew infection was reduced to a negligible quantity, while the check trees were badly diseased. The less favorable results obtained from the use of the other materials can be attributed partly to the fact that they did not possess as efficient wetting power as the lime-sulphur solution, a point which will be more fully discussed in a later paragraph. However, in the case of the sodium-sulphur sprays the poor results were doubtless influenced largely by the relatively low concentration of polysulphids and free sulphur, which can be regarded as the active ingredients.

SPRAYING EXPERIMENTS IN 1916.

The results of the spraying experiments conducted in 1916, together with the resulting spray injury and the control established, are shown in Table II. In 1916 most of the Pryor Red trees were sprayed with the same materials as in 1915, but the Jonathan and Black Ben Davis trees, which were not included in the 1915 experiments, were given two applications of iron sulphid, formula 7 (see p. 11) by the owner of the orchard.

In the spraying experiments in 1916 only a negligible amount of foliage injury developed early in the season. Only about 5 per cent of tip burning was found prior to June 22 in plat 13. On that date, however, some injury appeared in nearly all plats. Sulphur spotting of the fruit began to appear on June 18, and by June 20 a considerable portion of the exposed fruit which had been sprayed with sulphur preparations was severely burned. As in 1915, the injury was confined to the portions of the tree receiving the direct rays of the sun in the hottest part of the day. The extent of the injury was estimated by actual counts of several hundred apples on the affected portion of each tree. It appeared to be most severe where the deposits of spray material were heaviest. In considering the fruit injury it was found that high temperatures had again prevailed between the time of the completion of the last spraying (June 10) and the date of the first appearance of the sulphur spotting on the fruit (June 18).

Thermograph records during the period from June 8 to 18 revealed the following temperatures:

Maximum shade temperatures.

Date, 1916.	Maximum.	Date, 1916.	Maximum.
	°F.		°F
June 8	90	June 14	97
June 9	72	June 15	100
June 10	81	June 16	102
June 11	87	June 17	100
June 12	90	June 18	82
June 13	95		

There was no measurable precipitation during this period. The results again emphasized the danger of applying sulphur sprays when hot, burning sunlight is expected to prevail.

TABLE II.—*Results of spraying experiments for the control of apple powdery mildew at Wenatchee, Wash., in 1916.*

Variety and plat.	Spray formula.[a]	Dates of application.[b]	Spray injury.[c] On June 22. Foliage.	Spray injury. On June 22. Fruit.	Spray injury. On Aug. 1. Foliage.	Spray injury. On Aug. 1. Fruit.	Spray injury. Total. Foliage.	Spray injury. Total. Fruit.	Foliage infected.
Jonathan:[f]			Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.
No. 1	5 S 5 SL	Apr. 22 May 10, June 10.	1	18	(d)	(d)	1	18	1.1
No. 2	6 6 L	Apr. 22 May 10, June 10.	1	10	(d)	(d)	1	10	1.4
No. 3	2 2 L	Apr. 22 May 10, June 10, July 21.	2	10	(e)	(e)	3	10	.4
No. 4	3 3 L	Apr. 22 May 10, June 10.	3	12	(d)	(d)	3	12	.3
No. 5	4 4 L	Apr. 22 May 10, June 10.	1	13	(d)	(d)	1	13	.5
No. 6	8 8 L	Apr. 22 May 10, June 10.	5	21	(d)	(d)	5	21	.2
No. 7 (check)		Not sprayed							4.0
Pryor Red:									
No. 8[f]	7 7 L	Apr. 22 May 10, June 10.	5	37	(d)	(d)	5	37	1.1
No. 9[f]	1 1 L	Apr. 22 May 10, June 10.	1	19	(d)	(d)	1	19	1.0
No. 10[f]	9 9 L	Apr. 22 May 10, June 10.		25	(d)	(d)		25	1.5
No. 11[f]	13 13 L	Apr. 22 May 10, June 10.	2	43	(d)	(d)	2	43	.7
No. 12[f]	11a	Apr. 22, May 10, June 10.	1	32	(d)	(d)	1	32	1.4
No. 13[f]	11 aL	do	5	35	[g] 50	(d)	55	35	1.5
No. 14[f]	12	do		17	(d)	(d)		17	1.2
No. 15	10 10 L	Apr. 22 May 10, June 10.		22	(d)	(d)		22	1.1
No. 16[f] (check)		Not sprayed							16.2
Black Ben Davis:									
No. 17	14 S	July 21							7.1
No. 18	2 2 L	Apr. 22 July 21			(h)	(h)	(h)	(h)	9.4
No. 19 (check)		Not sprayed							15.1

[a] For composition of sprays used, see pp. 11–12.

[b] Buds in the "pink" (just before full bloom), Apr. 22; petals fallen, calyx not yet closed, May 10; other applications at the time of regular codling-moth sprayings. Where lead arsenate is not shown in the schedule for the applications on May 10 and June 10, separate applications of this material were made following the fungicidal spraying, in order to avoid possible spray injury from combining sprays reputed to be chemically incompatible.

[c] Foliage injury expressed in percentage of leaf-surface reduction; fruit injury expressed in percentage of injured apples found on the south side of the trees.

[d] No increase.

[e] Slight increase.

[f] Trees sprayed in the same manner as in 1915.

[g] Increase.

[h] Slight injury.

An experiment begun after the development of the fruit burning and designed to test Bordeaux mixture for late application showed that while some measure of control could be established by the use of this spray, it was objectionable because of the heavy deposit of spray material which remained on the apples until picking time in October and prevented proper coloring. Apples in plat 17 lacked about 50 per cent of the red color which had developed on unsprayed fruit of the same variety.

Lime-sulphur solution was applied late in July to fruit which had no sulphur spotting and which it was thought might have sufficiently hardened the skin to be resistant to sulphur burning. The results, however, demonstrated that injury might still occur from applications of lime-sulphur as late as July 21.

Severe foliage injury developed in plat 13 after midsummer. This injury was the result of the combination of the sodium-sulphur material and lead arsenate, as is indicated by the fact that no late injury developed in plat 12, where the lead arsenate was omitted. The results prove the incompatibility of lead arsenate and the sodium-sulphur sprays.

The disease control established in 1916 on Pryor Red trees reflected the cumulative effects of spraying for two years with the same materials, except in the case of plat 15, where a finely ground sulphur material had been substituted for the iron sulphid used the year before. For some reason very little mildew developed on the Jonathan trees, although in 1915 they had been as badly infected as the Pryor Reds. The method of measuring the control established was the same as that followed in 1915. Many of the trees yielded a fair crop of fruit, especially on the Jonathan plats; but among the Pryor Red trees the crop was uneven, and no attempt was made to obtain data on fruit russeting. The results again showed the effectiveness of sulphur sprays in controlling mildew and indicated that the benefits of these sprays are cumulative.

SPRAYING EXPERIMENTS IN 1917.

The results of the spraying experiments conducted in 1917, together with the resulting spray injury and the control established, are shown in Table III. These experiments were confined to Pryor Red trees, which, with the exception of the checks, were not included in similar plats in 1916.

As a result of the demonstration in the earlier work of the injurious effects of spraying with sulphur preparations during the season of hot, burning sunlight, the experiments in 1917 were planned to determine (1) what degree of control can be established by careful and thorough spraying with sulphur sprays before the danger period and (2) what sprays, if any, can be substituted for the sulphur materials, especially during the hot weather.

There was no injury from the copper sprays, and again foliage injury from sulphur sprays was negligible, while as a result of late spraying sulphur spotting of the fruit resulted in material loss. A period of hot weather again preceded the first appearance of fruit injury, as is shown by the following statement of the maximum temperatures recorded by a shaded thermograph in the near vicinity of the experimental plats, covering the period between the last spraying on June 11 and the appearance of severe fruit burning on June 19.

Maximum shade temperatures.

Date, 1917.	Maximum.	Date, 1917.	Maximum.
	°F.		°F.
June 11	74	June 15	98
June 12	81	June 16	91
June 13	87	June 17	79
June 14	95	June 18	90

TABLE III.—*Results of spraying experiments for the control of apple powdery mildew on trees of the Pryor Red variety at Wenatchee, Wash., in 1917.*

Plat.	Spray formula.[1]	Dates of application.[2]	Spray injury.[3] On June 19. Foliage.	Spray injury. On June 19. Fruit.	Spray injury. On July 9. Foliage.	Spray injury. On July 9. Fruit.	Spray injury. Total. Foliage.	Spray injury. Total. Fruit.	Infected. Foliage.	Infected. Fruit.
			Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.
No. 1	2 2 L	May 9 May 22 June 11	1	33	([4])	([4])	1	33	1.0	
No. 2	2 2 L L	May 9 May 22 June 11							2.4	1.5
No. 3	2 2 L 14 LS	May 9 May 22 June 11							2.5	
No. 4	8 8 L	May 9 May 22 June 11	4	45	([4])	([5])	4	45	1.8	.5
No. 5	15 15 L	May 9 May 22 June 11							5.5	.9
No. 6	15 15 L L	May 9 May 22 June 11							5.8	2.0
No. 7	14 S 14 SL	May 9 May 22 June 11							4.0	1.2
No. 8	14 S 14 SL L	May 9 May 22 June 11							8.7	2.0
No. 9	9 9 L	May 9 May 22 June 11		19		([4])		19	2.2	.9
No. 10	9 9 L L	May 9 May 22 June 11							1.9	.8
No. 11	9 9 L 15 L	May 9 May 22 June 11							2.2	.4
No. 12 (check)		Not sprayed							17.4	6.8

[1] For composition of sprays used, see pp. 11–12.
[2] Buds in the "pink" (just before full bloom), May 9; petals fallen, calyx not yet closed, May 22. June 11 application at the time of regular codling-moth spraying.
[3] Foliage injury expressed in percentage of leaf-surface reduction; fruit injury expressed in percentage of injured apples found on the south side of the trees.
[4] No increase.
[5] Heavy drop of injured apples.

The method of measuring the degree of control of foliage infection was the same as in the earlier work. The results again showed the effectiveness of the sulphur sprays and indicated that in seasons like that of 1917 good mildew control may be established by careful and thorough spraying with either lime-sulphur solution, colloidal sulphur, or sulphur in some other finely divided form, if the fungicides are applied at the time the buds are in the "pink" and again as soon as the petals have fallen. These experiments also demonstrated that there is little difference in the efficiency of Bordeaux mixture and ammoniacal copper carbonate for mildew control, but both are less efficient than the sulphur sprays. In the case of the Bordeaux mixture, the same objection arose as in previous years, i. e., apples sprayed with it failed to develop a good red color. For this reason, therefore, if it is necessary to spray for mildew after the advent of hot, burning sunlight, ammoniacal copper carbonate is to be preferred to the sulphur sprays.

In 1917, for the first time since the experimental work was begun, a fair crop of fruit was obtained on the Pryor Reds and gave the first opportunity to obtain data on the effects of spraying in the reduction of mildew russeting of the fruit. While the Pryor Red variety is less subject to russeting than some others, and while there was only a small amount of the trouble even on the check trees, the results, as shown in Table III, indicate that the russeting can be eliminated by proper spraying. This is a matter of considerable importance with such solid-color and high-grade varieties as Grimes, Jonathan, Newtown, and Esopus (*Spitzenburg*), and with others where the marking is prominently displayed, and causes a loss of grade and lowered returns. The efficiency of the different sprays in preventing mildew russeting of the fruit proved to be about the same as in the case of foliage infection.

In 1917 it was also possible for the first time to compare the cumulative effects of the different sprays used in previous years in the prevention of bud blight and in insuring a crop of fruit. These data were obtained only in the case of the Pryor Red variety and are presented in Table IV. The plat numbers refer to the designations of the plats in 1916.

TABLE IV.—*Average yield of fruit per tree of the Pryor Red variety in 1917, showing the cumulative effects of different sprays used in previous years for the control of apple powdery mildew at Wenatchee, Wash.*

Plat.	Average yield.	Crop increase over check.	Plat.	Average yield.	Crop increase over check.
	Bushels.	*Per cent.*		*Bushels.*	*Per cent.*
No. 8	18	50	No. 13	20	66
No. 9	22	83	No. 14	11	....
No. 10	18	50	No. 15	16	33
No. 11	15	25	No. 16	*a* 12	....
No. 12	17	42			

a Check.

The unsprayed trees were located adjacent to the sprayed trees and all were of the same age and size, and except for the spraying all were treated alike; yet those in plat 9, where the mildew had been most effectively controlled by spraying with lime-sulphur solution, produced an average of 83 per cent more fruit than the checks, and other sprayed trees also yielded greatly increased crops.

INJURY TO FRUIT AND FOLIAGE.

Only a small amount of foliage injury was usually found accompanying the fruit spotting. The foliage injury generally developed so soon after the application of the sprays as to indicate that it was induced by the wet sprays. However, hot, burning sunlight undoubtedly increased foliage injury as well as fruit spotting. The addition of lead arsenate to the sodium-sulphur sprays also resulted in increased injury and demonstrated the incompatibility of these spray materials.

The general appearance of the fruit injury or sulphur sunburn was the same in all plats. (Pl. II, fig. 7.) The injury was confined to apples exposed to the direct rays of the hot midday or early afternoon sun. The injured area was of a reddish brown color, usually sharply marked but of irregular outline, and soon became depressed. The affected skin became wrinkled, hard, and leathery, often scurfing off or becoming traversed by cracks which extended deep into the flesh of the apple. The injury most often appeared in the calyx region, probably due to the collection there of much of the spray material. Deposits of spray material usually were clearly discernible over the injured areas.

The conditions under which this fruit injury occurred were identical in each of the three years of the experiment, i. e., it followed the advent of hot, burning sunlight, and only those fruits which were exposed to the direct rays of the sun at the hottest part of the day were affected. The burning was generally more severe where the sulphur was applied in its free state. This fact, together with the delay in the appearance of the injury until after the occurrence of hot, burning sunlight, indicates that the burning of the fruit is not the result of any caustic action of the various sulphids at the time the fruit was wetted. The exact manner in which sulphur sunburn takes place has not been demonstrated.

During the course of the spraying experiments several of the trees developed the "collar-rot" disease, and others suffered severely from drought at certain periods. In such cases, where the vitality of the tree was reduced, the spray injury, especially the foliage injury, was much increased.

In view of the recent revival of dusting for fungous-disease control in certain sections of the United States, the question arises as to what reaction might be expected from the application of sulphur dusts in the production of sulphur spotting. There was no opportunity for investigating this point in the work at Wenatchee, but since it was demonstrated that the sulphur spotting of the fruit is the effect of hot sunshine on sulphur *per se* and not the result of toxic action of sulphids in solution, there appears to be no reason why the injury should be mitigated by the use of sulphur dusts instead of liquid sprays. Confirmatory evidence on this point is furnished by Mr. F. E. De Sellem, formerly State horticultural inspector in the Yakima Valley, Wash., who reported to the writer very severe fruit spotting as following the application of sulphur dust in 1917. (Pl. II, fig. 6.) The dust was a mixture of powdered lead arsenate and superfine sulphur, such as ordinarily has been used in recent dusting operations in the Eastern States. A power dusting machine was used in making the applications, and the climatic conditions under which the injury occurred were reported to be similar to those which obtained in the Wenatchee Valley when the injury occurred there.

Recent observations of Hundley (14) indicate that in the Yucaipa Valley, Cal., slight sulphur spotting may occur when the hot sunshine is delayed for as long a time as 60 days after spraying. Hundley found fruit injury resulting from sulphur applied in several of the forms used in the experiments at Wenatchee, and he records a marked difference in susceptibility to injury in orchards at different altitudes. He also found those trees most susceptible to spray injury which were low in vitality either because of drought or some other condition.

Apparently the application of sulphur in any form as a spray material for apples is dangerous in a hot, dry climate during the summer season, for in the production of fruit "spotting" or sulphur sunburn high temperature and burning sunlight are the controlling factors.

SPRAY MATERIALS.

In these experiments the lime-sulphur solution appeared to spread better than any of the other materials tested except colloidal sulphur. Lime-sulphur solution possesses great powers of penetration through the felted mycelium and spore coating, and it appeared that much of its beneficial action was due not only to its spreading qualities but to its immediate caustic effect, which destroyed the mycelium and conidia of the fungus. This conclusion is in agreement with the results noted by Eyre and Salmon (13) in their investigations of the fungicidal properties of certain sprays when used against mildews. They demonstrated that, against mildews, solutions of polysulphids act fungicidally as such and not by virtue of the sulphur which is deposited when they decompose. However, it is certain that such deposits of sulphur on healthy parts act in a protective manner against potential infections. This being true, the advantages of lime-sulphur solution are at once apparent, for not only does it exert an immediate effect against existing infections, but by its deposition over healthy parts free sulphur is soon made available and distributed where protection is needed.

It was found that colloidal sulphur possessed greater spreading power than any other material tested. The uniformly excellent control established by its use is doubtless to be traced to this fact. It appears that this material combines the most desired elements for control, since it not only possesses excellent spreading qualities and thereby deposits a very uniform coating of almost ultramicroscopic sulphur particles to form a protective coating over healthy parts, but at the same time it possesses in its excess lime-sulphur solution sufficient causticity to produce an immediate effect on the fungous mycelium and conidia. With the exercise of intelligent precautions in its preparation there would doubtless be no reason for not advocating its use on a commercial scale in general orchard practice, especially where mildew infection is severe. However, since good results attend the use of commercial lime-sulphur solution it is doubtful whether many orchardists would go to the trouble of making the colloidal sulphur.

With the iron-sulphid sprays, the finely ground sulphur materials, and the sodium-sulphur materials, from one-fourth to one-third more spray material was required to cover the same surface with an efficiency approximating that of either colloidal sulphur or lime-sulphur solution. This apparently was due largely to the greater surface tension and interfacial tension of these materials, giving them less ability to wet the foliage and twigs, especially when covered with mildew. This also resulted in lessened spreading power, and consequently many places inaccessible to the direct force of the spray when applied were not reached and remained unprotected. The addition of soap, when not chemically incompatible, would increase the spreading power and the value of such sprays. The poorer results obtained from the use of these sprays were also partly due to their lower concentration of active fungicidal ingredients.

Bordeaux mixture, if combined with soap, spreads very readily, but it proved objectionable in the climate of the Wenatchee Valley because of the pale fruit color developed under the heavy spray coating. Black Ben Davis apples sprayed with Bordeaux mixture failed to develop more than 50 per cent of the normal red color of this variety and were discriminated against on the market on this account. In the Wenatchee Valley there are no rains to wash off the spray coating, and fruit sprayed with Bordeaux mixture in July still retains it at picking time in the fall. Moreover, the control established by the use of this material did not approach the results obtained from the more efficient of the sulphur sprays.

Self-boiled lime-sulphur offered the same objection as Bordeaux mixture in that heavy deposits of spray material remained on the apples and prevented their proper coloring. It likewise proved less efficient than several of the other materials. It appeared to give some protection to healthy parts after application, but it failed to destroy existing infections, and conidia were abundantly pushed up through the spray coating.

Ammoniacal copper carbonate closely approximated the fungicidal action of Bordeaux mixture and left no objectionable deposit on the apples. For this reason it is preferred to Bordeaux mixture for use in spraying during hot weather.

The barium-sulphur preparation appeared to approximate the action of commercial lime-sulphur solution against mildew, but it proved more toxic to fruit and foliage during hot weather

SUMMARY OF CONTROL MEASURES.

The results noted demonstrate—

(1) That sulphur sprays are superior to Bordeaux mixture or ammoniacal copper carbonate for mildew control.

(2) That, except possibly in seasons of exceptionally heavy infection, apple powdery mildew can be commercially controlled by sprays applied before hot weather starts and consequently before there is danger of sulphur spotting of the fruit.

(3) That while Bordeaux mixture and ammoniacal copper carbonate may be less efficient as control agents than lime-sulphur solution or other sulphur sprays, their use may be advisable in years when continued spraying may be necessary.

(4) That ammoniacal copper carbonate is preferable to Bordeaux mixture for this purpose, since it does not leave an objectionable deposit on the fruit and thereby prevent normal coloring.

(5) That in the case of sulphur sprays efficiency is dependent on (*a*) the immediate caustic effect of the sprays on the fungous coating and (*b*) the deposit of a protective coating of free sulphur over noninfected areas. Both *a* and *b* are largely dependent on the spreading qualities of the sprays, which, in turn, are dependent on the surface tension and the interfacial tension of the sprays.

DORMANT SPRAYS.

A possible influence of winter or dormant sprays of strong lime-sulphur solution on the overwintering fungus has been suggested, but these experiments do not point to any such influence. Each year just after the buds had begun to swell, but before the appearance of the first leaves, the check trees were thoroughly sprayed with lime-sulphur solution at a strength of 3½° Baumé. These trees always became infected many times as severely as those which received in addition to the dormant spray the proper foliage spraying through the active growing season, as shown in Tables I, II, and III. The reason for this lack of effect of the dormant spray is to be found in its inability to reach the overwintering mycelium in the buds. If the perithecia alone were concerned there might be some beneficial effect from such sprays, but since these are known to be unnecessary in carrying over and disseminating the fungus little is to be gained by their destruction.

PRUNING EXPERIMENTS.

Many growers have endeavored to control mildew by pruning out the infected parts, both in the winter and while the infections are active during the growing season. By the removal of infected twigs the immediate effect secured is to eliminate a source of infection for the remainder of the season; the permanent effect is to prevent the overwintering of the fungus and the spread of the disease the following year. Hence, if all mildewed shoots and infected buds could be removed, the disease would doubtless be eradicated, and the practice of such pruning could be depended upon to hold the disease in check. However, in cases of severe infection, eradication by this method would involve not only the serious mutilation of the trees and often the destruction of practically all the new growth, but also a great amount of labor. In order to demonstrate the practicability and efficiency of this method the following experiments were undertaken.

Six Jonathan trees were very carefully gone over before they came into leaf, and every sign of mildew that could be detected was removed. At this time the terminals infected the previous year and bearing infected buds could be detected by their silvery gray color and glistening appearance in the sunlight, their stunted growth, and the reddish color and slender, elongated shape of their lateral buds, which were also less advanced than normal healthy buds.

After the active growing season began it was found that in spite of all the care in pruning, these trees were liberally covered with infected leaves coming from widely distributed buds on older branches that had escaped detection earlier in the year. To have distinguished these with certainty as infected at that time would have involved an inspection of every single bud on the trees, a task manifestly impracticable. When this result became apparent the experiment was continued to demonstrate the benefits to be derived from dormant pruning as a supplemental aid to foliage spraying during the growing season. The trees were sprayed at intervals of four weeks until the middle of July, receiving in all four applications of lime-sulphur solution diluted 1½ to 50, the same as plat 3 in 1915. For comparison, six unpruned Jonathan trees in the immediate vicinity of the pruned plat were also sprayed in like manner. At the end of the season it was plain that while there was less infection on the trees which had been pruned, the difference in control was certainly not sufficient to pay for the extra labor involved in the very careful examination of the dormant trees. These results are contrary to those obtained by Ballard and Volck (12) in the Pajaro Valley, Cal., and are undoubtedly due to the difference in spraying practices followed. On account of climatic conditions it is impossible in the Pajaro Valley to use lime-sulphur solutions or other sulphur sprays known to possess the power of easily wetting and penetrating the mildew. However, in the Wenatchee Valley full benefit could be had from the wetting effects of the lime-sulphur solution, and consequently better control could be established by spraying.

GENERAL NOTES ON THE CONTROL OF THE DISEASE.

It was always found that mildew first appeared before the blossoms opened—on the foliage expanding from dormant buds. By the time the trees were in full bloom conidia were being shed in abundance. This indicates that an application of fungicides must be applied earlier, and the experiments have shown that the first application should be made at the same time as in the case of apple scab, i. e., just after the cluster buds have separated, while the blossom buds are in the pink. There is little to be gained by an earlier application, because so little foliage is expanded, and the delay of the infected buds prevents an earlier spread of the disease. Most of the blossom infection results from mycelium carried over in the blossom buds from the previous year and not as a result of conidial dissemination of the current year. It is not, therefore, probable that a spray applied at the time mentioned would have much beneficial influence in preventing blossom infection, but it is extremely important in cleaning up incipient foliage infection and in protecting the healthy leaves. If this treatment is followed by others at such intervals that all of the new foliage is protected as it expands, adequate protection is gained. The experiments indicate that after the "pink" spray the disease can be held in check in ordinary years by combining the fungicides with the first two regular applications of lead arsenate used in codling-moth control. If supplemental spraying is required, the applications should be made at intervals not greater than four weeks.

There is a strong prejudice in the Wenatchee Valley against the combination of lead arsenate and lime-sulphur or other sulphur sprays. This seems entirely unwarranted, for in the course of these experiments no detrimental effects were observed from the use of the combined sprays except as noted in the case of the sodium-sulphur materials. It has been repeatedly demonstrated in other parts of the country that the combined spray is not only the most practical method of applying insecticides and fungicides when both must be used, but that the combined spray is more efficient than separate applications.

Orchard studies indicate that tender young foliage is most easily infected and that terminal growth is especially susceptible. The striking thing about a badly infected tree is the preponderance of mildewed terminals, which give it a whitened appearance. Most of this infection takes place early in the season, up to the time that vegetative growth is largely completed, but infection continues as long as new foliage is being formed. It frequently happens in the irrigated sections of the Northwest that a secondary vegetative growth takes place in the latter part of the summer, after the resumption of irrigation following a period of drought. In infected districts such new growth is usually attacked by mildew after its spread had apparently ceased with the checking of the earlier vegetative growth.

CONCLUSIONS.

(1) Apple powdery mildew is generally prevalent in the arid regions of the Pacific Northwest. It attacks foliage and twigs, reducing the vitality of the tree, and also attacks the young fruit, causing an objectionable russeting of the skin. It has often caused a reduction of more than 50 per cent of the crop in infected orchards, and it causes a further loss in a reduction of vitality that is impossible to estimate.

(2) The disease is caused by the fungus *Podosphaera leucotricha* (E. and E.) Salm., which winters over in dormant buds in mycelial form. Ascospores can not be regarded as essential to the propagation of the fungus. It is spread by conidia disseminated by the wind, and possibly to some extent by insects. Dews furnish sufficient moisture for spore germination.

(3) Dormant sprays of lime-sulphur solution at a strength of $3\frac{1}{2}°$ Baumé (a dilution of about 1 to 9, when lime-sulphur testing 34° Baumé is used) have had little or no effect on the overwintering fungus and have not hindered the spread of the disease.

(4) Pruning out diseased shoots can not be depended upon alone to effect control of the disease when it is present in epidemic form.

(5) The disease is readily controlled by applications of sulphur sprays during the growing season. However, after the advent of burning sunshine, which can be expected in the hot interior districts of the Pacific Northwest after the first of June, the use of sulphur spray materials is certain to cause severe fruit injury.

(6) Bordeaux mixture is less effective than sulphur sprays against powdery mildew and leaves such a heavy deposit on the fruit that it

does not color properly. Ammoniacal copper carbonate is practically as effective as Bordeaux mixture against this disease and leaves no deposit on the fruit to hinder coloring; it is therefore preferable to Bordeaux mixture for such use.

(7) The results of mildew control are cumulative, and with the establishment of adequate control the crops of fruit are substantially increased.

(8) These experiments have shown that the disease can be effectively controlled by spraying in accordance with the following schedule, which is recommended:

First application. Spray with lime-sulphur solution diluted 1 to 50 when the cluster buds have separated, but before the blossoms open—the "pink" spray.

Second application. Spray with the same material in combination with lead arsenate for codling-moth control as soon as the petals fall and before the calyx is closed.

Third application. Spray with ammoniacal copper carbonate in combination with lead arsenate for codling-moth control about three or four weeks after the second application.

If subsequent applications are necessary they should be made at intervals not greater than four weeks, using ammoniacal copper carbonate as a fungicide.

In spraying it is important to cover every part of the leaves and twigs, and special attention should be given to the terminals. A pressure of 200 to 250 pounds should be maintained, or sufficient to drive the spray in a fine mist through the tops of the trees. High pressure is especially important if spray materials are used which have poor spreading qualities. Eddy-chamber nozzles of the "driving-mist" type should be used.

(9) In the production of sulphur spotting of the fruit, high temperature from burning sunshine is the determining factor. It is believed that the injury is not the result of toxic chemical action of sulphids in solution at the time of spraying, but it probably is due to the heating of the spray deposits to such a degree that death of the adjacent cells occurs, the results being partly due to the physical effects of the heat and partly to the chemical effects of volatilized sulphur compounds.

LITERATURE CITED.

(1) Bessey, C. E.
1877. On injurious fungi. The blights (Erysiphe). *In* Bienn. Rpt. Iowa Agr. Coll., 1876–77, pp. 185–204, 2 pl.

(2) Ellis, J. B., and Everhart, B. M.
1888. New species of fungi from various localities. *In* Jour. Mycol., v. 4, no. 6, pp. 49–59. (Continued article.) Sphaerotheca leucotricha E. and E., p. 58.

(3) Galloway, B. T.
1889. Apple powdery mildew. *In* U. S. Dept. Agr., 1st Rpt., 1889, pp. 414–415.

(4) 1889. Experiments in the treatment of pear-leaf blight and the apple powdery mildew. U. S. Dept. Agr., Sec. Veg. Path. Circ. 8, 11 p., 2 fig.

(5) Burrill, T. J.
1892. Sphraerotheca mali. *In* Ellis, J. B., and Everhart, B. M. North American Pyrenomycetes, pp. 5–6. Newfield, N. J.

(6) Pammel, L. H.
1894. Notes on a few common fungus diseases. *In* Iowa Agr. Exp. Sta. Bul. 23, pp. 918–924, 2 figs.

(7) Grout, A. J.
1899. A little-known mildew of the apple. *In* Bul. Torrey Bot. Club. v. 26, no. 7, pp. 373–375, pl. 364.

(8) Pammel, L. H.
1900. Powdery mildew of the apple. *In* Proc. Iowa Acad. Sci., v. 7, 1899, pp. 177–182, pls. 33–35.

(9) Salmon, E. S.
1900. A Monograph of the Erysiphaceæ. Mem. Torrey Bot. Club, v. 9, 292 p., 9 pl. Bibliography, pp. 241–259.

(10) Lawrence, W. H.
1905. The powdery mildews of Washington. Wash. Agr. Exp. Sta. Bul. 70, 16 pp., 1 pl.

(11) Stewart, F. C.
1910. Notes on New York plant diseases.—I. N. Y. Geneva Agr. Exp. Sta. Bul. 328, pp. 305–404, 18 pl. Bibliography, pp. 399–404.

(12) Ballard, W. S., and Volck, W. H.
1914. Apple powdery mildew and its control in the Pajaro Valley. U. S. Dept. Agr. Bul. 120, 26 pp., 5 fig., 6 pl.

(13) Eyre, J. V., and Salmon, E. S.
1916. Fungicidal properties of certain spray fluids. *In* Jour. Agr. Sci., v. 7, pt. 4, pp. 473–507.

(14) Hundley, J. B.
1917. Sulphur injury in Yucaipa, 1917. *In* Mo. Bul. Cal. State Comm. Hort., v. 6, no. 10, pp. 402–403.

WASHINGTON : GOVERNMENT PRINTING OFFICE : 1918