RELATION OF ENVIRONMENTAL FACTORS TO CITRUS SCAB CAUSED BY CLADOSPORIUM CITRI MASSEI 1

By GEORGE L. PELTIER, formerly Plant Pathologist, Alabama Agricultural Experiment Station, and Agent, Bureau of Plant Industry, United States Department of Agriculture, and WILLIAM J. FREDERICH, formerly Assistant Pathologist, Bureau of Plant Industry, United States Department of Agriculture

INTRODUCTION

In connection with citrus canker investigations conducted by the writers, an opportunity was afforded to observe the behavior of citrus scab caused by Cladosporium citri Massee under the weather conditions prevailing in southern Alabama for four seasons. In the following pages an attempt is made to correlate field observations with studies made under controlled conditions in the laboratory and greenhouse on the pathogene, on the host plant, and on infection and development of the disease.

HISTORY AND DISTRIBUTION

Scab attacks the young fruit, leaves, and occasionally the shoots of Citrus plants. The effect of scab on the fruits is the most important aspect of the disease from an economic viewpoint, in that scabby fruit either results in lower market value or in cull fruits.

What probably constitutes the earliest record of scab was found by Lee (6) on a herbarium specimen of Citrus nobilis Lour. collected at Nagasaki, Japan, in 1863. He states that the early occurrence of this disease in Japan and the general distribution of citrus scab throughout the Citrus-growing regions of South China indicate that this disease may be indigenous to the Orient.

Reinking (7, 8), in a plant-disease survey of southern China found scab generally prevalent in this region, which substantiates Lee's conclusions. Considerable work has been done on scab in Japan, as it is there one of the more important diseases of Citrus, but owing to the inaccessibility of the Japanese literature it is difficult to obtain much information regarding the history of scab in that country. No doubt, as in the case of the citrus canker, Japan has indirectly served as the center for the distribution of scab to some of the countries in which the disease is now present. For several decades large exportation of Citrus nursery stock to various parts of the world has been made from several Japanese ports. Thus it is possible that Japan served as the center for scab distribution to Australia, the Gulf Coast section of the United States, and South Africa, as it did in the case of canker. So far as is known, no scab has ever been reported from California and the Philippine Islands, although there is every reason

1 Received for publication February 16, 1924. Published with the approval of the Director of the Alabama Agricultural Experiment Station. The paper is based on cooperative investigations between the Office of Crop Physiology and Breeding Investigations, Bureau of Plant Industry, U. S. Department of Agriculture, and the Department of Plant Pathology, Alabama Agricultural Experiment Station. Presented before the thirteenth annual meeting of the American Phytopathological Society, Toronto, Canada, December 28 to 31, 1921, and abstracted in Phytopathology 12:57, 1922. Since that time two papers dealing with certain phases of the work discussed have appeared, to wit:


9 Reference is made by number (italic) to "Literature cited," p. 254.

Journal of Agricultural Research, Washington, D. C. Vol. XXVIII, No. 3 Apr. 19, 1924 Key No. Ala.—10

(241)
to assume that scab has been introduced into these countries on nursery stock. Further, Reinking (8) does not mention the presence of scab in the Citrus-growing regions of Siam and Indo-China.

Fawcett (2) summarized the California situation as follows: "This disease (scab) has never been found in California. Before the strict quarantine laws were passed, thousands of sour orange trees with their leaves affected with scab were brought into California, but the new foliage came out free from attack. It would appear that this fungus is unable to persist in a climate like that of California."

According to Swingle and Webber (9), scab appeared in Florida about 1884 and spread rapidly over the State and into Louisiana. They state that it was probably introduced into America from Japan. Since that time it has been introduced from Florida and Louisiana, or direct from Japan on the many importations of nursery stock, especially Satsuma (Citrus nobilis unshiu (Makino) Swingle, into the Gulf Coast States of Alabama, Mississippi, and Texas. Thus, at the present time, scab is one of the more important diseases of Citrus fruits in the Gulf Coast States, although fortunately it can be controlled by spraying. Scab has also been reported from India, Formosa, the West Indies, Paraguay, the Canal Zone, Yucatan, and Hawaii.

Scab is a rather serious disease in the Gulf Coast States, South China, Japan, and parts of the West Indies. So far it has not been reported from the Citrus-growing regions of the Mediterranean countries, California, and the Philippine Islands. The absence of scab in these localities is an interesting phase of the scab situation. That scab has been introduced on nursery stock into California and the Philippine Islands, and possibly the Mediterranean countries without gaining a foothold, indicates that there are certain factors which prevent the successful propagation of citrus scab in these localities.

INFLUENCE OF ENVIRONMENTAL FACTORS UNDER CONTROLLED CONDITIONS

ON THE PATHOGENE

Fawcett (1, 2) has continually emphasized the fact that Cladosporium citri differs from other species of Cladosporium, and especially C. herbarum Lk., which is usually associated with C. citri on old scab spots. In fact, C. herbarum has in some cases been mistaken for the causal organism. He has so well described the difference in appearance of these organisms both in pure culture and on the plants themselves, that it will be sufficient to state here that C. citri is an unusual Cladosporium, which makes an extremely small and slow growth in pure culture.

The optimum temperature, as worked out by Fawcett (4) for the best development of the fungus in pure culture, is 21° C. (69.8° F.). Growth occurs in culture within a range of temperatures between 13.5° and 32° C. (56° and 89.6° F.). Judging from Fawcett's results, spore production in pure cultures seems to be limited to temperatures between 16° and 27.5° C. (60.8° and 81.5° F.).

It has also been observed by Fawcett (1) that the spores of this fungus germinate readily both in tap water and on agar; germination of the spores beginning in from 5 to 24 hours. It is not known whether the spores will germinate in a saturated atmosphere or at lower humidities.

ON THE HOST PLANTS

The results obtained by the senior writer (6) at the University of Illinois indicate that each type of Citrus plant reacts differently under similar environmental conditions. Under controlled conditions, grapefruit plants (Citrus grandis
(L.) Osbeck) made an extremely slow growth at 18° C. (59° F.), while the other plants tested did not start until a temperature of 20° C. (68° F.), was reached. Even at this temperature C. mitis Blanco, a native of the Philippine Islands only made a slow growth. At 30° C. (86° F.) all plants tested developed rapidly. Above this point the growth of plants of the grapefruit type were inhibited, while Poncirus trifoliata (L.) Raf. made a good growth.

It was also found that at 15° C. (59° F.), grapefruit plants, although making an extremely slow growth matured their foliage rapidly, in most instances within a week's time, while at 30° C. (86° F.) growth was rapid, but the period of leaf maturation was extended over a period of about two weeks. The mature leaves at the low temperature were only from one-fourth to one-half the size of those on plants held at 30° C. (86° F.). The small leaves maturing at the lower temperature retained their same size when transferred to higher temperatures.

Plants held at 30° C. (86° F.) were inhibited in their growth when transferred to lower temperatures. The growth of citrus plants was inhibited when held at a high temperature during the day and at a low temperature during the night.

ON INFECTION AND DEVELOPMENT OF THE DISEASE

As far as the writers are aware, no one has successfully infected Citrus plants with Cladosporium citri under field conditions. Even in the greenhouse, infection has not always been successful. In practically all cases the only successful infections which have been produced under greenhouse conditions have been made on plants held under bell jars, or where abundant moisture on the surface of the leaves was supplied for a period of several days. In this connection it should also be stated that only the young leaves have been infected.

In the experiments reported by Fawcett (4), and in the observations made by the senior writer, the two factors of young growth and sufficient moisture for initial infection have always been supplied. Fawcett inoculated his plants and placed them in the temperature chambers, with sufficient moisture, for a period long enough for initial infection to take place. In the senior writer's observations on scab, the plants were held in temperature cases in a saturated atmosphere under bell jars.

Fawcett (4) has shown that the temperature limits for successful infection of sour orange and pummelo plants under controlled conditions lies between 16° and 23° C. (60.8° and 74.3° F.). No infections were obtained at 14° (57.2° F.) or below, nor at 24.5° C. (76.1° F.) or above, so that infection is limited to a rather narrow range of temperature. The largest number of scab spots occurred at the temperatures between 18.5° and 21° C. (65.3° and 69.8° F.).

In the senior writer's experiment with citrus canker (6) optimum conditions for scab development were afforded and typical scab spots did occur naturally on some of the plants growing in the temperature cases at 15° and 20° C. (59° and 68° F.). No scab appeared on plants held at temperatures of 10° C. (51° F.) or below, nor at 25° C. (77° F.) or above. At 15° C. (59° F.) scab spots occurred only on the grapefruit plants showing new growth. It should be noted that grapefruit were the only plants making any growth at this temperature. At 20° C. (68° F.) scab appeared on grapefruit, calamondin, and citrange plants. The spots were much more numerous on grapefruit than at 15° C. (59° F.). In all cases, scab was limited to the plants with young leaves.

The results show that when abundant moisture is supplied and young growth is present, infection of Citrus plants by Cladosporium citri is limited to temperatures between 15° C. and 23.5° C. (59° and 74.3° F.), a range of less than 10 degrees. The optimum for the best and greatest development of scab appeared to be about 20°-21° C. (68°-69.8° F.), which is also the optimum found by Fawcett (4) for the fungus in culture.
INFLUENCE OF ENVIRONMENTAL FACTORS UNDER FIELD CONDITIONS

ON THE HOST PLANTS

Citrus scab is usually prevalent during the development of the first spring growth. Under controlled conditions the maximum temperature for successful infection is about 75° F. Under Alabama conditions a mean weekly temperature of 75° F. and above is reached and the first spring growth of the plants is usually completed by the first of June. For the purpose of our discussion, then, we are interested primarily in the behavior of the plants during the interval required for the development of the first growth period.

It might be of interest in this connection to correlate the appearance of new growth of the more common Citrus plants under Alabama conditions, with the prevailing temperatures recorded at Mobile for the first five months of the years 1914 to 1920.

In Table I are listed the weekly mean temperatures from January 1 through June 10 for these years. In figure 1 the weekly mean temperatures for 1918 and 1916 are plotted with the two late seasons of 1915 and 1920 for comparison.

In 1915 no weekly mean temperatures suitable for active growth of Citrus plants were recorded until the week of April 9–15, when the mean rose to 67° F. and proceeded rapidly upward. This temperature was sufficient to force all plants into activity at practically the same time.

During the early part of 1916 the weekly mean temperature rose to 59° F. and above on three separate occasions, each of which was sufficient to force active growth of grapefruit plants but not Satsuma or trifoliate orange. In each case, however, these temperatures were followed by killing frosts. It was not until the week of March 19–25 that the weekly mean temperature was high enough to force new growth. The mean for this week was 68° F. which was high enough to force all Citrus plants into active growth.

While January, 1918, was conspicuous for its low temperatures, weekly mean temperatures for forcing and continuing growth of grapefruit plants occurred from the middle of February on. By the last of February the weekly mean temperatures were high enough for Satsuma and trifoliate orange to develop. Notes on the plants made in the isolation field on March 8 showed that the majority, which survived the low temperatures of January, were in full leaf or starting growth. In fact, scab was observed on a number of plants on this date. Without any question, the season of 1918 was the earliest under discussion.

During the 1920 season temperatures high enough to cause active growth of grapefruit plants and swelling of the trifoliate orange and Satsuma buds occurred during periods in January and February. In fact, grapefruit plants were almost in full leaf when killed back by the freezes of February 15 and 16. The lowest temperatures of the season occurred during the first week in March. All new growth which occurred prior to that time was killed back. With the advent of higher weekly mean temperatures it was some time before new growth started. The late season of 1920, then, was due to the destructive frosts the first week in March. The development of the uninjured buds was also delayed until suitable temperatures were again at hand. To summarize, most of the plants were in full leaf or were starting growth the week ending February 4 in 1918, March 25 in 1916, April 1 in 1920, and April 15 in 1915.

From the above notes it can be clearly seen that the dormancy of Citrus plants during the early part of the year is variable and depends to a large extent on the prevailing temperatures. The seasons of 1914, 1915, and 1920 can be
Fig. 1.—Graph showing the weekly mean temperature from January 1 to June 10, for the years 1915, 1916, 1918, and 1920 at Mobile, Ala., together with the minimum, optimum, and maximum temperatures for citrus-scab infection.
classed as late, the season of 1918 as extremely early, while the remainder were more or less normal.

When the temperature is correlated with the appearance of new growth in Alabama, grapefruit plants are forced into new growth at any time after the first of the year when a weekly mean temperature of 59° F. or above prevails. For the trifoliate orange and Satsuma, a weekly mean temperature of above 65° F. is necessary.

Not all plants of the same variety start growth at the same time in the spring. Thus, we not only have various species starting at different times, but even plants of the same variety. It is also a well-known fact that, the first spring growth is usually smaller than that produced during the succeeding growth periods. The leaves formed are also smaller and mature more rapidly. Thus the amount of spring growth formed and the rapidity with which it matures are also dependent on the prevailing weather conditions.

### Table I.—Weekly mean temperatures from January 1 through June 10, for 7 years at Mobile, Ala.

<table>
<thead>
<tr>
<th>Month</th>
<th>1914</th>
<th>1915</th>
<th>1916</th>
<th>1917</th>
<th>1918</th>
<th>1919</th>
<th>1920</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan. 1-7</td>
<td>44.0</td>
<td>51.0</td>
<td>54.0</td>
<td>53.0</td>
<td>41.0</td>
<td>47.0</td>
<td></td>
</tr>
<tr>
<td>8-14</td>
<td>51.0</td>
<td>54.0</td>
<td>53.0</td>
<td>41.0</td>
<td>58.0</td>
<td>50.0</td>
<td></td>
</tr>
<tr>
<td>15-21</td>
<td>60.0</td>
<td>59.0</td>
<td>60.0</td>
<td>54.0</td>
<td>43.0</td>
<td>50.0</td>
<td>61.0</td>
</tr>
<tr>
<td>22-26</td>
<td>58.0</td>
<td>61.0</td>
<td>57.0</td>
<td>50.0</td>
<td>57.0</td>
<td>54.0</td>
<td>56.0</td>
</tr>
<tr>
<td>Feb. 4</td>
<td>55.0</td>
<td>53.0</td>
<td>57.0</td>
<td>50.0</td>
<td>50.0</td>
<td>55.0</td>
<td>56.0</td>
</tr>
<tr>
<td>Feb. 5-11</td>
<td>53.0</td>
<td>51.0</td>
<td>60.0</td>
<td>45.0</td>
<td>55.0</td>
<td>49.0</td>
<td>57.0</td>
</tr>
<tr>
<td>12-18</td>
<td>52.0</td>
<td>56.0</td>
<td>52.0</td>
<td>66.0</td>
<td>62.0</td>
<td>53.0</td>
<td>48.0</td>
</tr>
<tr>
<td>19-25</td>
<td>51.0</td>
<td>54.0</td>
<td>49.0</td>
<td>66.0</td>
<td>65.0</td>
<td>59.0</td>
<td>56.0</td>
</tr>
<tr>
<td>26-Mar.4</td>
<td>49.0</td>
<td>51.0</td>
<td>54.0</td>
<td>69.0</td>
<td>65.0</td>
<td>56.0</td>
<td>44.0</td>
</tr>
<tr>
<td>Mar. 5-11</td>
<td>53.0</td>
<td>52.0</td>
<td>56.0</td>
<td>65.0</td>
<td>68.0</td>
<td>58.0</td>
<td></td>
</tr>
<tr>
<td>12-18</td>
<td>54.0</td>
<td>54.0</td>
<td>54.0</td>
<td>67.0</td>
<td>65.0</td>
<td>65.0</td>
<td>62.0</td>
</tr>
<tr>
<td>19-25</td>
<td>50.0</td>
<td>48.0</td>
<td>66.0</td>
<td>65.0</td>
<td>65.0</td>
<td>65.0</td>
<td>65.0</td>
</tr>
<tr>
<td>Apr. 2-8</td>
<td>67.0</td>
<td>54.0</td>
<td>64.0</td>
<td>62.0</td>
<td>69.0</td>
<td>63.0</td>
<td>64.0</td>
</tr>
<tr>
<td>9-15</td>
<td>60.0</td>
<td>67.0</td>
<td>56.0</td>
<td>61.0</td>
<td>55.0</td>
<td>69.0</td>
<td>61.0</td>
</tr>
<tr>
<td>16-22</td>
<td>68.0</td>
<td>72.0</td>
<td>69.0</td>
<td>69.0</td>
<td>64.0</td>
<td>70.0</td>
<td>70.0</td>
</tr>
<tr>
<td>23-29</td>
<td>74.0</td>
<td>75.0</td>
<td>67.0</td>
<td>73.0</td>
<td>69.0</td>
<td>70.0</td>
<td>68.0</td>
</tr>
<tr>
<td>30-May 6</td>
<td>76.0</td>
<td>75.0</td>
<td>68.0</td>
<td>69.0</td>
<td>70.0</td>
<td>72.0</td>
<td>73.0</td>
</tr>
<tr>
<td>May 7-13</td>
<td>73.0</td>
<td>71.0</td>
<td>78.0</td>
<td>68.0</td>
<td>75.0</td>
<td>75.0</td>
<td>75.0</td>
</tr>
<tr>
<td>14-20</td>
<td>72.0</td>
<td>75.0</td>
<td>77.0</td>
<td>69.0</td>
<td>75.0</td>
<td>75.0</td>
<td>75.0</td>
</tr>
<tr>
<td>21-27</td>
<td>75.0</td>
<td>80.0</td>
<td>77.0</td>
<td>77.0</td>
<td>75.0</td>
<td>80.0</td>
<td>80.0</td>
</tr>
<tr>
<td>28-June 3</td>
<td>80.0</td>
<td>77.0</td>
<td>82.0</td>
<td>79.0</td>
<td>75.0</td>
<td>75.0</td>
<td>77.0</td>
</tr>
<tr>
<td>June 9-10</td>
<td>83.0</td>
<td>82.0</td>
<td>80.0</td>
<td>80.0</td>
<td>81.0</td>
<td>81.0</td>
<td>77.0</td>
</tr>
</tbody>
</table>

### ON THE DISEASE

Judging from the results obtained under controlled conditions, we would expect initial infection to occur in the field on young growth during periods when free moisture was present on the surface of the leaves between temperatures of 59 and 74.3° F. Initial infection would be most abundant under these conditions when a temperature of about 68 to 70° F. prevailed.

Observations point to the fact that the spores of the pathogene overwinter on the leaves in the old scab spots formed during the preceding season. At least these old scab spots serve as the chief source for the early spring infections. Judging from the many observations made in the field, it appears that the spores of the fungus may also lodge in the scales of the dormant buds and then when these begin to grow in the spring the spores are at hand to produce infection on the young unfolding leaves.

The presence of free moisture on the surface of the leaves is necessary for a rather long interval for the successful germination of the spores to take place and for the germ tube to enter the tissues of the leaf. Even after the hyphae
have entered the tissues, the small and slow amount of growth which the fungus makes necessarily lengthens the period of incubation. The period of initial infection for citrus scab is a question of hours and not minutes. A summary of Fawcett's (4) infection experiments shows that the period of incubation is also long, six days to two weeks being required even under optimum conditions for infection.

Primary infection in the spring usually occurs on the unfolding buds, while secondary infection takes place on the young fruits very soon after the petals drop. It is rather unusual under Alabama conditions for the pathogene to attack half-grown leaves or fruits. It is true that scab is found on leaves and fruits of this age, but the length of the incubation period indicates that initial infection takes place while the leaves and fruits are quite small.

The fact that the disease appears on either side of the leaves, precludes the possibility of stomatal infection as no stomata are present on the upper surfaces of Citrus plants. Infection is accomplished, for the most part, by the direct penetration of the epidermis by the fungus hyphae. As the leaves mature the firmer leaf texture would necessarily become less penetrable by the hyphae of the fungus.

Initial infection is not dependent on rapidly growing tissue so much as on the fact that the leaves must be young, whether rapidly growing or not. However, after initial infection takes place, rapidly growing infected tissues produce more malformations and consequently larger and more misshapen leaves and fruits. Any conditions favoring the rankness of the first growth would also contribute to produce larger scab spots.

In figure 1, the minimum, optimum, and maximum temperatures for scab infection, as determined under controlled conditions, are indicated. While these points may not be strictly applicable to what actually occurs in the field, they are sufficiently accurate for the purpose of our discussion. During the early part of some years, the weekly mean temperatures rise above the minimum for infection for short periods, but in most instances, they are followed by sudden drops in temperature. No scab has ever been found during these periods, as the other two conditions for successful infection are not always at hand; namely, sufficient moisture and the presence of young foliage. Temperatures suitable for slight infection occur at different times during the various seasons, as indicated in figure 1. The period during which optimum temperatures for infection prevail is usually from the middle of April through most of May. By the third week in April the temperature during most years reaches the optimum and by the first of June the prevailing temperatures are above the maximum for infection.

If the temperature factor is considered by itself, we should expect the same amount of scab each year, as the optimum temperature for infection is reached practically the same time. There is only one week or at the most, two weeks' difference in the time required for the temperatures to reach the maximum. We should also expect that the earlier the season the more prevalent scab would be. However, it is exactly the reverse, as will be brought out later.

The presence of moisture over a long enough period for initial infection to take place has been continually stressed as one of the essentials for successful infection. The weekly rainfall, including the number of rainy days per week for the spring season of 1914 to 1920, was tabulated, but no positive correlations between the relative prevalence of scab and the amount or frequency of rainfall could be made. Under Alabama conditions, there is rarely a week in which rain does not occur during the development of the first spring growth. In the majority of cases, when temperatures suitable for infection are at hand, moisture sufficient for initial infection is present. Thus, as far as Alabama is concerned, we can take

88287—24†——4
it for granted that the rainfall is sufficient during the greater part of the time in which temperatures suitable for infection prevail.

We come now to the most important variable factor and by all means the most difficult to present, namely, the development of the early spring growth and its relation to scab.

In the preceding pages, it has been pointed out that the various types of Citrus plants start growth in the spring when different weekly mean temperatures are reached. These points vary during different years so that in some cases they may occur as much as six weeks apart. Again, not all plants of the same variety start at the same time. Furthermore, during certain seasons all plants may start at practically the same time, or at different times, during years when the weekly mean temperatures are low. The amount of first spring growth and the rapidity with which it matures are also dependent on weather conditions. Thus, all these points must be taken into consideration in discussing the relative prevalence and susceptibility to scab of various plants.

Any environmental factor or factors which induce a slow or slight spring growth and rapid maturation or late starting of susceptible Citrus trees favor scab escape; while any environmental factor or factors which induce a large amount of spring growth and subsequently slower maturation, especially during the period of optimum infection, favor scab attacks. Thus, we must not only consider the internal factors influencing the development of spring growth of the Citrus trees, but also the external factors which may inhibit or stimulate these processes.

To illustrate, grapefruit plants, as a rule, start rather early in the season and during normal years complete their growth before optimum conditions favorable for scab are at hand. However, plants may go into the winter in a devitalized condition and so start extremely late in the spring and thus escape infection. It is only when environmental conditions are such that the development of the first spring growth coincides with the optimum conditions for scab development that the disease is at all serious on grapefruit plants.

As is well known, Satsumas are generally susceptible to scab. The somewhat higher temperature necessary for the forcing of active growth of Satsumas usually means that it starts later in the season and first spring growth is well developed at the time optimum conditions for infection are at hand.

Until more data are at hand, we can roughly divide the susceptible commercial Citrus species and varieties into three groups, according to their normal development (internal) in the field as follows:

1. Varieties which start early in the season and make a slow and slight growth, which matures rapidly.
2. Varieties which start somewhat later, and produce a larger amount of spring growth, which matures slowly and about the time optimum conditions for infection are at hand.
3. Varieties which start late in the season after the optimum for infection has occurred.

Plants falling in Groups 1 and 3 are generally free from scab, while those in Group 2 are usually easily infected and badly attacked by scab.

External factors, however, play an equally important part in determining the type of spring growth developed and in its scab susceptibility or escape. After a thorough consideration of the numerous factors involved, it is not surprising that no successful infections have been made in the field with this disease. However, it should not be difficult to do when all factors are taken into consideration. Evidently some essential requirements for successful infection in the experiments so far reported have been omitted.
CONDITIONS DETERMINING THE YEARLY PREVALENCE OF CITRUS SCAB

It is a well-known fact that there are epidemic and nonepidemic scab seasons. Thus, in Alabama, the seasons of 1914, 1915, and 1920 were noted as very bad scab years. The season of 1918 was probably the lightest scab year recorded and yet scab was plentiful on some plants in the isolation field as early as March 8. Some scab was present during the years 1916, 1917, and 1919, but these can be classed as nonepidemic years.

Although scab is present during the month of March in some seasons, the weather conditions prevailing during April and May determine largely the relative prevalence of scab. To determine the conditions necessary for an epidemic or nonepidemic year, the seasons of 1916 and 1918 are contrasted with those of 1915 and 1920 (fig. 1).

To facilitate the discussion, it can be said that most plants were in full leaf or were starting growth by the week ending March 4, during 1918. In other words, the mean temperatures for February and March were above the normal for these months, so growth responded very early in the season. Note also that the prevailing temperatures did not approach the optimum for infection until well along in April, by which time the plants had about completed their first spring growth, and so escaped the disease. Let us contrast these conditions with those of 1915. The monthly mean temperature for March was almost 7° below the normal. No temperatures suitable for growth and subsequent infection occurred until the middle of April. The following week, just as the young growth was developing the weekly mean temperature went above the temperature for optimum infection and remained more or less at this point for several weeks. During the first two weeks in May almost 4 inches of rainfall occurred on eight different days. The three conditions essential for infection were thus well supplied so that the year 1915 is noted as the worst scab year on record in Alabama.

### Table II.

**Monthly mean temperature, precipitation, and number of rainy days at various localities**

#### Monthly Mean Temperature

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Manila, P. I.</td>
<td>77.0</td>
<td>77.2</td>
<td>80.2</td>
<td>82.9</td>
<td>83.5</td>
<td>82.2</td>
<td>80.8</td>
<td>80.6</td>
<td>80.4</td>
<td>79.0</td>
<td>77.4</td>
<td>80.2</td>
<td></td>
</tr>
<tr>
<td>Los Angeles, Calif.</td>
<td>51.0</td>
<td>52.7</td>
<td>60.1</td>
<td>60.4</td>
<td>65.2</td>
<td>70.6</td>
<td>76.3</td>
<td>76.4</td>
<td>72.1</td>
<td>64.2</td>
<td>58.2</td>
<td>53.2</td>
<td>63.0</td>
</tr>
<tr>
<td>Mobile, Ala.</td>
<td>46.8</td>
<td>52.2</td>
<td>59.1</td>
<td>66.0</td>
<td>75.6</td>
<td>79.1</td>
<td>80.5</td>
<td>79.7</td>
<td>75.0</td>
<td>71.0</td>
<td>61.1</td>
<td>57.5</td>
<td>66.1</td>
</tr>
<tr>
<td>Nagasaki, Japan</td>
<td>42.4</td>
<td>42.4</td>
<td>48.7</td>
<td>57.9</td>
<td>64.4</td>
<td>71.1</td>
<td>78.3</td>
<td>74.5</td>
<td>64.6</td>
<td>54.9</td>
<td>46.0</td>
<td>60.4</td>
<td></td>
</tr>
</tbody>
</table>

#### Monthly Mean Precipitation

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Manila, P. I.</td>
<td>1.40</td>
<td>0.67</td>
<td>1.18</td>
<td>4.06</td>
<td>9.80</td>
<td>15.32</td>
<td>13.78</td>
<td>14.53</td>
<td>7.46</td>
<td>5.16</td>
<td>2.29</td>
<td>75.87</td>
<td></td>
</tr>
<tr>
<td>Los Angeles, Calif.</td>
<td>2.01</td>
<td>2.34</td>
<td>0.70</td>
<td>0.35</td>
<td>0.65</td>
<td>0.14</td>
<td>6.14</td>
<td>0.54</td>
<td>0.77</td>
<td>1.57</td>
<td>10.09</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mobile, Ala.</td>
<td>4.86</td>
<td>5.06</td>
<td>7.17</td>
<td>4.35</td>
<td>5.95</td>
<td>7.04</td>
<td>6.81</td>
<td>5.62</td>
<td>3.18</td>
<td>3.74</td>
<td>4.57</td>
<td>62.04</td>
<td></td>
</tr>
<tr>
<td>Nagasaki, Japan</td>
<td>2.96</td>
<td>3.03</td>
<td>5.04</td>
<td>8.12</td>
<td>7.44</td>
<td>11.10</td>
<td>10.16</td>
<td>7.73</td>
<td>7.09</td>
<td>5.52</td>
<td>3.38</td>
<td>3.64</td>
<td>74.29</td>
</tr>
</tbody>
</table>

#### Number of Rainy Days

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Manila, P. I.</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>9</td>
<td>16</td>
<td>21</td>
<td>21</td>
<td>20</td>
<td>16</td>
<td>12</td>
<td>8</td>
<td>138</td>
</tr>
<tr>
<td>Los Angeles, Calif.</td>
<td>6</td>
<td>6</td>
<td>7</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>6</td>
<td>40</td>
</tr>
<tr>
<td>Mobile, Ala.</td>
<td>11</td>
<td>10</td>
<td>10</td>
<td>8</td>
<td>8</td>
<td>12</td>
<td>15</td>
<td>14</td>
<td>10</td>
<td>6</td>
<td>7</td>
<td>7</td>
<td>121</td>
</tr>
<tr>
<td>Nagasaki, Japan</td>
<td>16</td>
<td>13</td>
<td>14</td>
<td>15</td>
<td>14</td>
<td>16</td>
<td>14</td>
<td>13</td>
<td>13</td>
<td>11</td>
<td>12</td>
<td>16</td>
<td>165</td>
</tr>
</tbody>
</table>
While the season of 1916 was somewhat later than that of 1918 and more scab was noted, temperatures below those of 1918 were recorded during most of the development of the spring growth. By the time optimum temperatures for infection occurred growth was completed. However, the amount of growth was smaller and maturation of foliage was more rapid.

The lateness of the season in 1920 was due to the low temperatures which occurred during the first week of March. All the young growth formed before this time was killed back. The mean monthly temperature for March was also below normal. Thus the forcing of growth from new buds was resorted to by the plants, which naturally delayed the development of the first spring growth. However, temperatures very much like those which prevailed during 1915 occurred for the rest of the season, which were very conducive to maximum infection. Thus, during the season of 1920, scab was almost as bad as in 1915.

For practical purposes it appears that a mean monthly temperature below the normal for March in Alabama can be used as an indication of a scab epidemic, while temperatures above the normal for this month and with no freezing temperatures are indicative of a light scab season. The orchard grower then can forecast to some extent light or bad scab seasons from the mean monthly temperature, and its departure from normal for March and can regulate his spraying program accordingly, depending on the prevailing conditions.

It might be stated at this point that there is not much use in spraying after the weekly mean temperatures go above 75° F. nor after the first growth period is completed.

WEATHER AND ITS EFFECT ON THE DISTRIBUTION AND PREVALENCE OF CITRUS SCAB

In discussing the distribution of citrus scab it was stated that this disease was rather serious in the Gulf Coast States, Japan, and South China, while scab was not known in the Mediterranean countries, California, and the Philippine Islands, although scab had undoubtedly been introduced into California and possibly the Philippine Islands many times. It was further stated that there were certain factors which prevented the successful propagation of citrus scab in these localities.

To determine just what some of these factors might be, the mean monthly temperature and precipitation and number of rainy days for Manila, P. I.; Los Angeles, Calif.; Mobile, Ala.; and Nagasaki, Japan; were obtained. These data are tabulated in Table II and plotted in figure 2. For the sake of simplicity, in the discussion which follows, all references to the relation of these environmental factors to the development of the host plants will be eliminated. It should be understood, however, that young growth must be present as one of the prerequisites for successful infection.

It can be readily seen that the principal reason why scab is not prevalent in the Philippines is the fact that the mean monthly temperatures for the whole year are above the maximum for infection. Even though scab was introduced on Citrus stock, the fungus could not propagate itself because of this fact. There is no doubt that citrus scab has been introduced into the Philippine Islands on nursery stock from Japan in the past, but owing to the prevailing high mean temperature militating against it, scab has never gained a foothold.

If we follow the temperature curve for Mobile through we find that some scab could occur in March, but that by the end of May temperatures are already above the maximum. The period of optimum infection would be rather short.

---

1 Climatic data were kindly supplied by J. Warren Smith, agricultural meteorologist, Weather Bureau, U. S. Department of Agriculture.
Fig. 2.—Graph showing the monthly mean temperatures, precipitation and number of rainy days for Manila, P. I.; Mobile, Ala.; Los Angeles, Cal.; and Nagasaki, Japan, together with the minimum and maximum temperatures for citrus scab infection.
At the most, only the months of March, April, and May would be suitable for scab infection judging from the temperature factor alone. However, we should note that for these three months an average of approximately 5 inches of rain occurs during about ten days each month.

At Nagasaki, Japan, the monthly mean temperatures for the first five months of the year are from 8° to 11° lower than at Mobile. In other words, the season at Nagasaki is from one to one and one-half months later. Scab should be prevalent in Japan during the last of April, May, June, and part of July. Optimum conditions for scab infection should prevail during the month of June. During these months from 7 to 11 inches of rain occur during approximately 15 days each month. Scab is more serious in Japan than in Mobile district because of the slower start made by the plants in the spring, the larger amount of precipitation, and the greater number of rainy days.

After following through the temperature curve for Los Angeles, Calif., we would expect that as far as this one factor was concerned scab would be more serious than in either Japan or Alabama. Note that the curve follows that of Mobile for the first three months and then crosses over and runs along that for Nagasaki through July. We should expect then from the temperature standpoint alone to have conditions favorable for scab during the months from March through July. However, one need but look at the amount of precipitation to determine why scab cannot propagate itself in California. This is a further indication that generous precipitation over most of the year is necessary for the development and propagation of scab.

The absence of scab in a locality may be due either to a mean temperature too high for the pathogene to infect the host or to a deficiency in rainfall. In the Philippine Islands the high mean temperature and possibly the effects of the dry season are sufficient reasons to prevent the spread and development of scab, while in California the large deficiency in precipitation alone is sufficient.

The factors necessary for this disease to develop in any locality are a suitable temperature, sufficient moisture, and young growth. Wherever these conditions are fulfilled as in the Gulf Coast States and Japan, scab becomes a serious disease. No doubt, as has been pointed out before, we may have epidemic and nonepidemic years, depending on the prevailing weather, but some scab is present each season.

DISCUSSION

In the foregoing pages the relation of environment to the various phases of the development of citrus scab, from the standpoint of experimental results obtained in the laboratory and greenhouse and from observations made in the field, are discussed. The temperature to which the pathogene and the plants were submitted under controlled conditions have been constant and not fluctuating as occurs in nature. Observations made under field conditions in south Alabama, where the Citrus-growing area is small and rather compact, when correlated with results obtained under controlled conditions are in close uniformity and the interpretations placed of these correlations can be made specific. Note also that we have confined ourselves to the relation of the scab during the development of the first spring growth. It is usually only during this period that scab does any serious damage. Occasionally scab appears in the fore part of June, late in August, or September on the young growth, when there are periods of several days during which the mean temperatures and other factors suitable for infections are favorable.

In the discussion of the effects of weather on the distribution and prevalence of scab in the other Citrus-growing regions we have tried to point out in a general way that there are certain types of weather which either favor or inhibit the
development of scab. Obviously one could not without a close study of the conditions prevailing in an entire Citrus-growing region state positively that the whole region would be free from scab, from the weather data obtained from one locality in that region. The exact correlation of environment to the development of scab in a Citrus-growing area must be left to trained observers present in that locality.

**SUMMARY**

1. Citrus scab, caused by *Cladosporium citri* Massée, has been encountered with frequency during citrus-canker investigations made by the writers in Alabama during the past four years.

2. The disease is probably indigenous to the Orient, and has been distributed directly or indirectly from Japan to the Citrus-growing regions where it is not prevalent.

3. Citrus scab is a rather serious disease in the Gulf Coast States of Florida, Alabama, Mississippi, Louisiana, and Texas; in South China, Japan, and the West Indies. Scattering reports of citrus scab have also been made from South Africa, Australia, Formosa, Yucatan, Paraguay, Hawaii, India, and the Canal Zone. As yet, no scab has been reported from California, the Philippine Islands and the Citrus regions of the Mediterranean.

4. The three essentials for successful infection of Citrus plants by *Cladosporium citri*, under controlled conditions, are the presence of free moisture, young growth, and temperatures between 15° and 23.5°C. (59° and 74.3°F.). The optimum for the best development of scab appears to be about 20°–21°C. (68°–70°F.).

5. Under Alabama conditions, temperatures favorable to optimum infection usually prevail during parts of April and May. Sufficient moisture is generally at hand during this interval for successful infection to take place. The most important and variable factor is the development of the early spring growth.

6. Susceptible species or varieties of Citrus making a slight or slow spring growth which matures rapidly are not subject to scab. Likewise, those plants which do not start growth until late are also free from scab. In both instances it is apparently a question of escape. Plants making a large amount of spring growth, with slow maturation of foliage are easily infected and as a rule badly attacked.

7. Any environmental factor or factors including a slight spring growth and rapid maturation or late starting, favors scab escape; while any environmental factor or factors inducing a large amount of spring growth and slow maturation, favors scab susceptibility.

8. We must consider not only the internal factors influencing the development of spring growth of Citrus plants, but also the external factors which may inhibit or stimulate these processes.

9. Conditions essential for an epidemic scab year in Alabama depend to a large extent on a late season, coupled with sufficient moisture and the development of spring growth at the time optimum temperatures for infection prevail. An early season is favorable to scab escape, in that first growth is about completed when optimum conditions for infection are at hand.

10. Under Alabama conditions it appears that a light or bad scab year can be predicted to some extent by the mean temperature prevailing in March; a temperature below normal indicates a bad scab season; a temperature above normal, a light scab year.

11. The relation of weather and its effect on the distribution and prevalence of citrus scab is shown and the absence of scab in certain localities is correlated with either a mean temperature too high for infection or a deficiency in rainfall.
LITERATURE CITED

(1) Fawcett, H. S.

(2) ———

(3) ———

(4) ———

(5) Lee, H. A.

(6) Peltier, G. L.

(7) Reinking, O. A.

(8) ———

(9) Swingle, W. T., and Webber, H. J.