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Department of Plant Pathology

HOP MILDEW

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HOP MILDEW

F. M. Blodgett

HOST PLANTS

Although the disease known as hop mildew occurs on a number of plants, it has become well-known and of much importance in New York State at the present time because of serious epidemics that have occurred during the past four years in yards of the cultivated hop, *Humulus lupulus*. The disease is also common on the strawberry, on which it is occasionally reported as doing serious damage. Since the disease has been given careful attention only as it occurs on the hop, no other host plants than the hop will be discussed here.

Distribution of the hop

The hop is a widely distributed plant and is of considerable importance. It is a native of Europe and is reported from practically every European country, as well as from Canada, Australia, New Zealand, and other lands. In the United States it occurs wild over the northern part of the country, especially in alluvial creeks to the northwest. Its commercial production is limited to four States, in the following order: Oregon, California, New York, and Washington. At times it has been grown in Wisconsin, Michigan, and Vermont.

Hop regions of New York

Formerly hops were produced in many counties of this State, but their production is now limited principally to Oneida, Otsego, Schoharie, Franklin, and Madison counties. In these counties many farmers have discontinued hop-raising altogether, because of the uncertainty of the market for a number of years and the prevailing low prices. For the last four years, however, prices have averaged higher and a considerable number of hopyards are being set out. Unfortunately, these four years have been marked by the coming into prominence of the hop mildew, previously unknown in this country as a destructive disease of hops but of long standing in Europe.

Economic importance

For a number of years there has been a decline in the acreage of hops in New York State and an increase in the acreage on the Pacific Coast.

This is due to the cheaper production on the western coast, where climatic conditions are more favorable and methods of production cheaper. The estimated crop for 1912* is: New York, 31,500 bales; Washington, 30,000; Oregon, 110,000; and California, 105,000 bales. The crop in England has been estimated as 300,000 hundredweight and the continental crop as 1,000,000 hundredweight. Although the yield for New York this year is low, it is evident that a comparatively small proportion of the world's crop of hops is raised in this State.

THE DISEASE

Names applied to the disease

The disease has been known for many years in England as the mildew, or mold, and by the more descriptive name of "powdery mildew." For some unknown reason New York growers have chosen to speak of the disease as the "blue mold." The term "mold" is not entirely inappropriate; but just why the adjective "blue" should be attached appears rather uncertain, inasmuch as the writer has never seen a case in which there was the slightest indication of blue coloration, nor has he ever found a grower who could satisfactorily explain the use of such a name. The name "mildew" has been in long and constant usage, and in order to avoid confusion it should be employed to the exclusion of all others.

Occurrence of the disease

Hop mildew is said by Whithead (1887) to have been known in England for more than one hundred and eighty-five years. He quotes Marshall as saying in 1790: "A garden at Dean Street, near Maidstone, is entirely gone off, not a healthy hop to be seen. Some of the leaves are evidently mouldy, but they are not generally so. The diseased hops are contracted into hard knobs." During the early days of the disease in the locality referred to it was limited to certain sections; but as time went on the mildew spread more generally and, while at first it attacked only certain varieties, later it came to be destructive to all varieties.

At the time when Whithead was writing in 1887, the mildew had proved destructive in hopyards in Germany, Austria, and France, and more particularly in Belgium and Holland. Recently considerable attention has been given by Bondarzew ('08) to the disease in Russia, where considerable losses have occurred.

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* Country Gentleman 77^{43}: 18. 1912.
(1887) Whithead, Chas. Ann. Rept. Agr. Advisor [Great Britain] **1887**:33–42. *f. 1.* 1888.
('08) Bondarzew, A. S. Jahrb. Pflanzenkr. St. Petersburg **2**:13–25. 1908.

In the United States the disease has been reported in only a few places as affecting hops. Harvey (1896) reports having found it in Maine; Doctor Harkness (1892) reports it in California; Atkinson (1891) reports it in Alabama; and Griffiths (1899) reports it in Wyoming. In most of the States it has been reported on plants other than the hop. Humphrey ('11) writes: "This fungus is parasitic on a number of Washington plants, but in the three years I have served as Plant Pathologist for the State, hop mildew has not been reported as affecting hops. I have no doubt, however, that it occurs here and there, though as yet is of little economic importance."

The importance of the disease may be understood from the fact that in years favorable for its development it has been known to completely destroy a crop. Often the total crop has been almost completely destroyed in whole counties. In this State, during the past three years the writer has seen a large number of hopyards where the loss was complete, and many more where yield has been decreased and the quality of the product materially lowered. The disease has been a serious menace in all the hop-growing sections of the State during the past year. In fact, its attack was so severe in some sections, where no control was attempted, as to threaten the continued production of hops.

Symptoms of the disease

On leaves and stems.— The mildew may make its appearance on hop-vines from early in May until the hops are harvested. It is to be found particularly on the succulent, growing parts (Fig. 93). Early in the season it appears first on the leaves as white, powdery spots, circular in outline (Fig. 94). These enlarge rapidly, and when there are a number on a leaf they may coalesce, forming large, irregular areas covered with a white, floury growth. The patches may occur on either surface of the leaf, and often also on the tender growing branches or the petioles of the leaves. If the attack is early the spots usually appear on the lower leaves first, and are found later on the higher leaves.

On flowers.—As soon as the flowering spikes, or catkins, appear, these white, powdery spots are likely to be found on them. All the flower parts are quickly covered and the entire catkin has the appearance of having been dusted with flour. These mildewed catkins cease growing and fail to "hop out" (Fig. 95). Often only a part of the flowering catkin is thus affected; some of it may grow out and the remainder be dwarfed.

(1891) Atkinson, G. F. Some Erysiphaceae from Carolina and Alabama. Journ. Elisha Mitchell Sci. Soc. **1890**:61–74. 1891.
(1892) Harkness, ——. Ellis and Everhart's North American Pyrenomycetes **1892**:5–6.
(1896) Harvey, F. L. Contributions to the Pyrenomycetes of Maine. 1. Bul. Torrey Bot. Club **23**:50. 1896.
(1899) Griffiths, D. Some northwestern Erysiphaceae. Bul. Torrey Bot. Club **26**:138–144. 1899.
('11) Humphrey, H. B. Letter to Jay Sedgwick, Dec. 22, 1911.

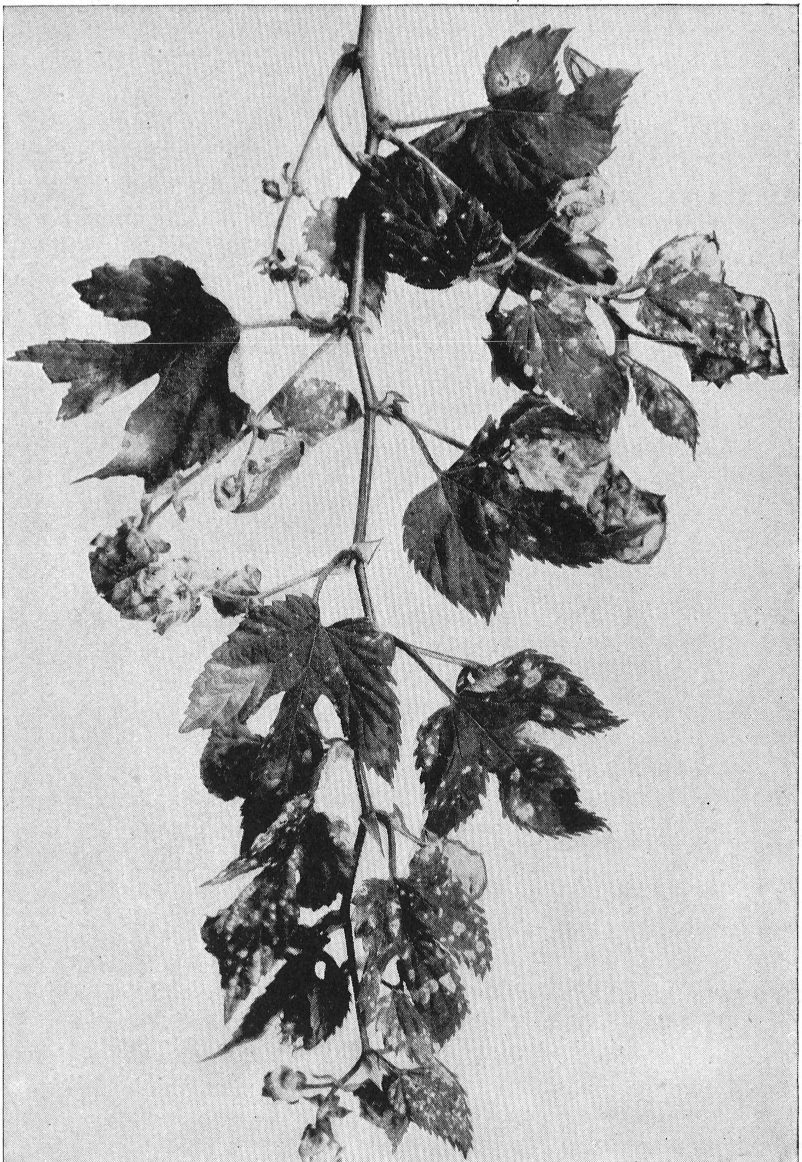

FIG. 93.— *Branch showing mildew spots on foliage, and dwarfing of clusters*

On the hops.— Later, after the flowering season, the mildew, or mold, is less apparent on the leaves. Often areas may be seen on which the white, downy growth has entirely disappeared, leaving brown spots on the surface of the leaves. In other places, especially on the under surface of leaves and on the deformed hops, minute brown bodies begin to appear, which are distinctly visible to the naked eye. As these become more numerous, the undersides of the leaves and the deformed hops gradually become brown and later nearly black. Frequently the hops turn brown, when the attack of mildew is late, without the formation of these brownish bodies covering the surface and with only a trace apparent of the whitish, floury growth. In such cases the hops become at first a dull green, gradually changing to brown; and finally they be-

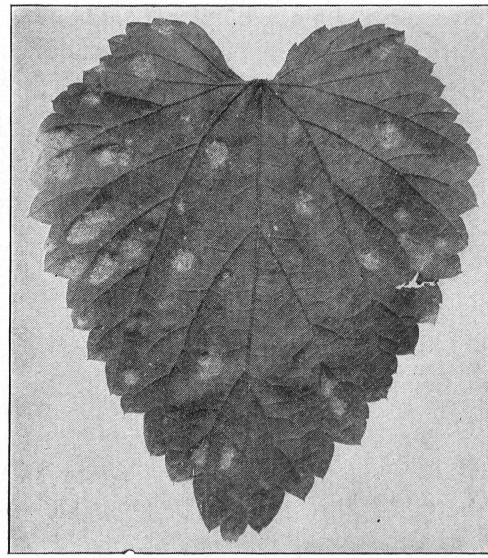

FIG. 94.— *Spots of the mildew fungus on a hop leaf. Natural size*

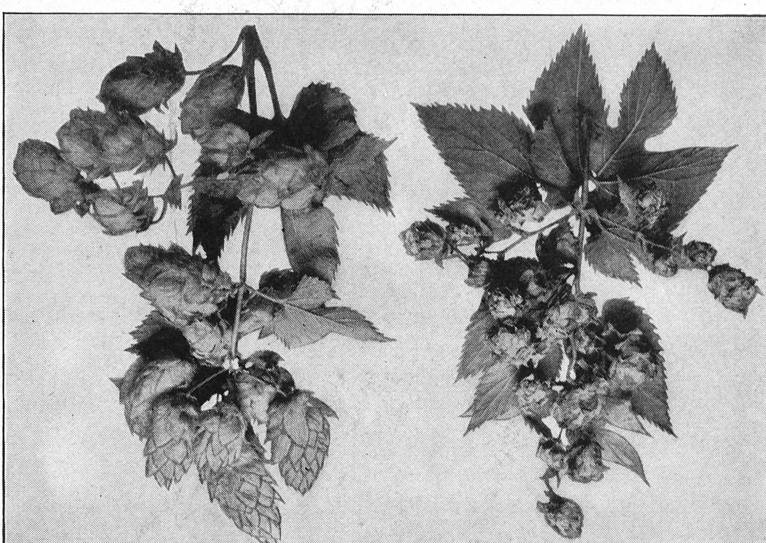

FIG. 95.— *Healthy hops on the left, hops partially dwarfed on the right. The dwarfing is often more complete than this. Reduced*

come covered more or less with the previously mentioned dark brown bodies, which gradually change to black. When this change begins to take place the growers find it necessary to get the hops off the vines as quickly as possible; and as this brown color cannot be removed by bleaching, it gives a bad color to a sample of hops. Such hops are also poor in quality because they contain little lupulin, and they are light in weight.

Cause of the disease

The mildew, or " blue mold " as it is frequently called in this State, is caused by a vegetable parasite belonging to a large class of organisms known as fungi. This parasite is technically designated as *Sphaerotheca humuli*. All the fungi are destructive in nature and live on food manufactured by other plants or animals. Some of them live on dead vegetable and animal matter, while others attack living plants and animals and are therefore known as parasites. There are many fungous parasites, some of which are internal and others external. It is to the latter group that the hop mildew fungus belongs, and the common name, "powdery mildews," aptly expresses the general appearance of these fungi on the plants that they attack.

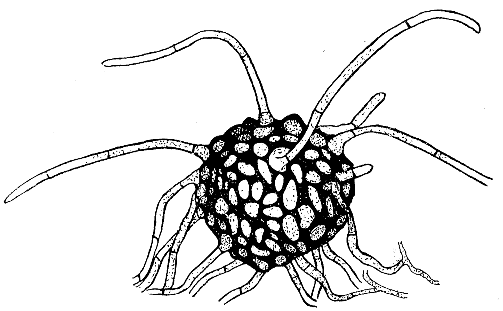

FIG. 96.— *Mature perithecium, showing organs of attachment. For a section of this body see Fig. 97. Magnification 250*

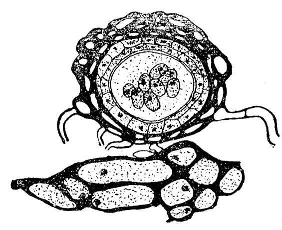

FIG. 97.— *Cross-section of perithecium, showing thick-walled cells of outer covering, thin-walled cells of inner layer, and the ascus inside containing spores. The thickness of the wall shows the futility of trying to kill the fungus in its winter stage. Magnification 250*

Life history of the fungus

Perithecia.— In common with many other fungi, the hop mildew fungus produces spores for propagation and spores for conservation over winter. If one examines carefully the half-decayed fragments of leaves and hops about a yard in early spring, he may find the perithecia — the minute black bodies that constitute the winter stage of the fungus; but they are so small that it is difficult to see them with the naked eye. They are globose, or nearly so, and are 58 to 120μ (.0023 to .0047 inch) in diameter. These perithecia are provided with numerous arms by means of which they retain their hold on the leaf (Fig. 96). The walls are made up of two layers, a very thick outer layer and a thinner inner layer. Inside the case is a sac, or ascus, which contains eight oval, thin-walled bodies — the ascospores (Fig. 97). These average 22μ (.00086 inch) long and 15μ (.00059 inch) wide. Particular attention is directed to the relative thickness of the perithecial wall, and to the exceedingly small size of the spores as well as the thinness of their walls.

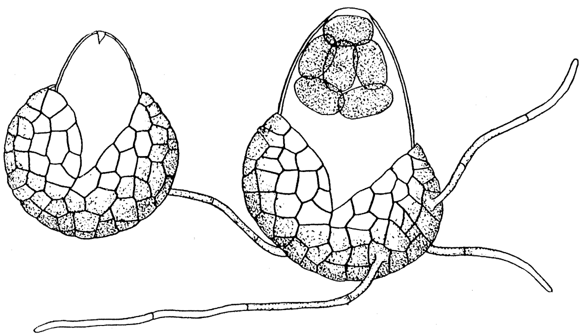

FIG. 98.— *Perithecia. At the right, just before the spores are discharged in the spring; at the left, the partly closed perithecium after spore ejection.* (*After Salmon.*) *Magnification 250*

Discharge of spores.— The manner in which the spores are shot out of these winter fruit-bodies, or perithecia, has been carefully studied by Salmon ('07) in England. He found that perithecia gathered in January and kept three or four months in a dry condition would shoot out their spores in about three quarters of an hour when wetted. He placed them in water and watched them under the microscope. The outer wall of the fruit-body begins to split in a vertical slit from the apex. The apex of the ascus at once appears at the slit, and rapidly swells by taking up water until it protrudes sufficiently to show the ascospores inside. The ascus continues to swell until it reaches dimensions often considerably larger than the perithecium which originally contained it (Fig. 98), and considerable tension seems to be developed. The ascospores are usually collected close under the pore at the apex of the ascus. In a few minutes the ascus bursts by a small hole in the apex and the ascospores are forcibly expelled together. The now empty ascus contracts and shrinks back into the perithecium, which partly closes (Fig. 98).

This process takes place in nature during wet, rainy periods of the spring and early summer. Not all the perithecia are discharged at once, but a few probably shoot out their spores with each successive rainy period. Salmon has caught these spores in large numbers two fifths of an inch above the dehiscing perithecia. Once they are thrown out into the air in this way, they may be borne about for considerable distances by air

('07) Salmon, E. S. Notes on hop mildew. Journ. Agr. Sci. 2:327–332. 1907.

currents in much the same manner as are particles of dust. The extremely small size and lightness of the spore must be borne in mind. The spores blow about and some of them lodge on hop plants. Others, falling in unfavorable places, soon dry up and perish for they are very thin-walled (Figs. 97 and 101).

Spore germination.— When the ascospores fall on hop leaves and there is moisture present, they begin to send out a germ-tube in the course of a few hours. This is a thin-walled, nearly cylindrical tube that grows on the surface of the leaf. Before the tube has gone far, however, a branch from its underside penetrates the wall of a leaf cell by a very narrow opening. When the branch reaches the inside of the cell wall of the leaf it broadens into a sac-like structure (haustorium), which gradually enlarges until it may entirely fill the cell (Figs. 99 and 100). This haustorium serves as an organ of attachment for the branch growing on the surface of the leaf, and also as a means of obtaining nourishment from the leaf.

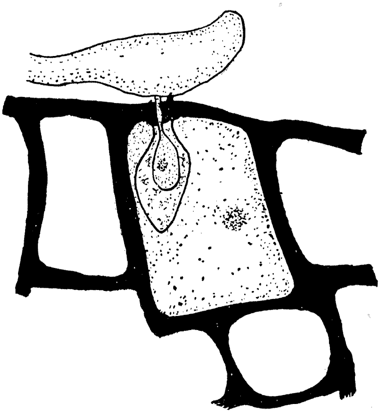

FIG. 99.— *Haustorium, or sucker, of the mildew fungus penetrating a cell of the hop leaf and absorbing nourishment. Magnification 690*

Mycelium.— With the absorption of food by the haustorium the tube continues its growth, branching and rebranching so as to form a net on the surface of the leaf. It is now known as the mycelial, or vegetative, stage of the fungus. At frequent intervals new branches are sent down into the leaf cells, so that this interwoven mass of mycelium is all fastened to the leaf by the haustoria that penetrate the surface cells of the leaf (Fig. 100).

Summer stage.— Before the mycelium has grown far in this way on the surface of the leaf, in fact before it can be seen with the naked eye, upright branches begin to appear, at first from the center of the spot and later, as the spot enlarges, from nearer the margin. These branches grow to a height of 180μ (.0072 inch); cross-walls appear, beginning at the upper end, until eight or ten divisions are formed (Fig. 100) leaving a short stalk at the base. These short segments are to become the summer spores, or conidia, of the fungus, and the stalk that bears them is the conidiophore. The upper spore in this chain gradually becomes rounded out on the sides and is first detached from the chain; then the next spore in succession is detached, and so on. These spores are easily carried about by the wind, as were the ascospores, and, although many of them perish, some find suitable conditions for growth on other hop leaves. The number of conidia produced on a single spot is enormous. On a square millimeter of mildewed surface 440 conidiophores were counted, averaging 8 spores each. This would mean 285,000 on a square inch of leaf surface covered with mildew, or 2,280,000 spores. From this it will be seen that, while the large majority of these spores may perish, there may still be enough left on a single leaf to infect a whole field.

Germination of conidia.— When a conidium falls on a leaf, under favorable conditions of moisture and temperature, germination takes place in

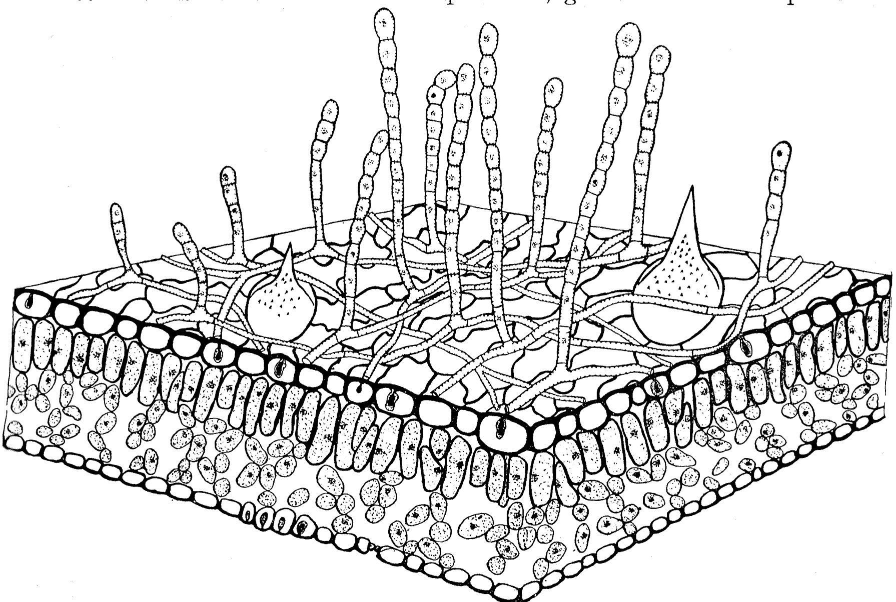

FIG. 100.—*Diagrammatic section of a small piece of hop leaf, showing the mildew fungus on the surface, with conidiophores and chains of spores reaching into the air and haustoria extending into the epidermal cells of the leaf. Magnification 150*

very much the same manner as in the case of the ascospore. A germinating conidium is illustrated in Fig. 101. It has been shown by both Salmon ('01 and '07) and Steiner ('08) that seven to fourteen days usually elapse between the time when spores (ascospores or conidia) are placed on a leaf and the time when the powdery mildew patches can be seen. Sometimes these can be seen by careful observation at the end of four days, but such development would be noticed only by an expert.

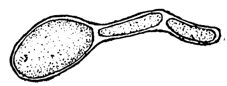

FIG. 101. — *Germinating spore (conidium) of the hop mildew fungus. Magnification 425*

('01) Salmon, E. S. The strawberry mildew. Journ. Roy. Hort. Soc. [London] 25:132–138. 1901.
('07) Salmon, E. S. Notes on hop mildew. Journ. Agr. Sci. 2:327–332. 1907.
('08) Steiner, J. A. Die Specialisation des Alchimillen-bewohnenden Sphaerotheca Humuli (DC.) Burr. Centbl. Bakt. 2, 21:677–736. *pl.* 1. *fig.* 3. 1908.

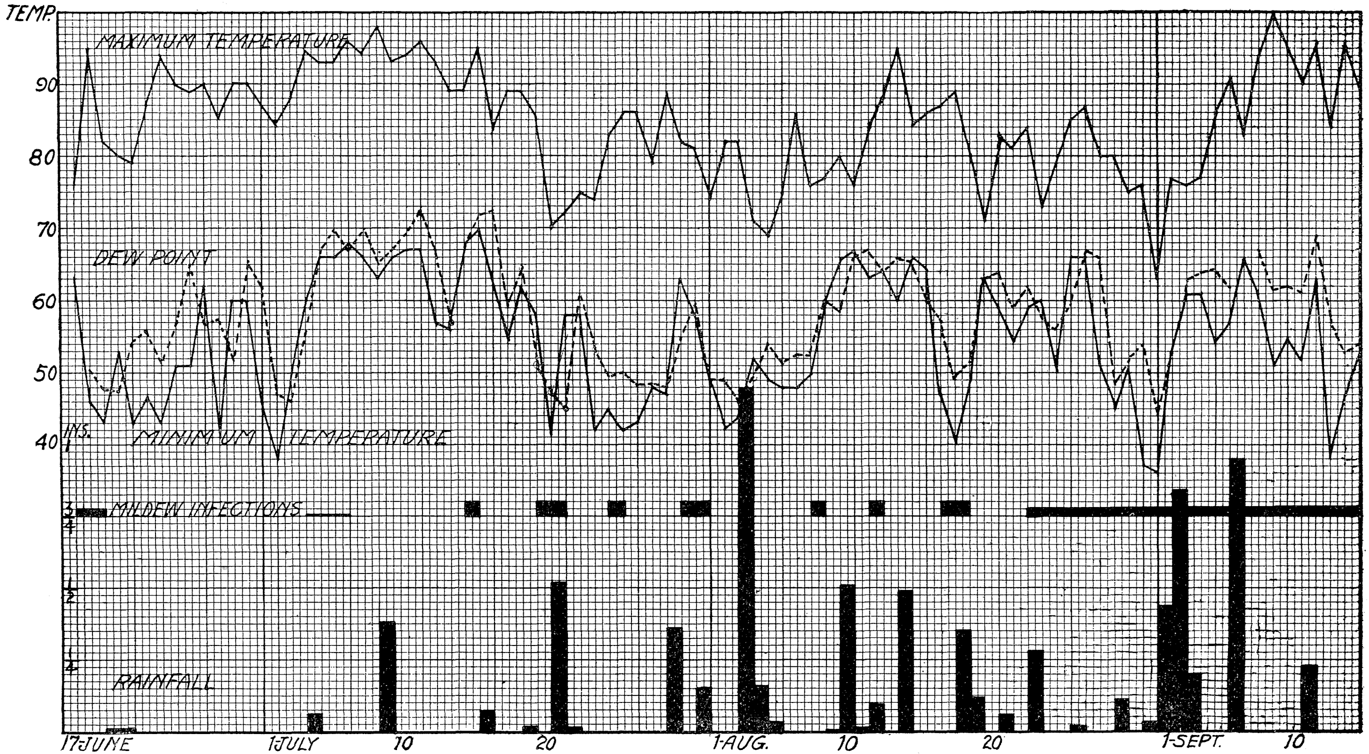

FIG. 102.— *Weather records taken at Waterville, New York, June 17 to September 17, 1912. The chart shows maximum and minimum temperature, dew-point, date and amount in inches of rainfall, and dates on which new infections of mildew occurred. For correlation see explanations on the opposite page*

Dependence of fungus on moisture.— Since these spores are supposed to germinate in water, a weather record was kept during the past summer by men making daily inspections in 800 acres of hops about Waterville and Milford (Fig. 102). From this record it may be seen that many light infections appeared about June 18 and 19. Although the weather record does not go back far enough to show to what condition this may be attributed, it was in all probability permitted by a heavy rainfall on June 6. Infections appearing on July 3 to 6 probably obtained a start on June 20 and 21. Those appearing on July 15 probably began on July 4; those on July 20 from the rainy weather on the 10th; those on July 24 from the rains of the 16th; another, on the 30th, from the 21st; those on August 25 from rains on the 17th; and the subsequent almost continuous infection of young hops from the almost continuous rains beginning early in August, as shown in Fig. 102.

Points of infection

Since the earlier infections come from the winter fruit-bodies, or perithecia, which are scattered about on bits of leaves on the ground, it is natural to expect that the first signs of mildew will usually be seen on leaves near the ground. This natural inference as to what is likely to occur has been borne out by observations made during the past two years. Later the conidia are produced abundantly and, being blown about by the wind, gradually reach the higher leaves.

Another inference that appears to play an important part is the apparent susceptibility of the younger, tender parts to the disease. After the plants are well up the poles, the larger, lower leaves do not appear to be nearly so frequently attacked as are the younger ones, that is, those near the top of the vine or those on sprouts near the base. It is probably for this reason, also, that the mildew often appears so virulently on the flowering catkins and the young hops. These are tender and their cells are thin-walled. Thus it happens that the disease may not appear on the Cluster hops — the leaves of which appear to be more resistant than do those of the Canada, or red-vine, variety — until flowering time, when the mildew often spreads rapidly through the yards of Cluster hops, attacking the young flowers and later the hops.

Development of winter fruit-bodies, or perithecia

During the latter part of July or early in August, if the mildewed spots on the undersides, and occasionally on the upper sides, of the leaves or the mildewed hops are examined carefully, minute brown spots may be seen to be appearing. These are the young perithecia, or winter fruit-bodies. They arise where two mycelial branches cross or come near each other.

A short branch is sent up from each. These short branches are soon cut off by cross-walls. One of the branches develops into the male reproductive organ and the other into the female reproductive organ. After the fertilization which is believed to take place, threads of mycelium grow up around the fertilized reproductive body, which is known as the ascogonium. At first a thick-walled outer layer is formed, from some of the cells of which the arms (known as appendages) grow out. A second layer of cells is then formed inside the first. These two layers of cells become the outer and the inner wall of the perithecium. Inside, the thin-walled ascogonium develops into an ascus containing eight ascospores. This process goes on during the late fall and winter; the spores reach maturity in the spring, when they are shot out as previously described.

How the mildew injures the hop

Practically all the surface cells of an affected area are penetrated by the haustoria of the fungus. These haustoria gradually become larger and the cell contents less, until the former occupy nearly the entire cell; thus, many of the surface cells become dead as the spot grows older, leaving brown areas on the leaf. The leaf, however, has a thickness of about seven layers of cells; and since only the surface cells are thus affected, the leaf is not so seriously injured as are the bracts of the hop, which are only about four cell-layers thick and the walls of which are much thinner. So large a part of the nourishment of the bracts is apparently absorbed that they become dwarfed and fail to develop — in other words, do not " hop out."

When the attack of the mildew is late — that is, after the hops are out — it often causes a serious reddening or browning of the hops. In such cases the summer spores of the mildew may or may not be developed in abundance. In some cases the white, moldy stage is scarcely apparent, and yet careful microscopical examination reveals the presence of the mycelium of the mildew and the winter fruit-bodies, or perithecia. Hammond ('00) seems to have first attributed this reddening of the hops to the mildew. There are undoubtedly other causes of premature browning of the hop bracts; but much of the browning that has appeared previous to picking during the past three years can be safely attributed to this fungus, as has been found by repeated examinations. As previously described under "Symptoms of the disease," the hop first becomes dull green in color and then gradually grows more and more brown. This browning of the hops is the more easily brought about by the fungus because the hop bracts are very thin and delicate, so that the haustoria entering the

('00) Hammond, W. H. Red mold of hops. Journ. Southeast Agr. Col. Wye **9**: 19–20. 1900.

surface cells can easily absorb a large part of the nourishment normally going into the hop.

Infection from mildewed weeds

The basis on which fungi have usually been classified in the past, and are for the most part to-day, is that of their structure. If one were to examine the mildews taken from the hop, strawberry, Agrimonia, Potentilla, groundsel, avens, meadowsweet, and other plants, he could find no structural differences among them. It is natural to assume, therefore, that the same fungus grows on a number of different kinds of plants and might readily spread from one to another. The question as to whether or not it is dangerous to allow such plants to grow near a hopyard has been discussed by many writers. When this question first arose, many writers of the time apparently accepted the theory and recommended that all such weeds be removed; and some persons even now recommend the removal of any such plants that may be growing near hopyards.

In recent years, however, much has been done which shows that there is a high degree of specialization in certain fungi. This work was at first concerned with some of the rusts on cereals. Later, much work was done with certain mildews, among others the hop mildew. Cross-inoculation experiments have not included all the strains of mildew from the different host plants. Enough cross-inoculations have been made, however, to show that the fungus is highly specialized and, like certain others of the mildews, the strain that attacks the hop is confined to the hop plant and to another closely related plant, *Humulus japonicus*, and is entirely unable to attack other plants. So, also, the strains that attack other plants are unable to attack the hop.

The writer has been unable to find anything in the situation in the hop-growing section of this State which would lead him to think that weeds have any part in the spread of hop mildew. While the disease may be found on a few weeds, it is not especially plentiful. Practically all early infections might be traced to bad management of the yards during the previous year, and the later infections might easily have come from neighboring yards.

CONTROL

Sanitation

Since there is no growth of this mildew in leaves or plants or on the soil over winter, but merely a development inside the somewhat thick-walled perithecium, it would seem nearly or quite impossible to destroy the fungus by applying a chemical to the soil. If such a substance were strong enough to affect the mildew in this condition, it would quite likely be strong enough to affect injuriously the roots of the hop plants themselves. It is self-evident, however, that the more thoroughly the vines and mummied hops are burned in the fall, the fewer there will be of the fruit-bodies that they harbor to cause infection in the spring. It is also a common recommendation that any remaining perithecia be buried in the soil by plowing under or some other means, so that they will decay in a short time through the agency of other fungi and bacteria. It has been definitely shown by Reddick ('11), in the case of the black rot of grapes, that when fruit-bodies are buried under six inches of soil for three months a complete disintegration takes place. This would seem, then, to be a very practicable method of decreasing the amount of early infection by mildew. In the vineyard, where the vines are planted at about the same distance as in the hopyards, this is accomplished by plowing the centers of the rows in the spring so as to completely cover any material remaining on the surface of the soil in the center. This is followed by a horse hoe, which turns over the remainder of the soil in the rows except a little directly around the hills. This last soil is turned over by means of a hand hoe. This method would seem to conform so nearly with the common practice of tilling hops in the spring as to be directly adaptable, if it is borne in mind that the object of the treatment is merely to bury any debris on the surface of the ground that might harbor the fungus, and to bury it deeply enough so that it will remain undisturbed for some time.

One other suggestion that might be offered in regard to the treatment of vines in the spring is that, since early infections are caused by the shooting of the spores from the fruit-bodies on old leaves and hops over the surface of the soil, and since the spores are not shot very high, it would seem advisable to get the hops started up the poles early, and, as far as possible, to keep the suckers that sprout at or near the ground surface removed.

Work of 1910

Preliminary experiments.— When the hop mildew appeared in virulent form in 1909, it was so late in the season before the disease was recognized that there was no advantage in doing anything to prevent its ravages since most of the harm had already been done. In 1910 the circumstances were nearly the same. The writer visited the hop-growing sections about the 8th of August. At that time it was possible to determine with certainty the cause of the trouble, as the winter stage was appearing in abundance and several yards were a complete loss. It was thought desirable to make even then some preliminary experiments with spraying and sulfuring for the control of the disease. One of the growers, Mr.

('11) Reddick, D. The black rot disease of grapes. N. Y. (Cornell) Agr. Exp. Sta. Bul. 293:310. 1911.

Allen, whose hops had thus far been only slightly attacked by the fungus, was particularly desirous to see what he could do to save the crop.

Liquid spraying.— For several reasons, spraying hops with a liquid spray seems impracticable. One of the chief difficulties is that the hops are trained on poles 15 to 25 feet high (Fig. 103). With the poles $7\frac{1}{2}$ to 8 feet apart this makes a large amount of surface to cover per acre. In addition, most hops grown in this State are trained also on strings running between the poles. The height of the poles and the various methods of stringing would make spraying with any arrangement of stationary nozzles ineffective. To spray such a yard with nozzles on spray rods, such as are sometimes used in spraying for the hop aphis, would make a large amount of hand work necessary. Not only this, but the amount of liquid necessary to cover an acre of hops would be large. Thus the cost of spraying materials would be high and the transportation of a large amount of water would be necessary. This would be especially true, as the hop makes a rapid growth and would have to be sprayed comparatively often in order to keep the new surface covered.

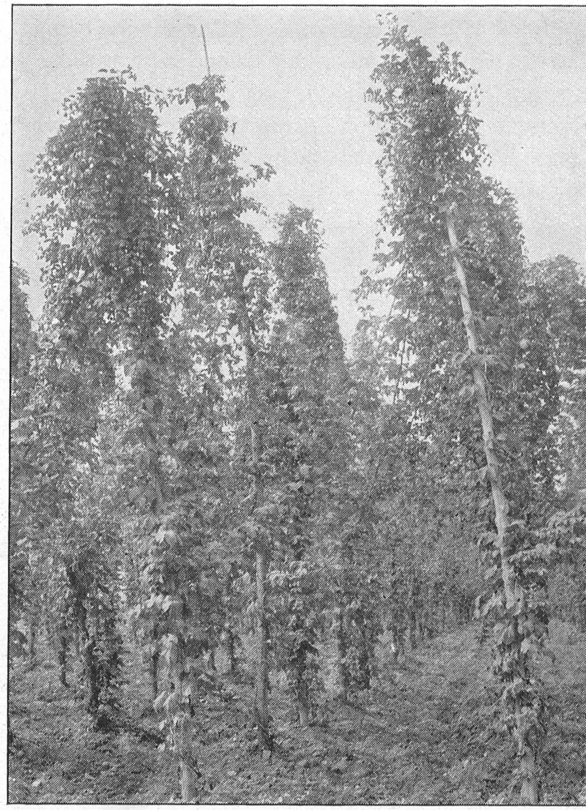

FIG. 103.— *A well-kept hop-yard. The system of training, particularly the use of strings, makes liquid spraying impracticable*

Sulfuring.— For the above reasons, sulfuring seemed to give promise of being of the greatest practical value. While this method had not been used largely in this section of the country for combating plant diseases, it is a well-known European treatment for the powdery mildews. The most pertinent question seemed to be, then, whether it would be practicable to use it in the cool, temperate climate of this section, with its rather small amount of sunshine and comparatively heavy rainfall.

Sulfuring was first begun by Mr. Allen, who obtained a machine for applying dry preparations. This machine was loaded on a stone-boat and turned by hand. One other grower did some sulfuring later in the season. This sulfuring was done less than two weeks before picking commenced, but even during that period it was noticed that the hops remained brighter until picking time than in surrounding yards that had not been sulfured.

FIG. 104.— *Sulfuring machine in operation*

Work of 1911

Plan of experiment.— In the following year the mildew was found appearing on the hops the last of June, and an experiment was laid out to test more thoroughly the efficiency of sulfur. Accordingly a yard was chosen which was severely attacked by the mildew; in fact, this yard was the first on which an attack of mildew was reported in that vicinity in 1911, and, at the date when the first sulfuring was made, was thought to be the most seriously infected of any yard in that section. One part of the yard was set to Canada, or red-vine, hops and about an equal part to English Clusters. The mildew throughout the season was more abundant on the Canada hops, and at the date of the first sulfuring it was found on practically all the lower leaves. This was recognized as a more general infection than a grower should allow to appear in his yard before trying to check it, but the yard was thought to be a desirable one to use under the circumstances in order to make the test as severe as possible. The field was divided lengthwise into three plats so that each plat included both varieties, the whole field having an area of four acres. It did not seem desirable either to divide the field into a larger number of plats or to make the plats smaller, as the sulfur often drifts with the wind through several rows of hops. Flowers of sulfur alone was applied on one plat; on the second, flowers of sulfur and lime in equal parts by weight; on the third, nothing was applied. The yard was sulfured on July 1, July 10, July 26, August 7, August 16, and August 21.

Observations.— When an examination was made of the field on July 8, the action of the sulfur on the mildew spots could be seen clearly. The weather after the first sulfuring had been very warm and the sulfur appeared to have been especially effective during this period. After the sulfuring on July 10 there followed a period of wet, rainy weather when the sulfur did not appear to be nearly so active; but at the date of the third sulfuring a marked difference could be seen between the part of the yard not dusted and the part to which sulfur was applied. Also, other yards in the neighborhood to which no sulfur had been applied showed one third to one half of the hops already affected with mildew.

From the first of August until picking time the weather was fairly good for the action of sulfur, as well as favorable for the growth of mildew. In the experimental yard little injury occurred after this date. Some losses had occurred during the rather unfavorable weather of July, when another sulfuring would undoubtedly have been of great value. The writer, however, was dividing his time between this work and work in other parts of the State, and was not able to watch the yard so closely as was desirable.

Results.— Counts were made in this yard from August 30 to September 1 and the hops were divided into three classes (Fig. 105). In the first class were the hops not affected with mildew at all; in the second, hops that were slightly affected, but marketable; in the third class, hops that were considered valueless for market purposes, many of which had not gone further than the bur stage.

It may be seen that perfect control was not secured, for reasons given above; but the value of flowers of sulfur as compared with sulfur and lime seems to be clearly shown. This point would appear to be of considerable interest for several reasons. Some manufacturers of dusting machines have recommended the mixing of various amounts of lime with sulfur in order to make it feed through the machine better; and many growers have been inclined to do this, as it seemed to make the sulfur feed somewhat better and it made the mixture cheaper. Various writers have recommended mixing lime with sulfur in sulfuring for various mildews, although no exact data appear available on the subject.

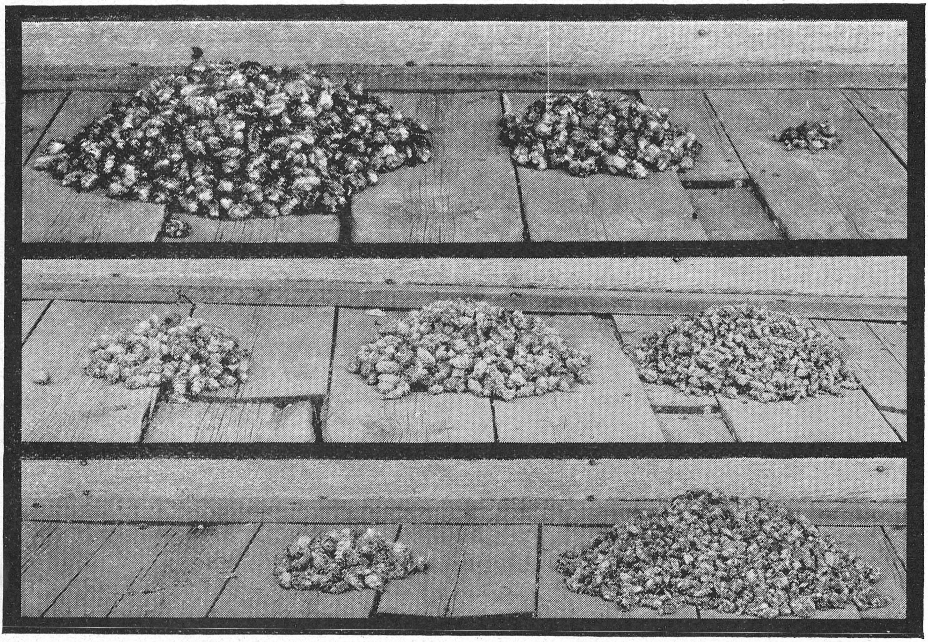

FIG. 105.— *Random samples from the three experimental plats. Upper row from sulfur-treated plat; middle row from sulfur-and-lime-treated plat; lower row from untreated plat. Lots at the left not affected (none in lower row), those in the center marketable but slightly affected, those at the right badly affected, by mildew*

NUMBER OF HOPS IN THE DIFFERENT CLASSES

Application	Free from mildew		Slightly affected		Valueless	
	Number	Percentage	Number	Percentage	Number	Percentage
Sulfur	1,296	61.2	610	28.8	213	10.0
Sulfur and lime	535	12.3	1,273	29.4	2,530	58.3
Check	0	0	95	2.3	4,070	97.7

Action of sulfur.— The above results are also of some interest in connection with the theory of the action of sulfur. A considerable amount of work has been done which seems to indicate that the action of sulfur is due to the gradual oxidation of the sulfur, forming sulfurous acid in the presence of water which in turn is oxidized to sulfuric acid. These acids in dilute solutions have been shown to destroy the mildew (Fig. 106). In the presence of lime these acids would naturally unite with the lime, forming compounds quite insoluble and presumably quite harmless to the parasite.

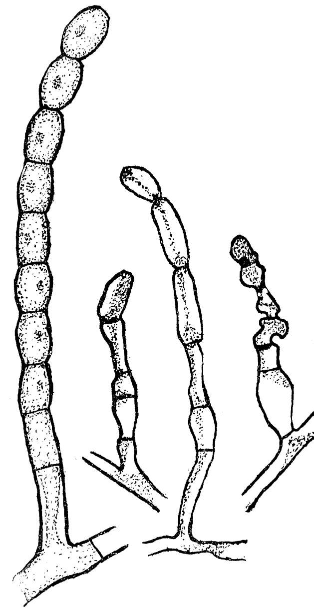

FIG. 106.— *Chains of conidia, or summer spores. Those on the left, healthy; those on the right, shriveled and dead due to the action of sulfur. Magnification 310*

Sulfuring done by growers in 1911.— Probably of greater importance than anything else in showing the value of sulfur for preventing the mold, are the favorable results obtained by growers during the past two years. Because of the great danger to the crop, many growers were willing to apply sulfur in 1911 if there were any chance of preventing the ravages of the disease. The writer, therefore, as far as possible, watched the yards of these various growers in order to determine whether the mildew was spreading or was being controlled by the sulfur, and advising accordingly. It thus happened that many interesting results were noted.

In one case all the fields on a farm were sulfured during the last of June, except a part of one yard where mildew had not appeared during the previous year. This was the only yard where mildew could be found on the 28th of July. In this case the sulfur had apparently acted as a preventive. Although no material loss occurred in the yard not sulfured the first time but sulfured together with the other yards during the remainder of the season, yet the mildew could be found here and there in this yard throughout the remainder of the season, while it seemed to get no start in the other yards. This appeared to the writer to be a very striking illustration of the importance of sulfuring a yard before the mildew appears, because of the greater value of sulfur as a protection (prophylactic) against mildew than as a destroyer (therapeutic) of it after it has a start.

One instance of particular interest occurred in the village of Waterville. A yard of Canada, or red-vine, hops had been practically a total loss in

1910 and the mildew was fairly well developed there in 1911. In the latter year the mildew was first discovered in the yard on July 8. Several days passed before the grower was able to sulfur, because of other work and because his machine had not yet arrived. When sulfuring was finally begun, the weather was unfavorable for a week or more and, although the sulfuring was repeated four times within a comparatively short period, not much seemed to be accomplished. The grower being determined to make a thorough trial, the sulfuring was kept up until the end of the season, ten applications in all being made. With the better weather that followed the mildew was checked successfully, so that only a small loss was sustained. On the eight hundred hills in this small yard one hundred and fifteen boxes* were picked — a larger average yield than was obtained in other yards on the same farm where there had been very little mildew at any time during the season. Without doubt this yard could have been saved more easily if the sulfuring had been begun earlier, but the results show what may be done even under adverse conditions. There seemed little doubt that if no attempt had been made to save it this yard would have been a complete loss, as were many other yards that were in the same condition at the time the sulfuring was begun.

In another case a grower had two yards, a considerable part of one being given to Canada hops. The yard in which were the Canadas was affected with mildew earlier than the other, and the first sulfuring was done during the latter part of June. More attention was given to this yard than to the other throughout the season because it was believed to be in a more serious condition. In the other yard no mildew could be found until some time after this. Thus it happened that little attention was given to the second yard for some time, when it was found to be in a much worse condition than the yard in which the mildew had started early, but which had been sulfured six times and had suffered no appreciable loss.

Many other instances might be cited. It is perhaps enough to say that when there was any appreciable attack of the mildew and sulfur was not used, picking had to be done early in order to save the crop at all, for the hops soon became brown if left and this color could not be bleached out. The yards that had been well sulfured could be left until mature, and it thus happened that the owners of such yards were the last to finish picking. In many instances when the sulfuring was not begun until shortly before picking, the mildew was checked so that the hops grew better instead of worse. These late sulfurings proved more effective in many cases than the writer had believed possible.

* A box holds ten to twelve pounds of dried hops.

Experiments of 1912

Grades of sulfur.— During 1912 it was thought desirable to test the effectiveness of different kinds of sulfur for control of the mildew. There are many opinions appearing in literature in regard to this matter, but few definite experiments on which to base conclusions.

Although flowers of sulfur (Fig. 108) has been most generally used for such work, both in the United States and in Europe — where thousands of tons are annually dusted on the vineyards alone — and it still has the preference in France, yet in Italy and some of the other vine-growing countries flowers of sulfur has been superseded to a great extent by a ground sulfur known as "flour sulfur," which can be produced even finer than flowers of sulfur (Fig. 110). Opinions have been advanced, possibly somewhat from a theoretical standpoint, that an exceedingly finely ground sulfur should be even more efficient than flowers of sulfur, because the finer the material the more uniform and perfect would be its distribution and the more readily would it adhere. In addition to this, the finer the particles, the more readily would they oxidize, assuming the action on the mildew to be as suggested above, because of the much greater surface area for a given weight of sulfur.

One other point to be considered in choosing between the two kinds of sulfur is, that the flour sulfur can be produced and can be obtained of a uniform and known fineness; while flowers of sulfur, from its method of manufacture, will vary more or less in quality.

Field tests.— It was therefore thought desirable to test these two kinds of sulfur on a commercial scale. Accordingly arrangements were made for getting a specially finely ground flour sulfur — which, though not generally on the market, could be obtained if it proved desirable to use it — and an equal quantity of flowers of sulfur.* Arrangements were made with twelve growers in various parts of the hop-growing section. Yards two to four acres in size were chosen, being in many cases yards that had been severely attacked by the mildew during the previous year. The growers were instructed to apply the two kinds of sulfur, at the same time and in the same amounts, as often as seemed necessary. No unsprayed parts were left in any of these fields. In order to be of any value at all in connection with sulfuring, such a block would have to be of considerable size, as the sulfur often blows through six to ten rows from the row where it is being applied. In order to get any accurate results a large area would have to be left untreated.

During the previous year hops at 50 cents a pound had been worth \$300 to \$500 or more per acre. It therefore did not appear practicable to leave check plats. These yards, with the exception of one or two which

* The flowers of sulfur was also of the best quality and very fine and uniform in texture.

were at a considerable distance, were visited at various times by the writer or by the men assisting in this work, all being visited at the end of the season. Although many of the yards had been seriously affected during the previous year, sulfuring was begun earlier in the present year and almost without exception the mildew did not appear to any considerable extent in the part of the yard dusted with either kind of sulfur.

Results.— The mildew was so uniformly scarce in these yards that it seemed hardly possible to find any considerable difference in the two parts of the yards by making counts. If this uniformity of control had occurred in only one or two cases it might have been considered as due to chance; but mildew in the different yards was so uniformly well controlled that there seems to be little doubt that the extra fine flour sulfur could as well be used as flowers of sulfur.

It may be said, also, that the fine flour sulfur seemed to float well in the air, forming a large cloud. This tended to give it a good distribution over the vines. On the other hand, it seemed to have a greater tendency to form lumps than does flowers of sulfur. The necessity of passing it through a screen in order to break up these lumps was thus more apparent than with most flowers of sulfur, although flowers of sulfur varies considerably in this respect. This tendency was especially apparent with one of the types of machines in use for sulfuring hops. With this machine many lumps were thrown out even with the flowers of sulfur, and this throwing of lumps was naturally even more apparent with the extra fine flour sulfur.

Formation of cooperative associations for control of hop mildew

After the destructive ravages of the mildew in 1911, the growers about Waterville came together in order to see what could be done toward controlling the disease. They decided to form an association for the purpose of cooperating with the Department of Plant Pathology at Cornell University. Soon afterwards the growers about Milford formed a similar association. To each of these places men were sent from the College for the purpose of studying the disease and of advising hop-growers throughout the summer as to its control. The expenses of these men were borne by the growers.

The nature of the disease made it possible for these men to direct its control with remarkable success. This was partly because the fungus causing it is almost entirely on the outside of the leaves and hops, where it is easily seen and recognized. For this reason, also, the course of its development is easily followed. Perhaps more important than this is the fact that it is possible to determine, partly by the appearance of the spot and partly by the condition of the mildew as shown by microscopical examination, whether the mildew has been killed by the applications of sulfur already made. In the case of the control of this disease, also, no one application of sulfur could be said to be of paramount importance as in the case of some diseases. As the cost of making a single application is comparatively slight and the method of applying sulfur rapid, the number of applications may be varied so as to suit individual cases and conditions.

In the association at Waterville there were represented over six hundred acres of hops, and in that at Milford over two hundred acres. Of the

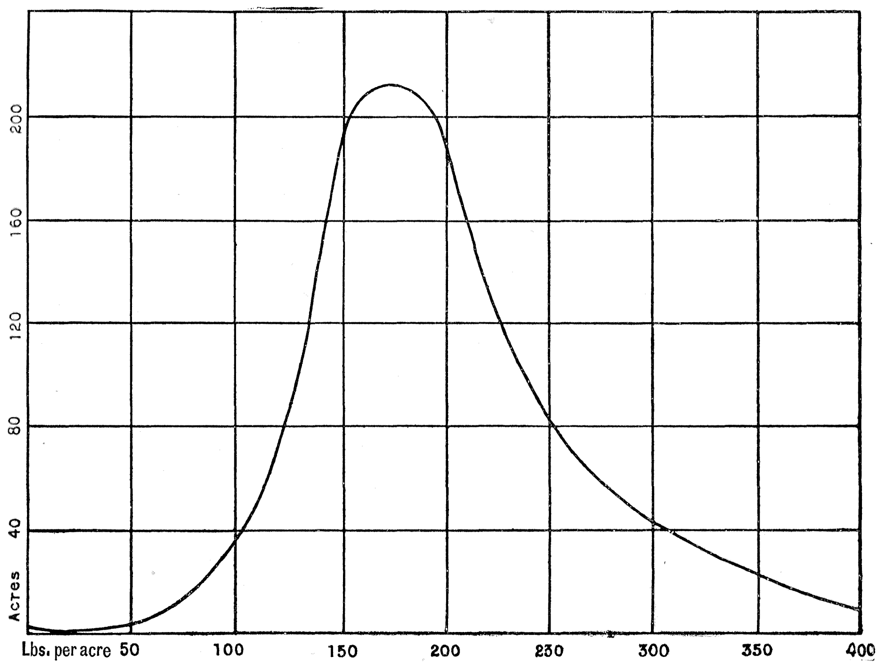

FIG. 107.— *Curve showing amounts of sulfur applied per acre in the season of 1912, by the associations at Waterville and Milford. Plotted with acres as ordinates and pounds per acre as abscissas. One hundred and fifty to two hundred pounds per acre was found necessary on the larger part of the acreage*

hops grown by the members of these associations there were very few losses caused by mildew. In a few cases, losses occurred because the yards were on side hills so steep that it proved impossible to sulfur them satisfactorily. In a few other cases poor results were attributed to machines that did not put on enough sulfur and did not distribute it well.

In Fig. 107 is shown a curve indicating the amount of sulfur found necessary for the growers in these associations to use in order to control the mildew. It may be noted by reference to the curve that the amounts of sulfur applied varied from none to over four hundred pounds per acre for the season. It must not be thought that this variation was due merely to difference in personal judgment of individual growers. On the contrary, it represents largely the variation in the amount of sulfur necessary to control the disease in individual cases, for the growers sulfured largely in accordance with advice of men assisting in the work. It will be noted, however, that on the larger part of the acreage it was necessary to apply 150 to 200 pounds of sulfur per acre in order to protect the crop from the mildew.

GENERAL RECOMMENDATIONS IN REGARD TO SULFURING HOPS

At this time it seems desirable to mention certain points which have not been under direct experimentation, but which are principally conclusions from observations made during the past two years while directing control operations and observing the results.

Sulfuring machines

One of the most important causes of failure during the past year has been the use of unsatisfactory machines for applying sulfur. It is very important that the sulfur should be applied uniformly and in sufficient quantity. The worst feature of some of the machines seemed to be the arrangement for feeding the sulfur into the outlet tube. The writer has often observed machines that would feed the sulfur fairly well only if it were in the best condition; and if the sulfur were not in good condition it would come out very irregularly, the machines often skipping half a dozen hills without throwing out any sulfur and then puffing out a considerable quantity at once. In such cases, often not half of the foliage would be covered with sulfur and frequently the amount applied per acre was entirely insufficient. Often it happened that growers failed to apply more than twenty-five pounds per acre with the feeding apparatus working at full capacity. In one instance a grower stated that he had sulfured four acres three times with one barrel of sulfur; or, in other words, he had applied about fourteen pounds per acre with the feeding arrangement wide open. On being asked why he used so little, his explanation was that this was all that his machine would feed. The writer would recommend that no machine with a maximum capacity of less than one hundred pounds be used.

The evenness of application is dependent not only on the formation of a continuous cloud of sulfur, but also to a considerable extent on whether or not the sulfur is thrown out in lumps. In many cases, after an application much of the sulfur could be seen on the ground in balls of various sizes. This was particularly likely to be the case when the sulfur was not put through a sieve, as recommended above. These balls are not hard and may be easily broken up, but some of the machines in use seem to have no tendency to do this and thus a considerable part of the sulfur is lost through falling to the ground. Of that remaining on the leaves, much is in small balls instead of being spread evenly over the surface. Many growers have adopted the practice of putting the sulfur through a screen just previous to putting it into the machine, in order to have it as free from lumps as possible. This is always to be recommended, and is of the utmost importance if the sulfur shows a tendency to be thrown out in lumps.

There seems no good reason why a machine should not be so made as to obviate this difficulty. Some of the machines at present in use are considerably better than others, but there seems to be a possibility of improvement in all of them.

Times for application

This is a very important consideration in controlling the mildew, and one for which it is difficult to give general directions. In the last two years the writer has found it necessary to sulfur many more times under some conditions than under others. This depends to a considerable extent on the weather, on the condition in which the yard was left the previous fall, and on the condition of the yard as regards development of the mildew at any particular time. It seems especially desirable to make one application of sulfur before the mildew gets any start at all. This should be made in most cases at about the time of the second tying. Sometimes it may be advisable to spray even earlier than this, if the mildew appears in the yard or in adjacent yards or is known to be early in that particular locality. A second spraying is generally advisable when the hops are well up on the poles, and a third while the hops are in full bloom. One or two further sprayings should be made before picking time. As stated before, it is not thought that these rules are applicable in every case, and possibly not strictly in many cases. Not infrequently, twice as many sulfurings are necessary. It should be borne in mind that heavy rains wash off a considerable part of the sulfur, and also that rains favor the germination of the spores of the mildew, which begin to grow at that time causing spots to appear seven to fourteen days afterwards. Thus it is usually desirable to resulfur after a heavy rain.

The writer thinks that the success of the two men sent by the College to work with the hop-growers' associations was due, in the first place, to the fact that they were able by careful observation to detect the first symptoms of mildew before these symptoms were found by most of the growers. When the first signs were discovered there seemed to be but little trouble in controlling the mildew if the sulfuring was begun promptly,

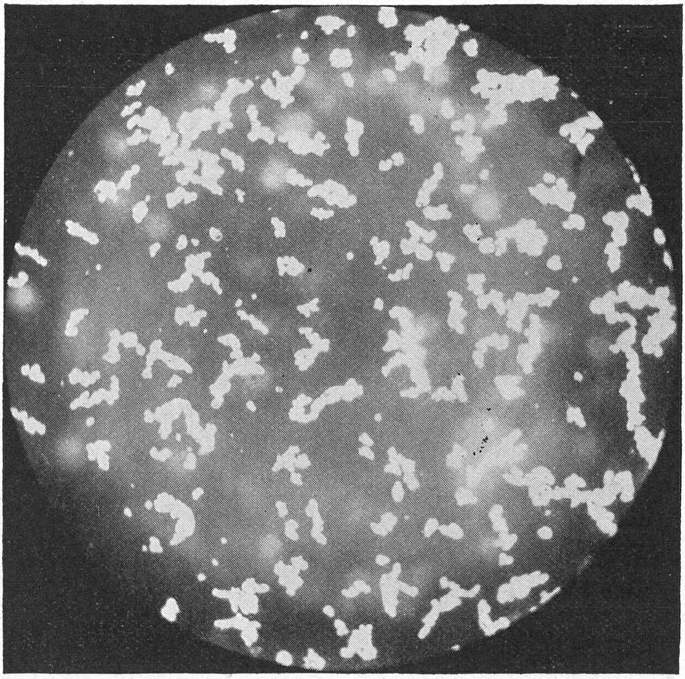

FIG. 108.—*Flowers of sulfur. The individual particles have a tendency to remain in chains. Photomicrograph. Magnification 95*

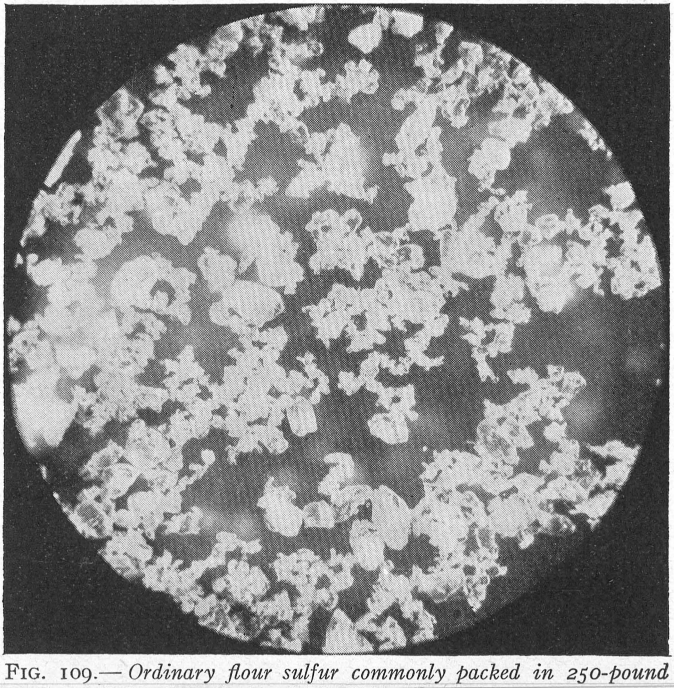

FIG. 109.—*Ordinary flour sulfur commonly packed in 250-pound*

although the disease was controlled more easily when sulfur was applied as a preventive before the first signs had appeared. In the second place, these men were able to judge, by a constant study of the mold in going from one yard to another and by making microscopical examinations, whether or not the mildew had been checked. With these points in mind they were able to judge the necessity of repeating the sulfuring. In 1912

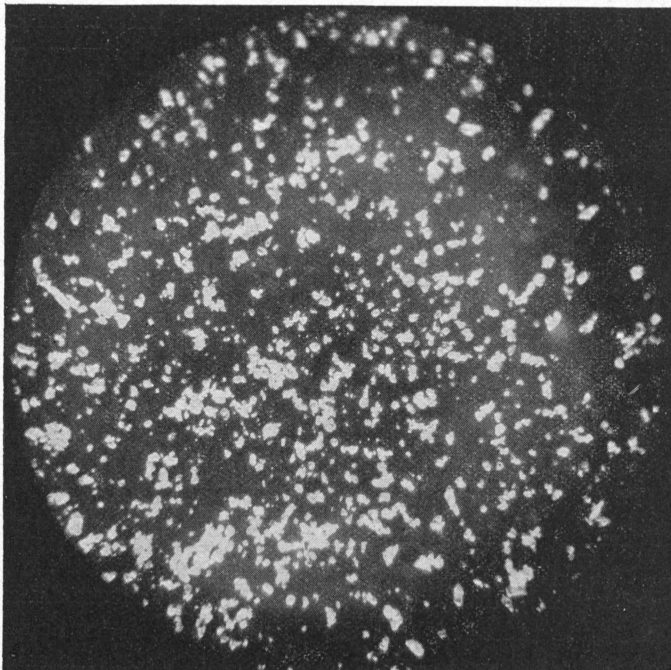

FIG. 110.— *Extra finely ground flour sulfur obtained by regrinding and sifting. Used in experiments of 1912. Photomicrograph. Magnification 95*

the season was so rainy after the first of August that it was difficult or impossible to get control of the mildew after that time; so that many growers who did not have control of the mildew by the first of August failed, although several sulfurings were made later.

Amounts of sulfur to be used

The best results have been secured when at each application not less than forty to fifty pounds of sulfur have been applied per acre, and in cases of severe attack of mildew this may be largely increased. In such cases seventy-five or more pounds per acre may well be applied.

Kinds of sulfur

There are two kinds of sulfur commonly on the market, flowers of sulfur and flour sulfur.

Flowers of sulfur is made by boiling crude sulfur in a retort and distilling it over into a large room, known as a chamber, which is so large that the temperature always remains below the melting-point of sulfur and the sulfur therefore condenses directly from a vapor to the solid form. Made in this way it appears under the microscope as composed of finely ground particles (Fig. 108). Flowers of sulfur varies somewhat as to size of particles and acid content, which is said to be due to the impossibility of keeping the condensing chamber at the same temperature the year round and to variations of atmospheric conditions. This sulfur is ordinarily packed in barrels of one hundred and fifty-five pounds net.

When sulfur was first used in Europe this was the only method of making it fine, so that it was naturally the only kind that was used; and, in fact, it is still the most largely used.

Flour sulfur is made by distilling sulfur into a small iron receptacle, or condenser, the temperature of which rises above the melting-point of sulfur so that the sulfur vapor is condensed as a liquid, run into molds, and allowed to harden. This sulfur is then ground in order to make flour sulfur. Flour sulfur may thus appear in widely varying degrees of fineness, depending on how much care is expended in its manufacture. By careful grinding and sifting it may be made even finer than flowers of sulfur. The comparatively coarse flour sulfur, such as is packed in barrels holding two hundred and fifty pounds net, and even most of that put in barrels of but one hundred and seventy-five pounds net — which are often only three fourths full — is shown, as it appears under the microscope, in Fig. 109. It is seen to be made up of a mixture of large and small particles. The extra fine flour sulfur used in the experiments previously mentioned, as shown in Fig. 110, is seen to be uniformly fine.

The coarse flour sulfur appears to be nearly the same golden yellow in color as flowers of sulfur; the finer grades of flour sulfur are whiter, and less can be packed in a barrel.

Thus far the writer has recommended the use of flowers of sulfur, because its value is known and it is finer than the flour sulfur on the local market. From the work reported above, however, and with the development of sulfuring machines better adapted to reducing the lumps that form in the fine flour sulfur, it is thought that the latter may prove more satisfactory than flowers of sulfur, since the manufacturers state that this flour sulfur can be made of more uniform quality and finer than flowers of sulfur. If flour sulfur is to be used, a product should be insisted on which is guaranteed to carry ninety-five per cent of material passing a two-hundred-mesh sieve in fineness.

It is an admitted fact that the Chancel test for fineness of sulfur is difficult of manipulation and many errors may be involved. For this reason the writer is pleased to offer here a new test which has proved satisfactory and which is easy to perform. The writer is indebted to F. H. Pough, Manager of the Research Department of the Union Sulphur Company, New York City, for the privilege of publishing here the method of making the test:

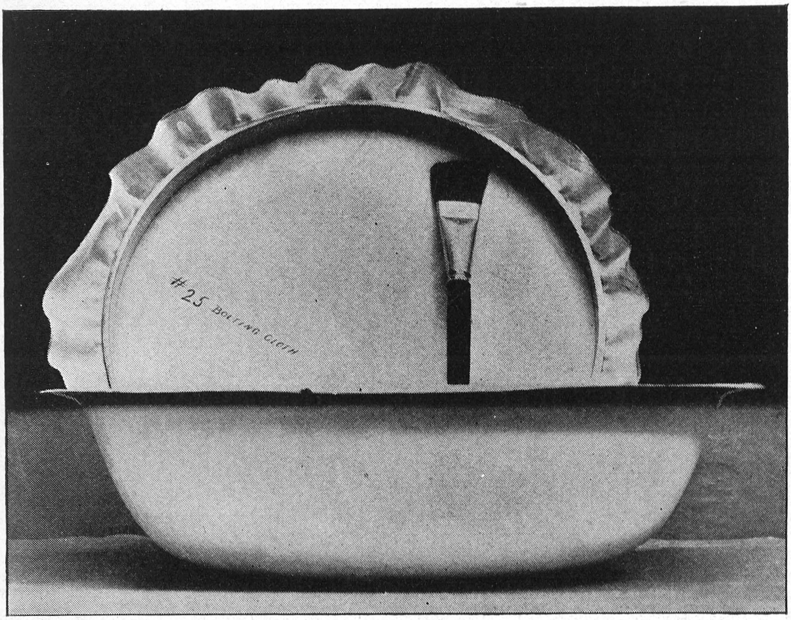

FIG. 111.— *Necessary apparatus for determining fineness of sulfur*

Because of the lack of reliability of the Chancel method of determining the fineness of sulfur, it seems preferable to substitute therefor actual sieve determinations. It is impossible to make satisfactory sieve determinations on dry sulfur, but, by immersing the sieve in a liquid, such as denatured alcohol, which readily wets sulfur and in which it is practically insoluble, it is possible to make determinations both rapidly and accurately. For this purpose, silk bolting-cloth, which can be obtained of quite uniform quality, is the most satisfactory material.*

The sieves are most conveniently made by clamping a piece of the bolting-cloth in an embroidery hoop six or seven inches in diameter, the bolting-cloth being cut round and of such diameter (nine inches for seven-inch hoop) as to leave about half an inch of it projecting above the hoop. By means of this surplus material, the silk can be pulled taut and kept so in the frame, which greatly facilitates the work (Fig. 111). The operation of testing is as follows:

* In order to obtain exact results, sieves of standard mesh of wire cloth must be used, but it must be remembered that sulfur rapidly deteriorates wire cloth.

Place the silk sieve in a hand-basin or pan of similar character having sloping sides and of such diameter that the sieve is supported about three quarters of an inch or more above the bottom of the basin, and pour denatured alcohol into the basin until the cloth is just covered. Weigh off ten grams of sulfur and transfer to the sieve; brush the sulfur gently through the sieve with a flat camel's-hair brush about three eighths of an inch wide. During the manipulation keep the sulfur near the center of sieve, by occasionally taking the basin in the hands and giving it a gentle rotary motion.* To determine when all the fine material has passed the sieve, transfer it to a basin of fresh alcohol and continue the manipulation. When completed, collect the residue of coarse sulfur at center of sieve and detach any sulfur adhering to the brush by rotating it rapidly between the fingers in a pool of alcohol formed by tilting the sieve slightly. Collect the sulfur at the center, remove the sieve from the basin, and allow it to dry spontaneously, or support the sieve on a V-shaped piece of metal or cardboard above a convenient source of heat other than a naked flame, regulating the height of the sieve according to the intensity of the heat.

It is quite difficult to transfer the residue of sulfur to a scale-pan by the usual methods, owing to the readiness with which sulfur becomes electrified and adheres to anything it touches when brushed. When all the sulfur has been collected at the center of the sieve, however, as directed, it can be transferred readily and quickly and without loss to a scale-pan (or watch-glass) by inverting same over the sulfur, and, while holding the pan firmly against the sieve, quickly inverting them. Upon weighing, the results are obtained on percentage basis.

The standard sizes of silk bolting-cloth:

No. 12, 124 meshes per lineal inch
No. 15, 150 meshes per lineal inch
No. 21, 178–182 meshes per lineal inch
No. 25, 194–198 meshes per lineal inch (rated in the trade as 200-mesh)

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* If any difficulty is experienced in doing this, depress the center of sieve slightly with reverse end of brush while rotating.

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