THE TIMING OF APPLE SCAB SPRAYS

OHIO

Agricultural Experiment Station

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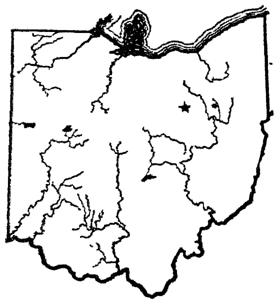

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BULLETIN

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THE TIMING OF APPLE SCAB SPRAYS

H. C. YOUNG AND CURTIS MAY

Probably no other disease of the apple has been so difficult to control as scab. In many sections growers do not fear it; in others its control constitutes one of the chief items of expense in growing apples. The weather, the topography of the land, and other general environmental conditions govern to a great extent the severity of infection. Practically every apple-growing state has a spray program which, if properly carried out, will control scab in at least four years out of five. The carrying out of any complete spray program is costly. It has to be made to cover practically all conditions, especially those of environments most favorable for the scab fungus to develop. Consequently, money is wasted in localities where conditions are less severe.

Many data are tabulated that show no need for the delayed dormant spray in some seasons or for the pre-pink in others, or even the pink in still others, in controlling scab. However, when results are considered for five or more years, each spray has been found effective in one or more of the seasons. Hence, we come back to the complete spray schedule and would stop there if the fruit grower could afford to carry it out. Many do. Others attempt to modify it and frequently fail. The point is, the schedule can be modified, but when and how?

The principal aim in this study of apple scab has been to determine procedures that will enable the grower to save material and labor, reduce spray injury, and control scab more effectively. In the main, the problem hinged around timeliness in spraying. To determine this point many things had to be considered, such as (1) a detailed study of the fungus; (2) the effect of environmental factors on the fungus, the host, and the spray materials; (3) the varietal resistance of the host; (4) the comparative value of methods in applying fungicidal materials; (5) the comparative fungicidal efficiencies of materials; and (6) the general spraying practice.

THE APPLE SCAB FUNGUS

Apple scab is caused by the fungus *Venturia inequalis*. The parts of the apple tree susceptible to attack are the leaves, fruit, blossoms, and, in some localities, the twigs. It is not necessary to describe the appearance of the disease on the fruit, leaves, and blossoms, as this is common knowledge. Twig infection has not been found in Ohio. A description of the life habits of the fungus may not be so familiar.

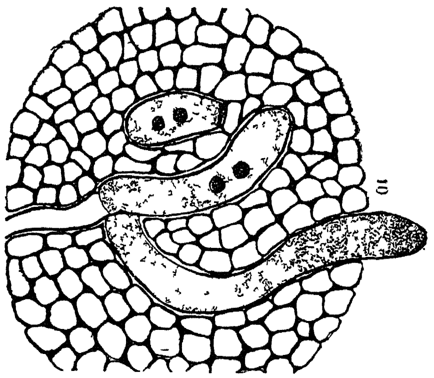


Fig. 1.—(Taken from Frey (5))

Practically every form of plant life germinates, grows, matures, and reproduces—all of which is called a "life cycle". It is thru the detailed study of the life cycle of parasitic organisms that points in their control are obtained. The life cycle of the scab fungus has been known since Winter 1880 shows the connection between the summer and winter stages of the organism. The summer stage of the organism has been known since 1819, having been reported from Europe at that time. Scab was first observed in this country in 1834 in some orchards in Pennsylvania. It is now known to be quite universal in its distribution, probably occurring whereever apples are grown.

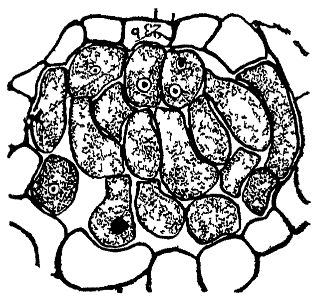


Fig. 2

In our description of the stages of development of the fungus it matters little where we start. Our point, however, can be illustrated best by beginning with the summer stage. The mycelium of the fungus penetrates the leaf only to the epidermis and then grows between the epidermal layer and cuticle as long as the leaf remains green on the tree. In the autumn after the leaves fall, the mycelium penetrates the entire decaying leaf and in a short time produces special bodies, the early stage of one of which is shown in Figure 1.

Later these produce many specialized cells, as shown in Figure 2, which finally develop into asci.

A section of a mature fruiting body, or perithecium, as it is called, is shown in Fig. 3.

At this stage each ascus contains eight ascospores. This breaking up into asci and ascospores takes place in the spring but only under conditions of favorable temperature and moisture. At maturity and with sufficient moisture available, the perithecia burst and discharge their ascospores with enough force to raise them into the air currents above the old leaves. These spores are then responsible for the initial infection of scab.

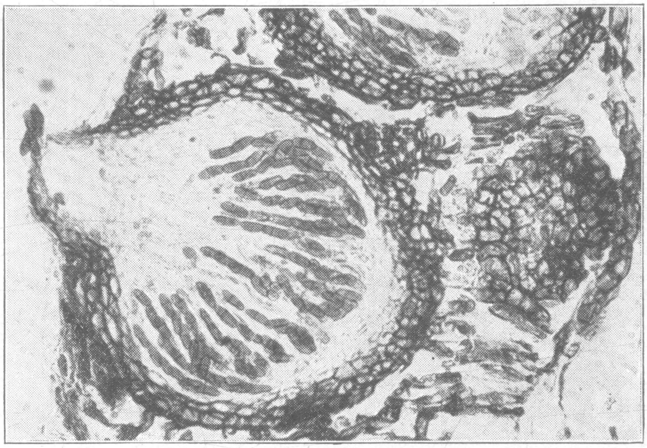


Fig. 3

The perithecia are produced in large numbers and each one contains from 40 to 60 asci. Wallace (12) made counts on the approximate production of ascospores and found that a fragment of leaf 1 cm. (2/5 inch) square could discharge 5 to 30 spores in 45 minutes. He estimates that if the surface of the ground beneath trees set 40 by 40 feet apart were covered with old leaves well infested with perithecia, there might be 8,107,200,000 ascospores discharged for each tree in 45 minutes in wet weather.

The ascospore is discharged and can infect only during wet periods. When it comes in contact with the young leaves or floral parts, the spore produces a germ tube that can penetrate any of these parts at any place. It does not have to grow along the leaf until it comes to an opening as many other fungi do. In fact, the germ tube may go directly from the spore into the leaf, the only visible evidence of a germ tube being an appressoria-like growth that seems to hold the spore in place. The relation of fungicides in this connection is interesting and will be discussed later in the section on fungicides.

After infection the fungous hyphae grow latterly between the cuticle and epidermis but penetrate no further into the leaf. It usually requires from 8 to 14 days for the incubation period, that is, from the time of invasion until the scab spot shows, after which the first crop of summer spores is produced. These spots are olive green as are the conidia (summer spores). The latter are responsible for what is known as secondary infection and for the spread of the disease during the remainder of the season. They are spread about by rain and possibly by insects. The distance they will spread is very limited as they are killed by desiccation. Infection, therefore, can be brought about by them only during rain or in periods of extremely high humidity. In reality, they are not windborne parasites. It would be almost impossible for spread to take place from one orchard to another. Conidia are produced thruout the summer.

It was first thought that conidia were also responsible for carrying the fungus over the winter. A great many data have been reported on this point, some of which are conflicting. Aderhold (1) found that conidia kept between glazed paper almost completely failed to germinate after 8 weeks. Ewart (4) subjected conidia to three periods of freezing each of 6 hours duration and found that rarely one would germinate. Wallace (12) concludes that conidia cannot withstand the winter temperature of New York and are therefore not a source of initial infection. He examined many thousands of the old infected leaves and never was able to find live conidia in the spring.

On the other hand, Aderhold (1) points out that the hyphae are not so affected by freezing temperatures and may live over in the old leaves. Lawrence (6) believed that he found conidiophores and conidia on the old dead leaves in the spring and that they may become sources of infection. In Australia, McAlpine (8) found conidia entangled in he hairs and scales of the buds and believed that these spores formed the source of initial infection.

Many workers—Stewart and Blodgett (10), Clinton (2), Voges (11), Salmon (9), Eriksson (3), and others—have found scab on twigs. Voges (11) states that in Germany scab is common on apple twigs. He states that the fungus remains dormant during the winter and produces a crop of conidia in the spring. We have not found twig infection in Ohio and, consequently, do not believe that infection ever results from this source.

On the other hand, we were not so sure that conidia from old leaves were not a source of infection. There seems to be some positive evidence, and we concluded that there must be regional variation and that such a source of infection might occur in Ohio. To determine this point an experiment was conducted in which the conditions affecting the longevity of the conidia were varied. Apple leaves bearing old scab spots were brought into the laboratory at weekly intervals beginning November 1. Spores were scraped off the scab spots and germination tests made. These results as well as those from leaves subjected to the conditions indicated, are given in Table 1.

TABLE 1.—Conidia Viability Tests

Germination tests made	December 7	14	21	28	January 7	14	21	28	February 7	14	21	28
Collected at regular intervals from under apple tree..	+	+	+	+	+	+	+	+	+	—	—	
Collected Nov. 1 and kept at 60% humidity at 35—40° C. (95—104° F.)......	+	+	+	+	+	+	—	—				
Collected Nov. 1 and kept dry at 35—40° C..........	+	+	+	+	+	+	—					
Collected Nov. 1 and frozen at —13° C. (8° F.)	+	+	+	—								
Collected Nov. 1 and kept at alternate 10° and —2° C. (50 and 28° F.)........	+	+	+	+	+	—						

+ Germinated.
— Did not germinate.

Another attempt was made to find viable conidia in the spring. Leaves, bud scales, and twigs were examined but no living conidia were found. It seems quite improbable that conidia are a source of initial spring infection in Ohio.

CONDITIONS AFFECTING ASCOSPORE EXPULSION

One of the reasons for many failures to control apple scab has been the general lack of information concerning the conditions affecting the development of the ascospore. For a number of years it was thought that the spores of the fungus matured and infected about the time the apple blossoms were in the pink. The growers were led to believe that the leaves and blossoms were not susceptible before this stage. Consequently, the "pink" was regarded as the time to spray for scab. It was not until a few years ago that the value of earlier sprays was demonstrated and as a result there came into use the terms "pre-pink" and "delayed dormant".

Experiments have shown that the stage of the tree is no indicator of the stage of the fungus and that infection can take place readily any time after the buds start to open, depending only on a supply of ascospores, sufficient moisture, and proper temperature. Failures to control scab have been reported in orchards when all three pre-blossom sprays were applied. Early sepal infection, which usually results in the most severely scabbed fruit, is frequently found. These results indicate that the exact time of ascospore dissemination must be determined and that the terms "pink", "pre-pink", and "delayed dormant" are obsolete in spray terminology.

With this in mind the writers undertook to devise procedures by which the exact time for spraying could be determined. The factors influencing the development of the ascospores were first considered. Is it possible to know in advance when the ascospores will be mature? What climatic factors influence their production and can these be forecast?

To answer these questions an extensive series of experiments was started in 1924. Three widely separated orchards were selected, one in the southern, one in the central, and one in the northern fruit growing region of the State. Previous to our experiments the control of scab in each orchard had been a serious problem and, consequently, we could expect definite results. A trained pathologist equipped with the necessary laboratory apparatus was located in each orchard. Work began in the spring just about the time the buds began to swell and before any parts of the tree were exposed to infection

At first attention was given entirely to the development of perithecia. Old infected leaves were examined and the stage of the development of the fungus was noted. Then the leaves were placed in moist chambers under conditions such that the perithecia would develop most rapidly. Spore traps were placed over these leaves and the length of time for the production of ascospores under these optimum conditions was determined. Both of these observations were made daily. In this way the exact stage of development of the ascospore under outside conditions was learned, as well as the length of time required for the maturing and the shooting of these spores when conditions became optimum.

This procedure enabled us to follow the ascospores to maturity and to predict that they would be discharged during the next rain period. The only element of uncertainty was the prediction of these rain periods. In this phase of the work we had the excellent cooperation of the U. S. Weather Bureau. They gave us a one-, two-, three-, and in some cases a seven-day forecast. In our three-years' work they did not fail to predict an oncoming rain period.

We do not mean by this that their predictions were perfect. In a few cases rain periods were predicted that did not occur in our region, which resulted in unnecessary spraying. A more extensive discussion of this point will be given below.

Records were also kept of the temperature, amount of rainfall, duration of rain periods, and extent of scab-spore discharge. Spraying experiments in which a 1 to 40 lime-sulfur was used in all applications were conducted in each orchard.

RESULTS IN NORTHERN OHIO, 1924

The orchard selected in northern Ohio is located near Chardon and owned by Dr. C. A. Bingham. This orchard was particularly desirable because of its excellent system of management and modern equipment. The results of the season's work are recorded in Plate 1.

The sprays applied May 7 and 8 controlled most of the scab. The test trees were of the Stayman Winesap variety, and at the time of the spray their blossoms were in an early pre-pink. Using the old terminology, they were about half way between the "delayed dormant" and "pre-pink". The so-called "pink" spray had very little effect on the control of scab. The weather during the spring of 1924 was quite favorable for abundant ascospore development, and discharge was exceptionally heavy during the eight-day rain period. There was no further discharge after this rain period.

The results at Wooster in 1924 are given in Plate 2. The ascospores developed slowly in this orchard and when a rain period was predicted for May 11 they were not quite mature. Consequently, the sprays were postponed until the 12th and 13th.

When Plates 1 and 2 are compared it will be noted that in one case an early spray controlled while in the other orchard a very late pre-blossom spray was most effective.

The results in southern Ohio are given in Plate 3.

The data on ascospore discharge in southern Ohio indicate that the spray should have been applied April 26 or 27. The omission of this spray was due to the delay in the arrival of the sprayer and the first application possible was May 2.

In 1925 conditions were quite different. Weather conditions were very unfavorable for ascospore development and little disease resulted. The results are given in Plates 4 and 5.

The pre-blossom sprays might well have been omitted in both the experimental orchards. The temperatures in northern Ohio

Plate 1. Bingham Orchard 1924

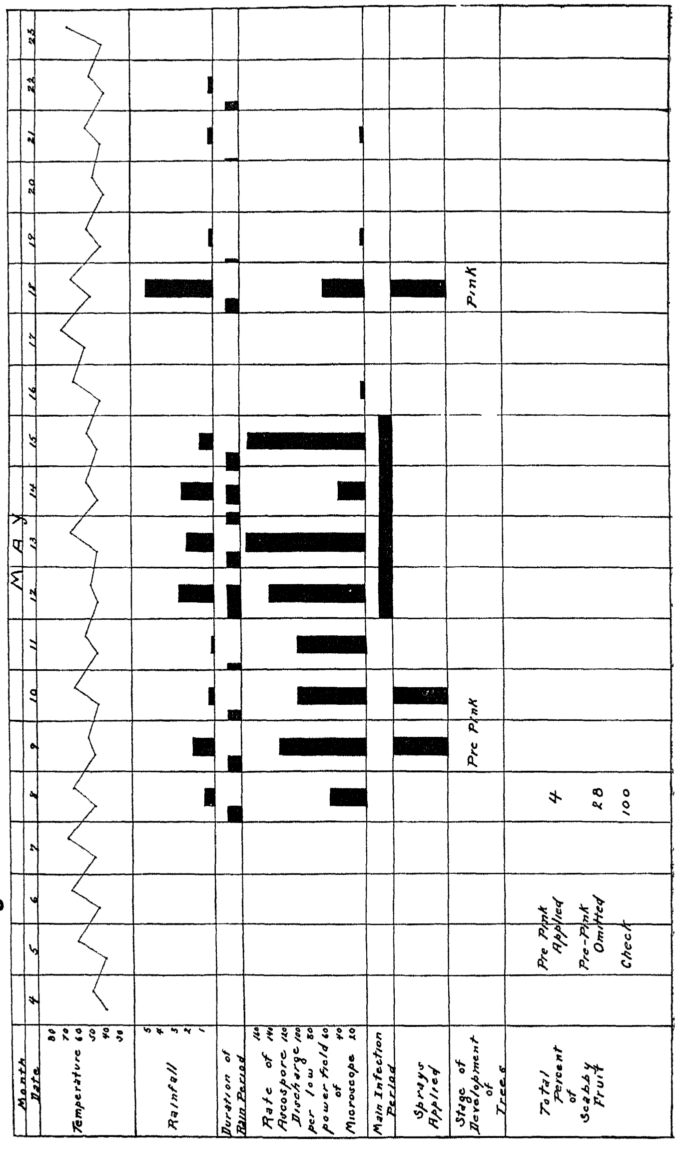


Plate 2. Whitmarsh Orchard 1924

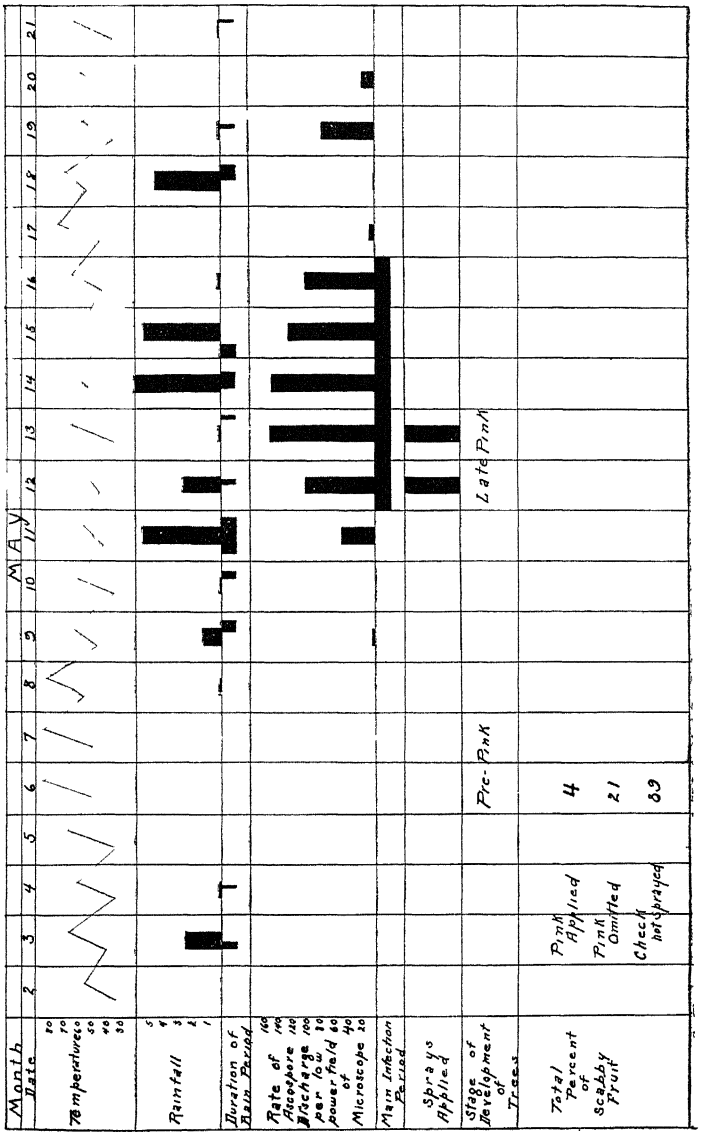
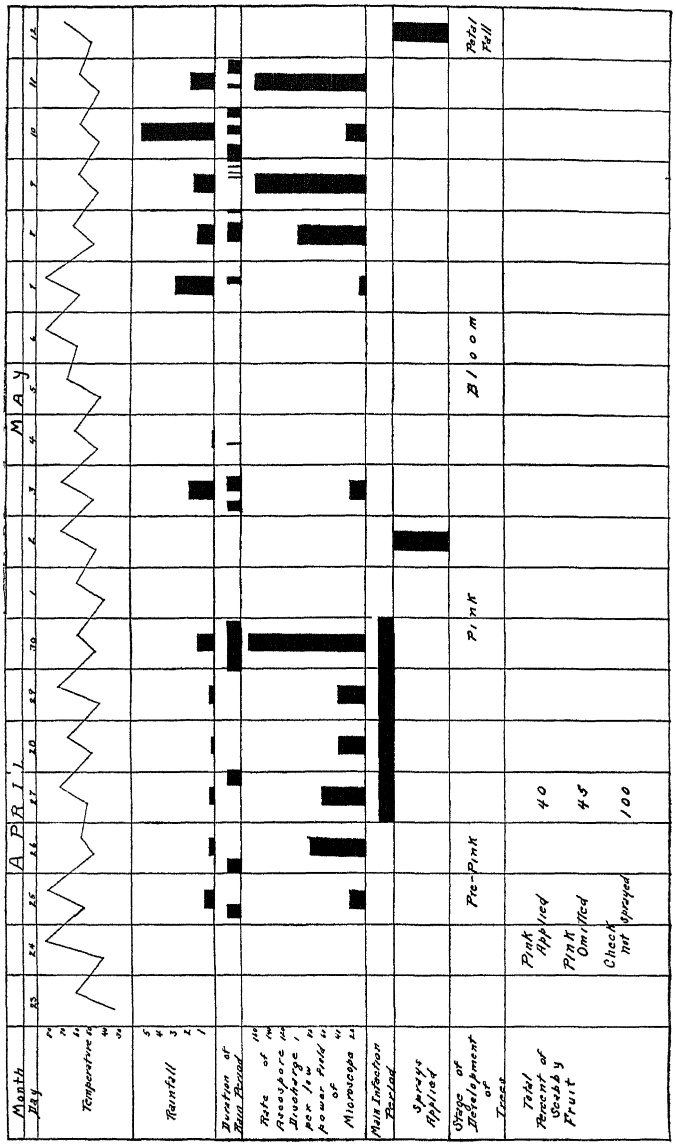


Plate 3. Hartman Orchard 1924



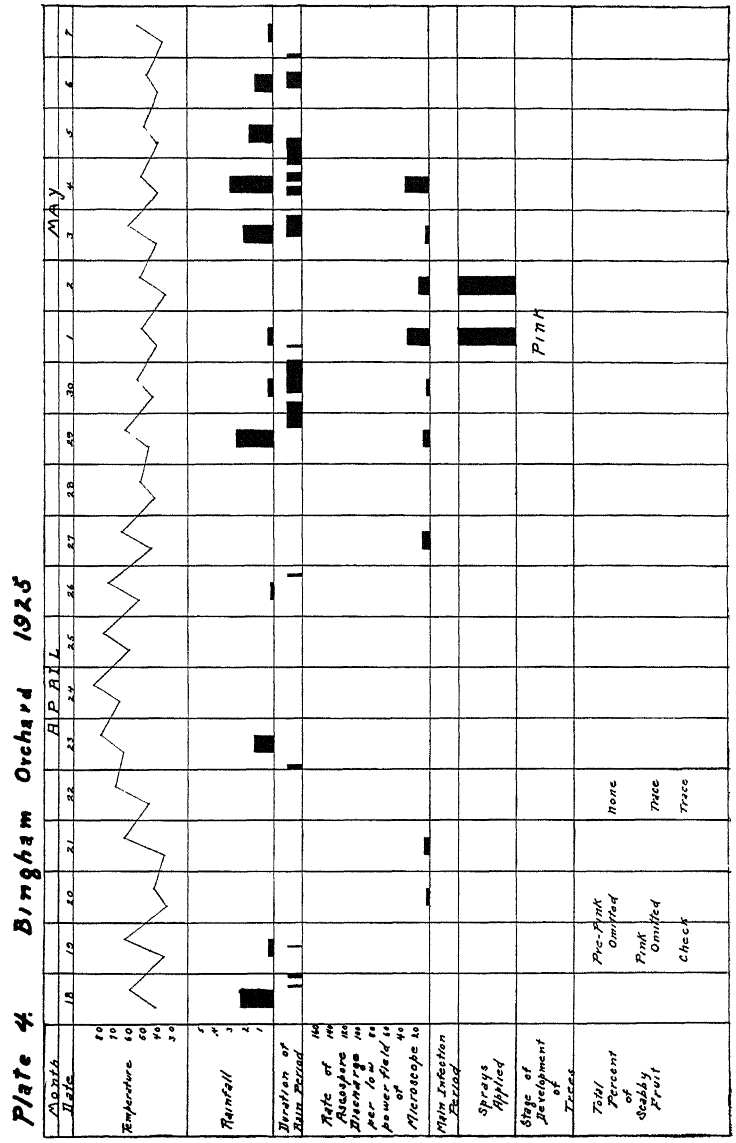
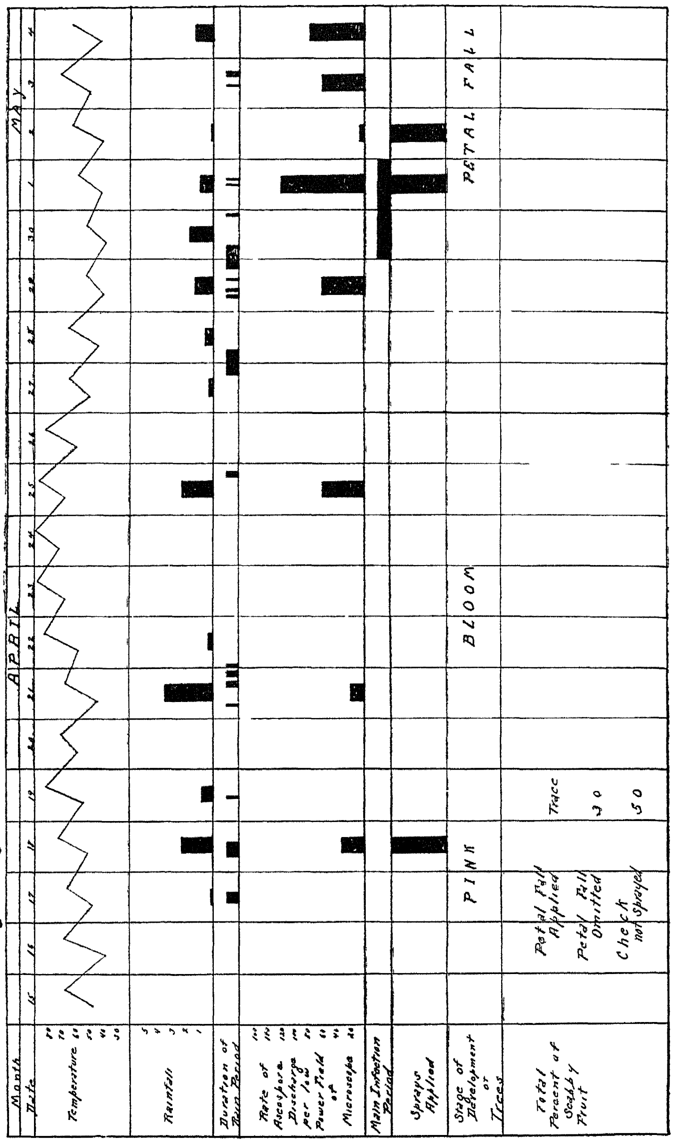


Plate 4. Bingham Orchard 1925
Month
Date
APRIL
MAY
Temperature
Rainfall
Duration of Rain Period
Rate of Ascospore Discharge per low power field of Microscope
Main Infection Period
Sprays Applied
Stage of Development of Trees
Pink
Total Percent of Scabby Fruit
Pre-Pink Omitted
Pink Omitted
Check
none
Trace
Trace

Plate 5. Augspurger Orchard 1925



were too low for any of the few ascospores developed to infect. In southern Ohio the rain periods were not of sufficient duration for infection to occur.

The results of 1924 and 1925 indicated that it was possible to determine the exact time for the application of the pre-blossom scab sprays. Furthermore, it was seen that such timing of sprays would result in better scab control and in most cases in a decided saving of materials and cost of applications.

PLAN OF 1926 EXPERIMENTS

Since positive results were obtained in the first two years' work it was thought advisable to attempt a state-wide experiment in 1926. Accordingly plant pathologists were placed in the fruit-growing regions of southern Ohio a short time before the apple buds began to swell. They followed the same plan as used in the previous two years—namely, that of observing the detailed development to maturity of the ascospores on the old leaves. Arrangements were made for the pathologists to receive special weather forecasts informing them of on-coming rain periods. This enabled them to time their sprays to just precede such periods following ascospore maturity. As soon as the period of ascospore discharge in the south had passed, the men moved northward with the advance of the season.

The success of the previous two years' work led us to believe that this year's findings would be invaluable in timing the scab sprays, and, consequently, the information was sent to the fruit growers. For the distribution of this information two different channels were used. The field man reported his findings to the county agricultural agents who then passed the information to the orchardists by telephone or by postal card. The other method was radio broadcasting. The Crosley Radio Corporation (W. L. W.), Cincinnati, kindly permitted us to use their station for southern Ohio. The Ohio State University Station (W. E. A. O.) was used for central Ohio, and the Willard Battery Station (W. T. A. M.), Cleveland, for northern Ohio. Thru these channels practically every fruit grower could regulate his spraying operations.

WEATHER FORECASTS

Forecasting the weather is an important factor in this work. The pathologist in the field can follow the development of the fungus and determine its exact stage of maturity. He knows that the mature spores will be discharged and cause infections only during rain periods. It is imperative then, to know in advance of an approaching rain period; because, first, sprays are not effective over a very long period and, second, control can not be obtained after infection takes place.

The weather forecasting was done very successfully by the U. S. Weather Bureau. Mr. Alexander, of Columbus; Mr. Deveraux, of Cincinnati; Mr. Howe, of Parkersburg; and Mr. Avery, of Cleveland, supplied us with 3-, 2-, and 1-day forecasts for their respective sections. For the north central section of the State the report was sent directly from Washington. A record of the forecasting is given in Tables 2, 3, 4, and 5.

The forecasting was in the main correct. In a few cases only was rain predicted that did not come. There were no failures to predict rain periods that did come. Possibly, there may be seasons in which weather forecasting will be more difficult.

RESULTS OF 1926 EXPERIMENTS

A number of very interesting points were obtained in this state-wide experiment. In the first place it will be seen from the foregoing results that the prediction of infection periods is not particularly hazardous. The weather is not often a disturbing factor in it. Much more depends upon the exact knowledge, at all times, of the development of the fungus. Furthermore, the only effective sprays were those applied exactly at the predicted time. It was found that there may be as much as a week's difference between the time of maturity of perithecia on high ground and in the valleys of the immediate vicinity. Moreover, their rate of development in the two locations may be very unequal. In southern Ohio few perithecia matured spores. Likewise, very few ascospores developed in the northern and eastern parts of the State. Consequently, the growers in these sections were advised in some cases to use dilute sprays and in other cases to omit all pre-blossom applications. An enormous saving of material resulted.

Plates 6 and 7 are representative for these sections of the State.

It was only in a small central region that ascospores developed normally and it was in this region that scab was serious. Plate 8 shows that in this section of the State ascospore expulsion occurred shortly after the trees came into bloom and that the most effective spray was the one applied in the late pre-bloom period. A spray earlier gave very little control.

TABLE 2.—Rain Forecast and Occurrence, Parkersburg District, April and May, 1926

Date	Forecast in advance			Weather	Precipitation*
	3 days	2 days	1 day		
April					
1	...	...	...	Cloudy	...
2	...	...	Rain	Rain	0.1
3	...	...	Rain	Light shower	T
4	...	...	Fair	Fair	...
5	...	...	Prob. showers	Cloudy	...
6	...	...	Rain	Rain	0.3
7	...	Rain	Rain	Rain	0.1
8	...	...	...	Rain	T
9	...	...	...	Cloudy	...
10	...	...	...	Rain	0.1
11	...	...	Rain	Rain	0.4
12	...	...	Fair	Fair	...
13	...	Fair	Fair	Fair	...
14	Fair	Fair	Rain or snow	Partly cloudy	...
15	...	...	Fair	F., partly cloudy	Snow T
16	...	Fair	Fair	Fair	...
17	Fair	Fair	Fair	Fair	...
18	Possible showers	Possible showers	Showers	Fair	...
19	...	...	...	Partly cloudy	...
20	...	...	Fair	Cloudy	Snow T
21	...	Fair	Fair	Fair	...
22	Prob. showers	Probably showers	Rain	Rain	0.3
23	...	Probably showers	Showers	Partly cloudy	...
24	Fair	Possible showers	Showers	Showers	T
25	Probably fair	...	Fair	Cloudy	...
26	Fair	Fair	Fair	Partly fair	...
27	...	Prob. light showers	...	Rain	0.4
28	...	Fair	Showers	Fair	...
29	Fair	...	Fair	Fair	...
30	...	...	...	Fair	...
May					
1	...	...	Fair	Showers	T
2	...	Rain	Showers	Showers	0.1
3	...	Fair	Fair	Showers	T
4	...	...	Fair	Fair	...
5	Showers	...	...	Fair	...
6	Fair	...	...	Fair	...

T=Trace.
*Rainfall in decimal inches was estimated.

TABLE 3.—Rain Forecast, Cincinnati District, April, 1926

Date	Forecast in advance			Weather	Precipitation
	3 days	2 days	1 day		
1	....	....	....	Fair	....
2	....	....	....	Cloudy	.02
3	Fair	Prob. light shower	Light shower	Light shower	T
4	Fair	Fair	Fair	Fair	.00
5	Fair	Fair	Fair	Fair	T
6	Rain	Rain	Rain	Rain	.68
7	Rain	Rain	Rain	Rain	.34
8	Rain	Rain	Rain	Rain	1.54
9	Fair	Fair	Fair	Fair	.00
10	Fair	Fair	Fair	Light shower	.04
11	Light rain	Light rain	Light rain	Light drizzle	.12
12	Fair	Fair	Fair	Fair	.00
13	Fair	Fair	Fair	Fair	.00
14	Fair	Fair	Fair	Fair	.00
15	Fair	Fair	Fair	Fair	.00
16	Fair	Fair	Fair	Fair	.00
17	Probably rain	Probably rain	Rain	Rain	.29
18	Rain	Rain	Rain	Rain	.70
19	Fair	Fair	Fair	Fair	.00
20	Fair	Fair	Fair	Fair	.00
21	Fair	Fair	Fair	Fair	.00
22	Probably rain	Probably rain	Rain	Rain	.22
23	Fair	Fair	Fair	Fair	.00
24	Fair	Fair	Fair	Shower	.01
25	Fair	Fair	Light shower	Shower	.01
26	Fair	Fair	Light shower	Shower	T
27	Rain	Rain	Rain	Rain	.68
28	Fair	Fair	Light rain	Rain	T
29	Fair	Fair	Fair	Fair	.00
30	Fair	Fair	Fair	Fair	.00

TABLE 4.—Rain Forecast, Columbus District, April and May, 1926

Date	Forecast in advance			Weather	Precipi-ation
	3 days	2 days	1 day		
April					
13	....	....	Fair	Fair	.00
14	....	Cloudy	Fair	Light rain	.00
15	....	Fair	Fair	Fair	.00
16	Fair	Fair	Fair	Fair	.00
17	Prob. light showers	Fair	Rain at night	Fair	.00
18	Prob. light showers	Probably showers	Fair	Fair	.00
19	Probably showers	Fair	Fair	Light snow	T
20	Fair	Fair	Fair	Fair	.00
21	Fair	Fair	Fair	Fair	.00
22	Probably showers	Probably showers	Showers	Rain	.20
23	Fair	Fair	Fair	Fair	.00
24	....	Shower	Showers	Showers	T
25	....	Fair	Fair	Fair	.00
26	....	....	Fair	Fair	.00
27	....	Probably showers	Showers	Rain at night	.40
28	Showers	Showers	Fair	Fair	.00
29	Fair	Fair	Fair	Fair	.00
30	Fair	Fair	Fair	Fair	.00
May					
1	Fair	Fair	Fair	Fair	.00
2	Probably showers	Showers	Showers	Showers	.16
3	....	....	Fair	Shower	.00
4	....	Fair	Fair	Fair	.00
5	Probably showers	Fair	Fair	Fair	.09
6	Rain	Fair	Fair	Fair	.00
7	Rain	Showers	Cloudy	Fair	.00
8	Fair	Showers	Cloudy	Fair	.00
9	....	Probably showers	....	Fair	.00
10	....	....	Showers	Shower	T
11	....	Fair	Fair	Fair	.00
12	Fair	Fair	Fair	Fair	.00
13	....	Fair	Showers	Fair	.00
14	....	Cloudy	Showery	Rain	.40
15	....	Fair	Fair	Fair	.00
16	....	....	Fair	Fair	.00
17	....	....	Showery	Rain	.20
18	....	....	....	Light rain	.02

TABLE 5.—Rain Forecast, Wooster District, April, May and June, 1926

Date	Forecast in advance			Weather	Precipitation
	3 days	2 days	1 day		
April					
24	....	....	Showers	Showers	.19
25	....	Fair	Fair	Snow flurries	.05
26	Fair	Fair	Fair	Snow flurries	T
27	Fair	Fair	Prob. showers	Rain	.36
28	....	Light showers	Light showers	Light rain	T
29	....	Fair	Fair	Fair	....
30	Light showers	Fair	Fair	Showers	T
May					
1	Fair	Fair	Fair	Light showers	T
2	Fair	Fair	Showers	Rain	.21
3	Fair	Rain	Rain	Rain	.38
4	Fair	Fair	Fair	Fair	....
5	Showers	Showers	Showers	Fair	....
6	Showers	Fair	Fair	Fair	....
7	Fair	Fair	Fair	Fair	....
8	Showers	Showers	Fair	Fair	....
9	Showers	Showers	Showers	Showers	T
10	Showers	Fair	Showers	Showers	T
11	Fair	Fair	Fair	Fair	....
12	Fair	Fair	Fair	Fair	....
14	Fair	Fair	Fair	Light showers	.02
14	Fair	Showers	Showers	Rain	.44
15	Fair	Fair	Fair	Fair	....
16	Fair	Fair	Fair	Fair	....
17	Fair	Fair	Showers	Showers	.11
18	Showers	Showers	Showers	Showers	.16
19	Doubtful	Showers	Rain	Rain	.37
20	Fair	Fair	Fair	Fair	....
21	Showers	Showers	Showers	Rain	T
22	Fair	Fair	Fair	Rain	.26
23	Fair	Fair	Probable shower	Fair	....
24	Fair	Fair	Fair	Fair	....
25	Fair	Fair	Fair	Slight shower	.07
26	Showers	Showers	Showers	Rain	.05
27	....	Showers	Fair	Fair	....
28	Fair	Fair	Fair	Fair	....
29	Showers	Fair	Fair	Fair	....
30	Doubtful	Showers	Showers	Showers	.31
31	....	Showers	Showers	Slight rain	.25
June					
1	Showers	Showers	Fair	Showers	T
2	....	Fair	Fair	Fair	....
3	Fair	Fair	Fair	Fair	....
4	....	Fair	Fair	Fair	....
5	Fair	Fair	Fair	Fair	....
C	Fair	Fair	Fair	Fair	....

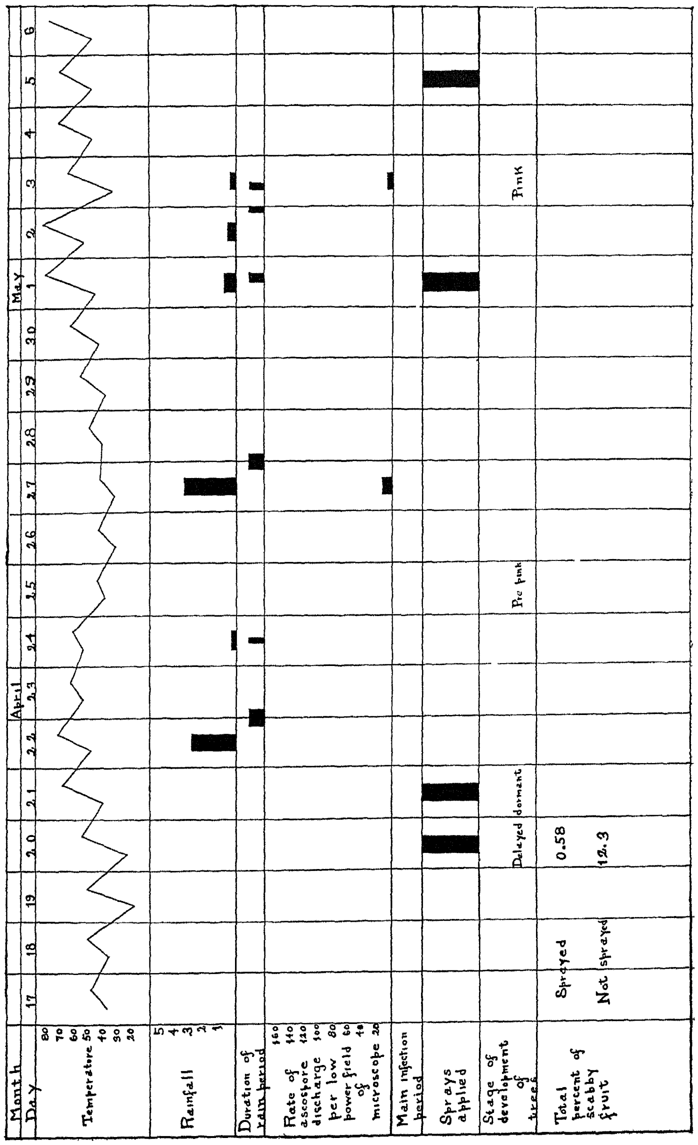


Plate 6. Torch Hill Orchard 1926

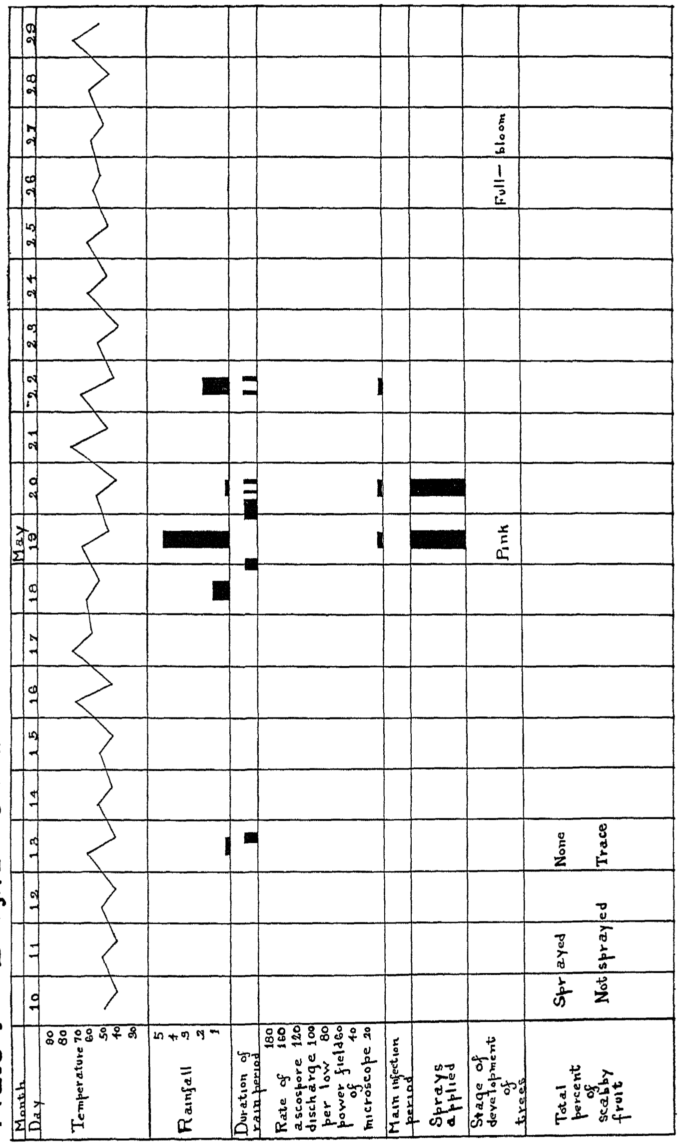
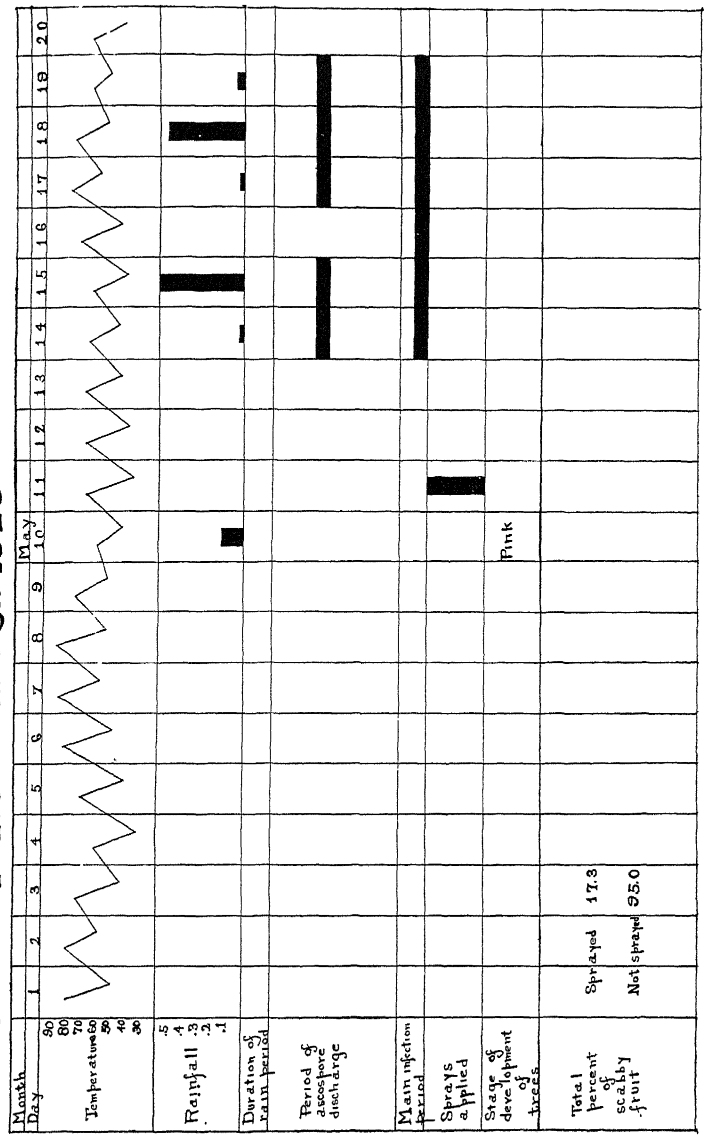


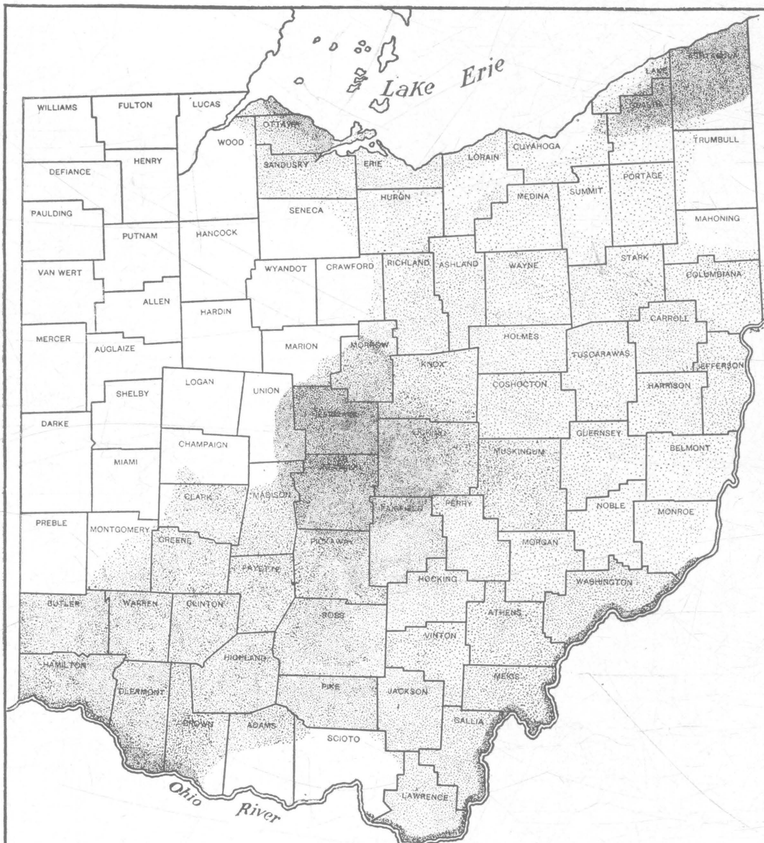
Plate 7 Bingham Orchard 1926

Plate 8. Delaware Orchard Co. 1926



Our experiences of the past three years have shown that there are regions in the State where scab control is not a very serious problem except occasionally on the more susceptible varieties of fruit. Plate 9 shows these regions in a general way.

Plate 9



It is especially in the lightly shaded areas of the map that materials and labor can be saved in the control of scab. The service can definitely advise the elimination of some sprays in some cases and greater dilutions of materials in others. The service can be of even greater benefit to orchardists in the regions indicated on the darker areas of the map, for, unless sprays are well timed, scab control is practically impossible.

Fungicides.—One other factor that makes timeliness in spraying so important is the limited period over which fungicidal materials remain effective. In the first place the critical scab period occurs when the leaves and blossoms are developing most rapidly. Fungicidal materials do not spread after they once dry on the tree and therefore remain effective over an increasingly small proportion of the developing tree. In the second place fungicides actually deteriorate or are washed off the tree.

There has been considerable investigation on what happens to the fungicide after it is applied. In discussing this point it is probably necessary to include only two chemicals, sulfur and copper.

Sulfur is used in spray materials, mainly in three forms: sulphides (lime sulfur, soluble sulfur, and sulfocide), colloidal sulfur, and dusts. The most generally used is the sulphide in the form of lime sulfur (calcium sulphide). When lime (calcium hydrate) and sulfur are boiled together in the proportion of 80 parts of sulfur, 36 pounds of lime, and 50 gallons of water, the following reaction takes place: 3 parts calcium hydrate plus 12 parts sulfur yields one part calcium thiosulphate, 2 parts calcium pentasulphide and 3 parts water ($3\ Ca\ (OH)_2 + 12\ S = CaS_2O_3 + 2\ CaS_5 + 3\ H_2O$). If less sulfur is used the reaction may be $3\ Ca\ (OH)_2 + 8\ S = CaS_2O_3 + 2\ CaS_3 + 3H_2O$. The amount of sulfur used governs the proportion of CaS_5, which is the most effective killing agent of lime sulfur. A solution containing the above proportions boiled properly will contain the highest possible amount of pentasulphide. Other proportions result in other sulphides, such as CaS_3 and CaS_2, which do not have lasting fungicidal effect.

When lime sulfur is sprayed on the tree it first kills because of its causticity. In a few minutes, however, the pentasulphide is decomposed, breaking down into free sulfur, sulphites, and sulfates. The lasting fungicidal action is brought about by this free sulfur alone. If the sulphide in the solution is not a pentasulphide very little free sulfur is formed and there is no lasting fungicidal action in the material.

The exact factor in sulfur that does the killing was worked out some time ago by the senior author, Young (13). He states that sulfur must be further oxidized into a slightly volatile substance before it is at all toxic. The production of this volatile substance depends upon a number of factors, as follows: (a) the higher the temperature the greater the volatilization and solubility; (b) the size of the particle governs the rate of change, the finer the particle the greater the yield of toxic substance; (c) basic substances prevent the formation of any toxic property; (d) the toxic property is most readily produced when the reaction is slightly acid, the natural condition of sulfur.

The sulfur in sulfur dust is affected by the same conditions.

The adhesiveness of sulfur is also dependent upon its fineness. Sulfur from the sulphides is usually very fine and is not washed off readily. Sulfur dusts, on the other hand, have been less effective than sprays, primarily because of their inability to stick to the foliage.

The other fungicide, copper, is used as bordeaux mixture and dusts. Bordeaux is formed when copper sulfate in solution is mixed with lime water, or milk of lime. The chemical composition of the resulting mixture depends largely upon the ratio in which the two components are combined. If dilute copper-sulfate solution is mixed with an insufficient quantity of lime, basic copper sulfates are formed which are non-gelatinous, settle rapidly, have poor spreading qualities, and in general form an inferior fungicidal mixture. However, if the ratio of lime to copper sulfate is increased, other basic copper sulfates are formed which are gelatinous in nature, remain in suspension for some time, and are known to be effective fungicides. The following reaction shows how such basic copper sulfates may be formed.

$$10CuSO_4 + 9\ Ca(OH)_2 = 10\ CuO\ SO_3 + 9\ CaSO_4$$

Copper is the toxic element in bordeaux mixture, but since the basic copper sulfates are insoluble in water there is no free copper in the mixture unless an insufficient amount of lime has been used.

Bordeaux may be fungicidal in one of three ways: (1) The fungus spore or germ tube may secrete a substance which dissolves sufficient copper from the basic sulfates to kill it. (2) Small quantities of free copper which then act as a fungicide, are liberated from the bordeaux films on the tree by atmospheric agencies, mainly carbon dioxide. (3) Ordinary bordeaux mixture is alkaline to the extent that spores may be killed by its alkalinity, Lutman (7).

The copper dusts are prepared from partly dehydrated copper sulfate and lime. The two are mixed together in dry form and applied as a dust. When moisture comes in contact with the dust the lime and copper sulfate react and bordeaux mixture is formed. The quality of the bordeaux film, however, is inferior to that formed from regular bordeaux and does not stick as well. Copper can exert its fungicidal power only when in direct contact with the spore. Sulfur, on the other hand, is effective over a greater area than it actually covers.

Excessive lime in either sulfurs or coppers reduces their fungicidal properties. Lime is added to reduce burning of foliage and russeting of fruit. Such practices are to be advised where scab is not particularly difficult to control. When scab is a serious factor the addition of lime to lime sulfur is extremely hazardous. Our experiments at Delaware in 1926 showed this fact clearly. Lime alone has some fungicidal value which is due in part to its alkalinity and in part to its dessicating action on the spore.

The ideal bordeaux spray does not contain excessive lime and the greater the excess the less copper can be freed for fungicidal purposes. However, lime is not in excess until the proportion of calcium hydrate is greater than one part to one of copper.

SUMMARY

1. The life cycle of the apple scab fungus is described briefly.

2. The conditions affecting ascospore expulsion are discussed and data showing the time and amount of ascospore discharge at various points in the State are presented.

3. A method of procedure is given for the prediction of periods of ascospore discharge and infection.

4. The most effective sprays were those applied just previous to the predicted infection periods.

5. The stage of development of the tree was found to be no indicator of the proper time to spray for scab.

6. Scab sprays were found to be effective over a comparatively short period.

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