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AGRICULTURAL AND MECHANICAL COLLEGE OF TEXAS

W. B. BIZZELL, President

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DIVISION OF PLANT PATHOLOGY AND PHYSIOLOGY

TEXAS ROOT ROT OF COTTON AND METHODS OF ITS CONTROL

THE STATE OF TEXAS

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*In cooperation with School of Veterinary Medicine, A. and M. College of Texas.
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BULLETIN NO. 307 APRIL, 1923

TEXAS ROOT ROT OF COTTON AND METHODS OF ITS CONTROL

BY

J. J. TAUBENHAUS AND D. T. KILLOUGH.

SUMMARY.

1. By reason of the large number of cultivated crops which it attacks, the Texas root rot disease is perhaps one of the most important of plant diseases in the State.

2. The same disease is equally serious in Arizona, and to a less extent in Oklahoma, New Mexico, and Southern California.

3. Texas root rot has been reported from sixty-seven counties in the State with the probability that it is present in other counties.

4. With similar soil and climatic conditions (winter conditions especially), it is strange that Texas root rot is not apparently present in Louisiana, Mississippi, Alabama, and the many other Cotton States. Should the disease ever spread further than its present known distribution, it may seriously threaten the cotton industry, the alfalfa, and the many other susceptible crops of the South.

5. The symptoms of the Texas root rot disease are the same or nearly the same on all susceptible hosts.

6. With cotton or other herbaceous crops, the Texas root rot begins to attract attention during July and August, reaching its height of destruction about September.

7. Texas root rot spots are not always circular in shape as is popularly believed.

8. Texas root rot spreads underground from contact of infected roots of one plant with adjoining healthy ones of another.

9. From studies thus far, it might be stated that the Texas root rot disease is capable of attacking thirty-one different economic field crops, fifty-eight different truck crops, eighteen different kinds of fruit and berries, thirty-five different kinds of forest trees and shrubbery, seven different kinds of outdoor herbaceous ornamentals, and twenty different kinds of weeds.

10. There seems to exist but slight difference in resistance in the various varieties of cotton.

11. Of the varieties of apples and pears tested none seemed to possess any resistance.

12. The peach seems to be highly resistant and the pecan apparently wholly resistant to Texas root rot. The same is true for all the grain and cereal crops. The guar, a newly-introduced legume, is highly resistant.

13. Cotton strains which seem to resist the disease longest during

the summer eventually become infected during the fall or winter. Such strains, however, may be valuable and selected for partial resistance.

14. There seems to be more root rot in cotton if this crop follows a more susceptible host, such as the sweet potato.

15. The factors which greatly influence the summer spread of root rot seem to be a wet season or irrigation, soil temperature, and a well-developed root system, which favors underground contact.

16. Deep plowing as a method of controlling Texas rot has been exaggerated at the expense of more fundamental factors.

17. It is doubtful if the addition of humus or manure to the soil will greatly influence root rot control although it may increase the yield in cotton.

18. Early planting and close planting of susceptible hosts greatly influence the amount of Texas root rot during a favorable season, because of a better contact of the roots underground.

19. Clean culture (not ordinary slipshod clean culture) may control Texas root rot of cotton if it is based on a knowledge of the many winter carriers, and on the life history of the causal organism.

20. Crop rotation may control Texas root rot if clean culture is practiced and all winter carriers are destroyed.

21. Crop rotation has failed to control Texas root rot wherever absolute clean culture was not practiced, and where winter carriers were left unmolested during the fall and winter months.

22. We are, as yet, unable to predict with certainty the effect of various fertilizers or sulphur in controlling Texas root rot. This requires further testing for several more years.

23. A root-rot spot one year may not necessarily reappear the following year if a susceptible crop is grown in that field. The disappearance of the spot in that case may be due to the fact that the disease has killed out the winter carriers.

24. The Texas root rot disease is not caused by alkali in the soil.

25. For a long time, scientists suspected, through circumstantial evidence, that the cause of Texas root rot was a fungus, *Phymatotrichum omnivorum* (Shear) Duggar.

26. Through our modified methods, we have shown, by artificial inoculations, that *Phymatotrichum omnivorum* is the cause of the Texas root rot disease.

27. The causal organism is difficult to isolate in pure culture. We have used and modified Atkinson's method with good results.

28. When the causal organism is once isolated in pure culture, it may be grown on any number of media. It grows poorly on sterilized soil.

29. Because of its peculiar structure, *Phymatotrichum omnivorum* may be readily distinguished from other parasitic organisms.

30. For a long time, *Ozonium omnivorum* was considered to be a sterile organism. Thornber and Duggar have found a spore stage in Arizona and Texas and they believed it to be the conidial stage of *O. omnivorum*. As a result of this finding, Duggar renamed the causal organism *Phymatotrichum omnivorum*. For the first time we

have found this conidial spore stage in a pure culture grown on sterilized soil. These spores whether collected in the field or from pure culture fail to germinate. It is, therefore, difficult as yet to ascribe their true function.

31. By nature of its parasitic habit, all evidences tend to show that *Phymatotrichum omnivorum* is unable to maintain itself on dead organic matter or in the soil, but that it needs and requires a living host on which to winter over.

32. Cotton roots, as well as the roots of the perennial morning glory (Ipomoea trichocarpa) and perhaps others, act as living hosts on which the root rot fungus winters over.

33. Infection is active both during the summer and winter months, as long as there is a susceptible host in the field.

34. During the summer months infection is rapid and results in the killing of the affected host. The causal organism to maintain itself must migrate to an adjoining healthy host. During the winter months infection is slow, and but partially kills the affected host.

35. The causal organism in nature dies out with the death of its host, which is complete about fifteen to twenty days after it is uprooted.

36. Fall plowing when the soil is moist does not result in killing cotton roots or the roots of other perennials.

37. After the last cotton picking, the cotton roots should be pulled out and exposed to drying and to the effect of weather for three or four weeks and then worked under.

38. Control methods can be successful only if based on a thorough knowledge of the life history of the causal organism.

39. Control methods should consist in entirely eliminating from the soil living susceptible roots of all kinds during the fall and winter months. This may be accomplished by frequent cultivation, by plowing when the soil is dry, and by using a system of fallow and rotation with non-susceptible hosts in which all weed carriers are eliminated.

INTRODUCTION.

Of the many plant diseases in the State none perhaps surpasses in economic importance the Texas root rot. This disease affects not only the cotton but a large number of other crops. Early studies by the Texas Agricultural Experiment Station and by others have paved the way for the present work. This Bulletin presents as briefly as is consistent, results of studies of field and laboratory experiments carried on by the writers during the last six years. We believe that the information here presented points the way to new and fundamental methods of control as far as the cotton and other herbaceous crops are concerned. Future research will no doubt develop control methods applying to fruit trees, shrubbery, and other perennials. All the field experiments were carried on by both writers, who share equal responsibility for results presented. The laboratory work as well as the preparation of the manuscript was done by the senior writer, who accepts full responsibility for it.

In this connection, we wish here to express our grateful acknowledgment to Mr. Sam Cater, a farmer of Bell County, for his cooperation in furnishing land to carry out new work or in duplicating field experiments which were tried at Substation No. 5 at Temple, the headquarters for all the field tests. The writers further wish to express their indebtedness to Professor J. G. Brown of the Arizona Agricultural Experiment Station for sending spore material of *Phymatotrichum omnivorum* for germination studies.

HISTORICAL.

Texas root rot as a plant disease of economic importance was first recognized by the Texas Agricultural Experiment Station as early as 1888 through work done by Pammel (14 and 15) and by Curtis (3), previously of this Station. From 1888 to 1906 no considerable attention was given this important disease. In 1907, Shear (20) and Miles (21 and 22) of the United States Department of Agriculture devoted some study to the control of cotton root rot by deep plowing. In 1916, Duggar (5) renamed the causal organism *Phymatotrichum omnivorum* (Shear) Duggar, because of the sport form which he found under field conditions. Recently (1919) Scofield (19) of the United States Department of Agriculture reported on studies of dead spots in cotton, which will be referred to later.

PRESENT WORK.

In undertaking the present project, the writers deemed it necessary to check up the preliminary work carried out by others, because of the importance of such work, which paved the way to many phases still requiring a solution. The present investigation endeavored to establish definitely the cause of the disease, the life history of the causal organism, the conditions which favor infection, the methods of spread, and the development, if possible, of practical methods of control. Many of these phases are practically completed, while others still require further time and patient research. In a certain sense, the present Bulletin is really a report of progress.

NAME OF THE DISEASE.

The disease is variously referred to in literature as cotton blight, cotton wilt, root rot, Texas root rot, and alkali disease. Inasmuch as the Texas Agricultural Experiment Station was the first to recognize and to study this disease, and to distinguish this from other root troubles, the name Texas root rot is here adopted. This specifically refers to the root rot disease of cotton and all other susceptible crops, which is induced by the fungus *Phymatotrichum omnivorum* (Shear) Duggar.

ECONOMIC IMPORTANCE.

Pammel (14) in 1887 estimated that Texas lost $1,000,000 from the cotton root rot disease alone. This estimate, however, only represented a fraction, since it was computed and based on information furnished by some fifty-seven cotton growers in the State. Orton (13) figured that in 1903, Texas lost $2,000,000 from cotton root rot, while Shear and Miles (21 and 22) and Gilbert (8) estimated that in 1906, Texas lost nearly 1.3 per cent. of the cotton crop, amounting to about 52,600 bales, or a money loss of $3,000,000. These estimates, the present writers believe to be too low. For estimating losses from root rot, it is imperative to keep in mind the kind of season in which the disease has worked. The trouble is undoubtedly far less serious during dry years than it is during wet seasons. In 1918, which was a very dry year in Texas, the production of cotton in this State, as reported by the Monthly Crop Reporter of the United States Department of Agriculture, was stated as 2,580,000 bales. Furthermore, in the same year, the losses from Texas root rot of cotton were negligible and conservatively estimated at about 5 per cent. of the total crop and equivalent to 130,000 bales. The year 1919, on the other hand, was wet, and Texas at that time produced 2,700,000 bales. The losses from root rot that year were conservatively placed at 10 per cent., or a total of 313,900 bales. Likewise, in 1920, which was also a wet year, the Monthly Crop Reporter advises that Texas produced 4,200,000 bales. The losses from root rot that year were conservatively estimated* at about 15 per cent. or equivalent to a net loss of 630,000 bales.

The sources of loss from the Texas root rot of cotton are threefold, (a) that which represents a dead net loss from plants which die early in the season before making any cotton whatsoever; (b) when the disease kills the plants just as the bolls are partly developed, resulting in few bolls and in an inferior grade of lint; (c) when the plants die comparatively late in the season after the bolls are matured, in which case the lint is not of the same high quality as that from bolls the plant of which remained alive during the entire season. The writers believe that a conservative estimate of the annual loss from Texas root rot of cotton and all other economic crops will vary from fifteen to thirty million dollars.

Effect of Texas Root Rot on Price of Staple.—In order to more carefully determine how closely estimates of losses from cotton root rot can be made, the following tests were carried out: During the fall of 1921, cotton bolls were picked at random in an infected field from fifty plants which had died comparatively late from the Texas root rot disease, and in which the lint seemed fully matured. The cotton from these bolls was picked out, thoroughly mixed, and placed in a paper bag labeled No. 1. Similarly, and in the same field, cotton bolls were collected from fifty other plants which died from root rot comparatively early, that is, plants in which the bolls were undersized and few in number, and the lint was visibly of a low grade. The cotton from these bolls was picked out, well mixed, and placed in a paper bag marked No. 2. Finally, cotton bolls were gathered from fifty healthy plants; these bolls were of normal size, and the lint in them was fully formed and matured. The lint from these bolls was all picked out, carefully mixed up, and placed in a paper bag labeled No. 3. These

*Estimates made by the senior author cooperating with the Plant Disease Survey of the U. S. Department of Agriculture.

three samples with their origin concealed were submitted to Mr. J. B. Beers, cotton classer of the Extension Division of the A. and M. College and of the United States Department of Agriculture. Mr. Beers was requested to estimate the approximate market money value of the three samples. The following were the results and are self-explanatory: Sample No. 1, commanding a premium of only $7 to $10 per bale, staple reduced to 1 inch full, fair strength, but not as good as No. 3, though better than No. 2. Sample No. 2, commanding no premium, staple reduced to ⅞ inch, uneven, irregular and "wasty." Sample No. 3, commanding a premium of $17.50 to $20 per bale, staple 1 1-16 inches full, strong and even in character. The above ratings in no uncertain way indicate that the Texas root rot disease not only reduces the yield by killing younger plants and preventing their bearing, but also lowers the quality and hence the price of the staple.

Effect of Texas Root Rot on Strength of Cotton Fiber.—In order to further determine the effect of the disease on the strength of the fiber, various samples of lint from healthy and diseased plants were submitted to the Office of Markets and Rural Organization of the United States Department of Agriculture for testing. Mr. Fred Taylor, cotton technologist, reports on the results of his tests, which are given in Table 1. From this table, the following conclusions may be drawn: (a) The lint taken from plants killed by the Texas root rot disease and in which the bolls were fully developed but not matured was 30 to 40 per cent. weaker than the lint from healthy plants. (b) The lint taken from plants killed by the Texas root rot disease at a stage where the bolls were fully formed and properly ripened was not apparently affected in strength of fiber.

Table 1. Comparative individual fiber tests on samples of cotton taken from plants that had been killed by the root rot disease, and samples from healthy plants.

	Healthy	Diseased	Diseased	Healthy	Diseased	Healthy	Diseased
Totals....	102.5	106.5	61.5	110.5	113.5	141.5	108.0
Averages..	5.1	5.3	3.1	5.5	5.7	7.0	5.4
	2.5	3.0	3.0	10.0	5.0	7.0	11.0
	8.0	5.0	2.0	3.0	9.5	5.0	2.0
	6.5	3.0	6.0	2.0	4.5	9.0	3.0
	5.5	4.5	2.0	9.0	3.0	6.5	3.0
	4.0	8.5	3.5	5.0	5.5	6.5	11.5
	5.5	4.5	3.0	5.5	2.5	10.0	6.5
	3.5	10.0	3.5	5.5	7.5	9.5	4.5
	5.5	7.5	4.5	5.0	3.5	10.5	5.0
	10.0	5.0	1.5	1.5	2.5	4.5	5.0
	3.5	7.5	3.0	11.0	5.5	4.0	10.0
	8.0	9.0	3.0	2.0	3.0	9.5	6.0
	8.5	6.0	3.5	10.5	5.0	6.0	3.0
	5.5	3.5	4.0	8.0	12.0	10.0	6.5
	4.5	1.0	4.5	4.5	3.5	6.0	6.0
	2.5	3.5	4.5	5.5	9.5	4.0	2.5
	6.5	7.0	1.5	7.5	7.0	6.5	2.5
	5.5	5.0	3.5	8.0	5.5	5.5	4.0
	2.0	7.5	2.0	4.5	7.0	9.5	3.5
	3.0	3.5	1.5	9.0	6.5	4.5	3.5
	2.0	2.0	1.5	3.5	6.0	7.5	9.0

Effect of Texas Root Rot on Seed Germination.—The ill effect of the Texas root rot disease on the germination of the cotton seed will depend on the stage in which the plants die. Under actual field tests, we have repeatedly found that germination is not seriously affected when such seed came from plants which were killed by the disease at a late stage of maturity. Germination is, however, very poor in seed the mother plants of which were early affected by Texas root rot. The same observations are also supported by Pammel (14) and in Table 2, the germination tests of which were made by the Texas Branch Seed Laboratory.

PROBABLE ORIGIN OF THE TEXAS ROOT ROT DISEASE.

It is difficult if not impossible to tell whether Texas root rot is indigenous to this State or whether it has been imported from elsewhere. Judging from its wide distribution in Texas and by the further fact that it is found killing native susceptible weeds on virgin land and even among timber, one is inclined to believe that the causal organism of Texas root rot is probably indigenous to this State, and it attracted attention with the extensive culture of the cotton crop. From Texas, the disease might have gradually spread to Arkansas, Arizona, New Mexico, and Southern California. It is probable that in time it may further extend into Louisiana, Mississippi, Alabama, and to the many other Southern States where soil and climatic conditions differ but little from those of Texas.

Table 2. Effect of Texas root rot on seed germination.

Sample No.	Source of cotton seed	Duration of tests in days	Germination per cent.
4247	Plants killed by root rot at a late stage of maturity....	10	85
4248	Plants killed by root rot early, bolls underdeveloped..	10	34
4249	Plants healthy, fully matured......................	10	86

Recently (June 13, 1922) the senior writer received from W. Ohlendorf of the United States Federal Horticultural Board freshly-killed cotton plants from Tlahualilo, Durango, Mexico. A careful study of these plants revealed unmistakable evidences of the Texas root rot disease, with the typical *Phymatotrichum omnivorum* fungus on the surface of the dead cotton roots. Further information from Mexico tends to indicate that the Texas root rot disease is even more severe there than it is in Texas. The reason seems obvious since most of the susceptible economic crops there are grown under irrigation. Extensive survey studies in Mexico may throw new light on the probable origin of the disease. Until this is done, all else is speculation.

DISTRIBUTION OF TEXAS ROOT ROT IN TEXAS.

In referring to Fig. 1, one will see that Texas root rot has now been reported from sixty-seven counties in the State. This does not mean that the disease may not be present in other counties where it

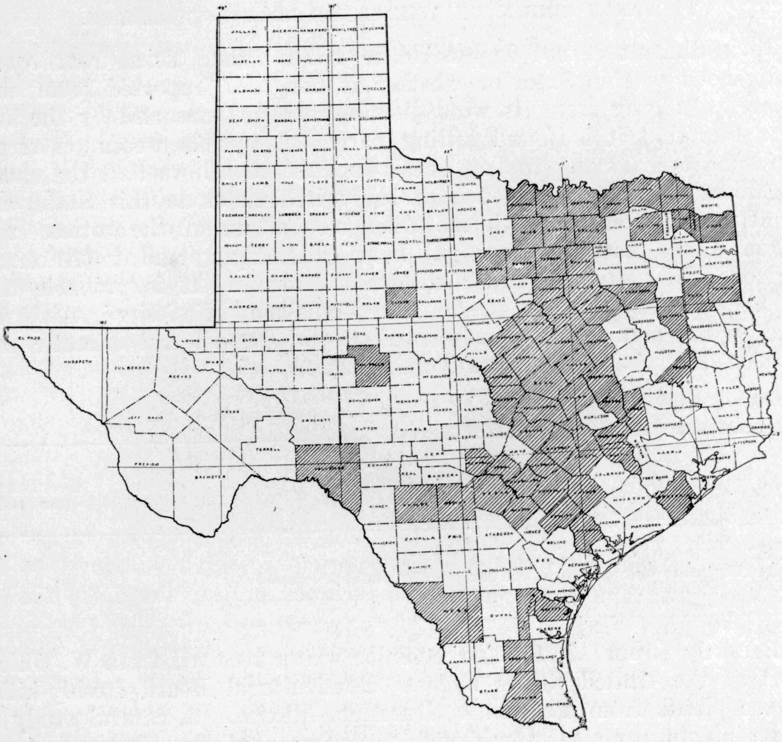


FIGURE 1.

Present known distribution of Texas root rot of Texas.

attacks the native flora or even cultivated crops. The report of its occurrence in the sixty-seven counties is based on actual examinations of infected specimens sent in by growers or from field inspections by the writers. It is to be noticed from Fig. 1 that the Texas root rot disease is reported from two counties in East Texas, where the disease is not supposed to prevail because of different soil conditions there. Just how prevalent the disease is in East Texas is as yet little known. It is probable that soil conditions there are unfavorable for Texas root rot and that the cases reported are probably isolated spots with either surface or sub-surface soil favorable to the disease. This will be more definitely determined in the future.

DISTRIBUTION OF TEXAS ROOT ROT IN THE UNITED STATES.

According to Shear (20), Shear and Miles (21), Heald (10), Gilbert (8), and others, the Texas root rot disease is known to occur in Texas, Southern Oklahoma, New Mexico, Arizona, and Southern California. Duggar (5) found it in Oklahoma in 1915. Chambers (2), in 1919, refers to a root rot of trees in Oklahoma, evidently Texas root rot. We have been unable to obtain information on the exact distribution of the disease in Oklahoma. Under date of November 30, 1921, Dr. Shear writes that he found the Texas root rot disease in New Mexico in the Pecos Valley. Professor Leonian, formerly of the New Mexico Agricultural Experiment Station, under date of November 22, 1921, writes as follows: "I have investigated rather carefully the root root of apple in New Mexico. It was reported to have been caused by Ozonium. I had dozens of sick and dead trees dug out, and found that in each case the tree was attacked by giant apple tree borers and wooly apple aphis." Professor Leonian* further found that *Valsa leucostoma* Pers. was also killing apple trees in New Mexico. It seems, therefore, evident that as far as New Mexico is concerned, definite information is still lacking on the exact distribution and the economic importance of the Texas root rot disease in that State.

In Arkansas, Elliott (6) reports traces of the disease in Miller County on the Red River. It seems that much of the Texas root rot in that State is mistaken for lightning injury.

According to D. C. George† (Plant Pathologist for the Arizona Commission of Agriculture and Horticulture), Texas root rot in Arizona is very widespread. The most serious infestation there is found in the irrigated districts of the river valleys, the disease apparently following the Gila River across the State. In Greenlee County, alfalfa, fruit, and shade trees suffer heavily. In Graham County, alfalfa, cotton, fruit, and vegetables are equally attacked. The same is true for Pinal County near Florence and Sacaton. Perhaps the greatest losses from the disease are found in Maricopa County, and in certain sec

*Leonian, L. H. Studies on the Valsa apple canker in New Mexico. Phytopath 11:236-242, 1912.

†From correspondence dated December 22, 1921.

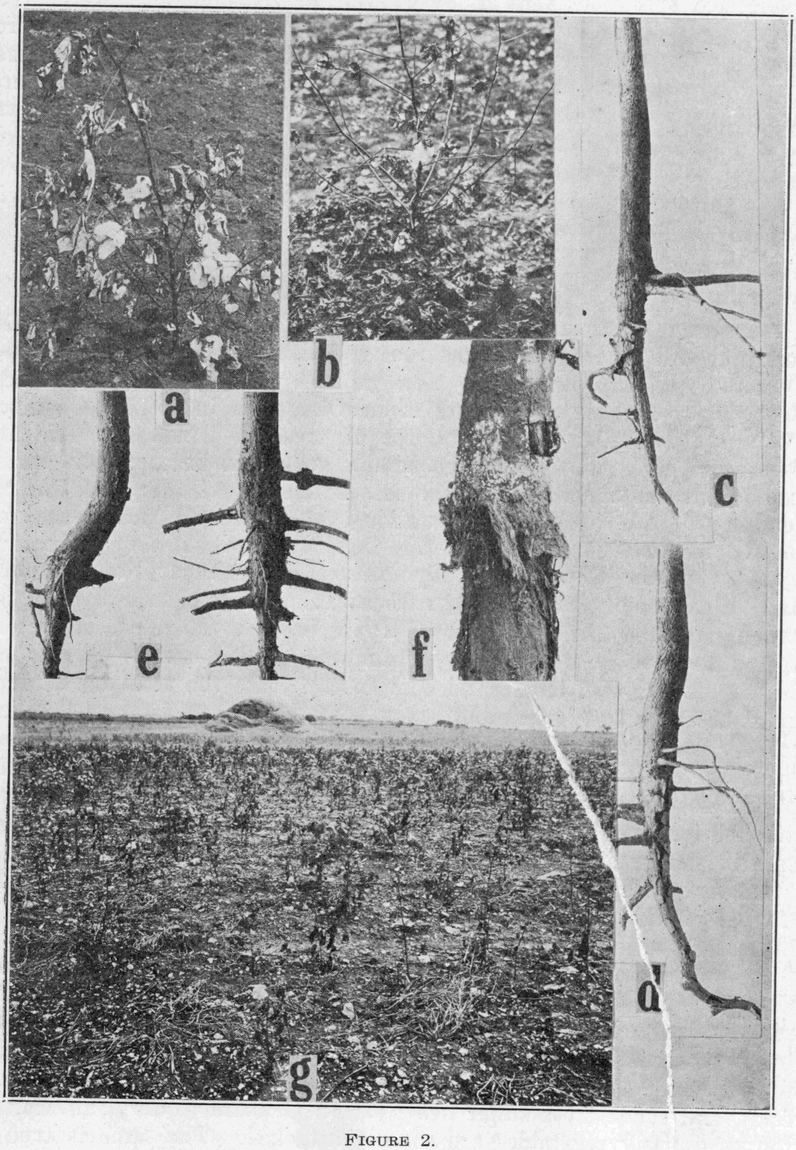


FIGURE 2.

a. Cotton plant freshly infected by root rot, showing drooping of foliage. b. Same as *a,* but five days later, foliage all shed, plant dead. c. and d. Splitting of epidermis and softening of cambium layers of roots of cotton plants recently killed by root rot. e. Two roots of infected cotton plants showing decay and breaking off of the lateral roots. f. Root of cotton plant killed by root rot early in the fall and remaining undisturbed in the field. Notice complete disappearance of epidermis and cambium layers. g. Cotton root rot spot in which most of the plants were killed early, resulting in practically no cotton.

tions of the Salt River Valley, especially near the towns of Mesa, Temple, Phoenix, and surrounding territories. The disease is further prevalent in the Buckeye Valley below the juncture of the Gila and Salt Rivers, and in the Gila Bend districts of cotton and alfalfa. The same is true for Yuma County, especially near the town of Somerton. The disease is likewise serious in Yavapai County from the town of Cottonwood to Camp Verde. In Pima County, the disease is especially virulent in the Santa Cruz Valley, and in the Sahaurita district.

In California, cotton culture is of but recent introduction. According to Waite* the first cotton grown was in Calexico in 1902. From a mere beginning it increased to 1200 acres in 1909 and to 110,000 acres in 1917. In 1921, it was probably ten times as large.

We have already stated that Dr. Shear and others have reported the Texas root rot disease of cotton in Lower California. Mr. M. A. Rice,‡ County Agent for Kern County, California, is authority for stating that there is some Texas root rot in the Imperial Valley, and that the disease is especially severe in the Palo Verde Valley, and in the San Pasqual Valley.

Whether the Texas root rot is present in other Southern Cotton States is not known. When one considers the numerous agencies by which plant diseases may be transported it is indeed surprising that it has not as yet apparently gained a foothold in neighboring States like Louisiana, Mississippi, and Alabama. Whether the disease will in time spread to the other cotton States of the South or whether it will remain restricted to its present area is difficult to predict.

SYMPTOMS OF THE TEXAS ROOT ROT DISEASE.

The symptoms of Texas root rot differ but little as it affects the various susceptible hosts, and, for this reason, the disease is frequently mistaken for other troubles. Susceptible herbaceous hosts seldom show any evidence of being stunted or of turning yellow, as is the case with many other diseases. On the contrary, the plants look normal and healthy, and wilting is sudden in which the entire foliage droops (Fig. 2, a) and dies, and after one to two days the leaves become blackened, shrunken, and in most cases drop off, leaving a bare dead stalk (Fig. 2, b). An infected cotton plant, for instance, seldom revives, although it may do so during prolonged wet weather when the affected host endeavors to send out new rootlets above the diseased area. Such a plant seldom survives for very long, but dies with the advent of dry weather. When a freshly-infected plant that has been dead two or three days is pulled out, the outer surface of its root will generally be found cracked (Fig. 2, c and d), the cambium softened, and the epidermis covered with numerous yellowish threads of the causal organism. Both epidermis and cambium readily peel off with the least scratch of the finger, exposing the unsoftened woody portion of the tap root. If a dead plant remains in the ground for eight

*Waite, F. A., Cal. Month. Bul. of the State Comm. of Hort., 6:427-429, 1917.
‡Correspondence dated December 3, 1921.

days or more, both the epidermis and cambium rot and disappear, leaving a short woody stub of the affected root (Fig. 2, e and f), which becomes a fertile field for a rich mycological flora.

With all susceptible hosts, the disease in every case is confined to the roots, although it occasionally works up an inch or two to the foot end of the plant above ground. The diseased area at the foot of the plant is distinguished from the healthy tissue above by a marked constriction, which is sharply defined in the freshly wilted host (Fig. 3, i and h). During wet weather, in addition to the presence of the characteristic mycelial threads on the surface of the affected root, numerous wart-like bodies (Fig. 3, g, h, and i) may also be present. These are frequently common on cotton and on okra. Heald and Wolf (12) met with this condition in a field of infected cotton at Falfurrias, Texas, and they believed it to be a new disease. According to their own description, "the dead plants exhibiting much the same general appearance as in the case of the well-known Texas root rot * * *" "Numerous small wart-like pustules also appear on the main root * * *" (Fig. 3, i).

Our own studies have shown that both cotton and okra frequently produce numerous corky lenticles at the root and foot end of the plant. These lenticles become very prominent and with age resemble wart-like excrescences (Fig. 3, g). If these plants succumb to Texas root rot, the Phymatotrichum strands will be found to collect and to overrun the exterior and partly even the interior of the tissue, giving the appearance of a pseudo-sclerotium. In some instances, the causal organism would even form pseudo-sclerotia-like bodies on infected cotton or okra roots without the presence of corky lenticles. Furthermore, and as we shall show later, p. 67, *Phymatotrichum omnivorum* frequently produces pseudo-sclerotia on culture media. This indicates that Heald and Wolf (12) did not deal with any new cotton disease, and that the warts on affected plants are frequently part of an additional symptom of Texas root rot.

With trees, as with the apple, for instance, the symptoms are the same as with herbaceous plants. This is evidenced by sudden wilting and dying of the foliage (Fig. 3, a). Later the dead leaves drop off exposing the dead bare limbs (Fig. 3, b).

In pulling out a freshly-wilted cotton plant and in removing the outer epidermis and cambium, one finds that the woody portions of the root lying immediately underneath are deeply discolored, brown to chocolate (Fig. 3, f). Furthermore, the healthy tissue is sharply marked off from the diseased area (Fig. 3, f) by a dark line. This area is invariably free from fungus hyphae, and it tends to show that the causal organism kills its host tissue in advance of its penetration and invasion. The toxic substance secreted by the causal organism is probably of enzymic origin.

TIME OF FIRST APPEARANCE AND LATER SPREAD OF ROOT ROT DURING THE SUMMER.

Opinions differ about the time in which the root rot disease of cotton first appears in an infected field. Pammel (15) records instances

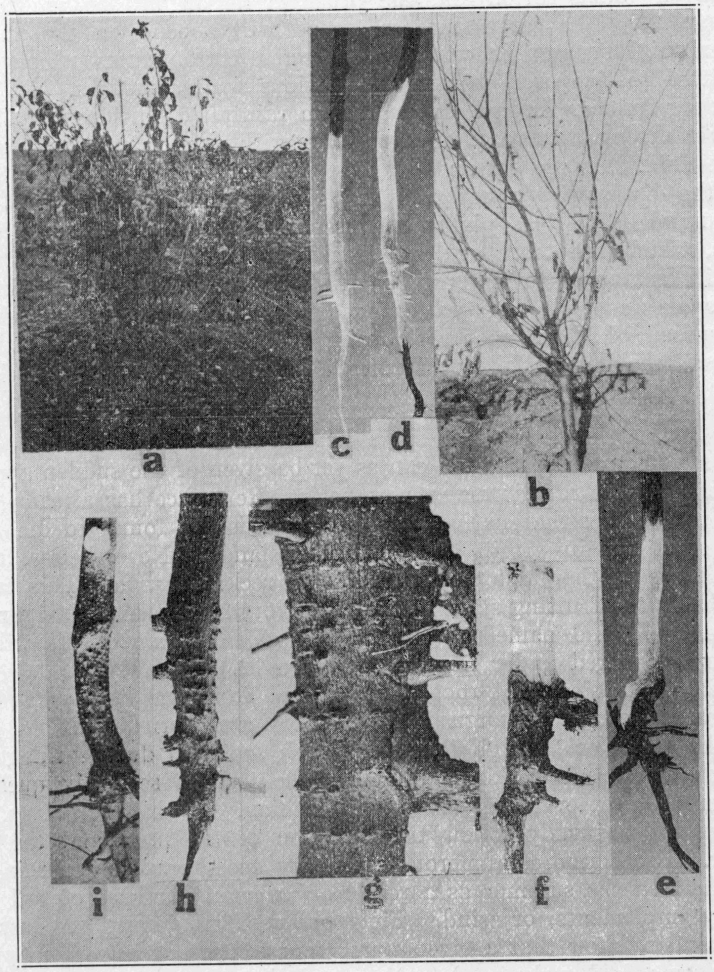


FIGURE 3.

a. Apple tree recently killed by root rot, showing wilted, clinging foliage. b. Same as *a*, but one month later showing bare limbs, tree dead. c. Living cotton roots wintered over in the field, showing the blackened stem which was killed by fall frost and the white living roots which stayed in the soil. d and e. Like *c*, but showing method of root rot infection during the winter months, in which the disease is confined to the tip of the root and without completely killing it. f. Root of cotton killed by root rot during the summer, resulting in immediate and complete dying of the affected root. i. Cotton root killed by root rot, showing constriction and sclerotia-like bodies (i after Heald and Wolf). h. Same as *i* (original). g. Same root as *h* magnified to show enlarged lenticels which frequently become invaded by *phymatotrichum* hypheae, and resemble sclerotial bodies.

brought to his attention in which young cotton was claimed to be killed by the disease as early as May. From our own work we have found this to be the case. However, the Texas root rot is never serious on young cotton and the probable reason will be referred to on page 17. The early summer spread will depend on the number of perennial susceptible weeds or infected cotton roots which were permitted to live over during the previous winter months.

During July or August, depending on rainfall conditions, the Texas root rot disease in cotton always starts with one or two dead plants in the field. As the season advances, weather conditions being favorable, the disease slowly but gradually spreads, involving in many cases large numbers of dead plants and assuming the shape of spots (Fig. 2, g), which are more or less circular in outline. Definite studies are still lacking as to how rapidly or slowly the disease spreads in the same spots under varying weather conditions during the summer season. The spread of Texas root rot during the fall and winter months is discussed under "life history studies," page 72.

SPREAD OF ROOT ROT FROM FIELD TO FIELD.

No satisfactory explanation can as yet be given of the sudden appearance of the root rot disease in new fields. Reference has already been made to the fact that native susceptible weeds are found to die from Texas root rot in virgin and in timber lands. Nevertheless, there seems to be another factor of spread to be reckoned with. This factor is probably the fruiting stage of the causal organism which Duggar (5) has described and named *Phymatotrichum omnivorum*. This will be further considered under life history, page 72.

Heald (9) claims that root rot is spread from one field to another through fragments of fungus threads which are carried with soil particles by wind, or through the tools which are used during tillage, or through birds and working animals. The writers seriously question whether root rot ever spreads in that fashion. If this were true, the spots would naturally follow the direction of the plow and the cultivator. Furthermore, numerous secondary spots would appear in the same field in the summer as a result of infected particles of soil carried by implements, or wind. Field observations during the last six years tend to show that a given number of centers of infection appear in the same field early in the season and that these centers first originated where living susceptible roots carried the causal organism over winter. These then spread and increase in size rather than in number irrespective of direction in cultivation. Furthermore, numerous attempts of transferring soil from a freshly-infected plant to a healthy distant plant never reproduced the disease.

SPREAD OF ROOT ROT IN THE SAME FIELD.

We have observed time and again that the root rot spreads through direct contact in the soil of an infected cotton root of one plant with that of an adjoining healthy root of another. Texas root rot may also spread from an infected to a healthy cotton root through intermediary susceptible weed hosts, of which there are many. For this reason, it is conceivable why early-planted cotton is always more susceptible and the root rot spots are larger during favorable seasons than is actually the case in very late-planted cotton. The explanation apparently lies in the difference in root system. Late-planted cotton ordinarily escapes many of the beneficial rains, and as a result forms a smaller tap root and few and shorter laterals, which are not apt to meet so readily with the roots of neighboring plants. With early-planted cotton, on the other hand, the root system is well developed, producing not only a longer tap root, but also numerous well-developed laterals, which travel in every direction and which invariably meet and overlap the lateral roots of neighboring cotton plants. These observations, which were frequently verified by us through actual field studies of the root system, seem to strengthen our claim that Texas root rot spreads by means of underground contact of the roots. This is also substantiated by Toumey (30), who has observed that with alfalfa the disease spreads by contact of the infected roots of one plant with those of a neighboring healthy plant. The same is especially true with the okra, the castor bean, and many other susceptible hosts which possess a well-developed system of lateral roots. This is especially apparent in such susceptible crops which naturally require close sowing or planting such as beets, carrots, or alfalfa and sweet clover. In such cases, the root rot spots seem to enlarge much faster in a given time than seems the case with the cotton, which has a more restricted root system and which requires more space between the rows. Further evidence of the method of underground spread of Texas root rot by means of root contact is hardly warranted. If this were not the case, we should find hundreds of plants dying all at once in a given spot. This, however, is the exception. During active spread of the disease, it is seen that freshly-infected plants are invariably found to follow those which border on those which have died a day or two before. In a so-called root rot spot, the freshly-infected plants are always found on the outer edge and within the immediate neighborhood of a dead plant or plants within.

SHAPE OF ROOT ROT SPOTS.

It is generally believed that Texas root rot spots are always circular and for this reason the disease is mistaken for alkali spots. It is not uncommon to find the spots to take on every conceivable shape or form. A case under observation is that of a cotton field in Bell County in which the root rot spot took on the shape of a large crescent with apparently no other dead spots in the field. No attempt has been made to ascertain whether this condition was purely accidental. Root rot spots are more or less circular in vigorous cotton which possesses a well-developed system of laterals which penetrate deeply in the soil, thus escaping destruction by cultivators. This condition is especially true with the okra, the castor bean, and other such susceptible crops which are deep rooted. On the other hand, with shallow-rooted plants, chief of which may be mentioned the cowpea, root rot spots lose all their circular outline, and the disease is frequently confined to the length of each row. In this case, the seed are planted quite closely in the row, a circumstance that causes very close contact and interlapping of the root system. Here, then, the disease may frequently follow the entire length of the rows. Likewise, Texas root rot seldom appears in spots in closely-planted crops such as carrots and beets, where there is practically direct contact in the roots, but attacks an entire row or more.

HOW THE TEXAS ROOT ROT DIFFERS FROM OTHER COTTON DISEASES.

Cotton is subject to three other diseases for which Texas root rot may often be mistaken, namely: alkali injury, lightning injury, and Fusarium wilt.

Alkali Injury. The reason Texas root rot is frequently mistaken for alkali injury is that the latter trouble always appears in spots. Dr. G. S. Fraps, Chief Chemist of the Texas Agricultural Experiment Station, in a recent press bulletin, says that alkali spots are common in many parts of the State. These spots have no connection with the Texas root rot disease. A case of alkali spot was reported from Hill County. Four years ago the spot barely covered a few square feet, and now it occupies four acres. Such spots contain an excess of various salts, including ordinary table salt. In alkali spots, cotton will barely sprout, corn will not grow, and even ordinary weeds will straggle along with great difficulty. On the other hand, in typical root rot spots, corn as well as every other grain or cereal crop will grow perfectly. Furthermore, in these same spots, cotton plants will germinate and grow normally until bearing, when they will usually succumb in greatest number to the root rot disease. Likewise, in these spots the alkali present, if any, is in such small quantities as to be practically harmless. This is shown in Table 22.

Lightning Injury. So far, the writers have not seen or observed dead spots on cotton which were induced by lightning. Elliot (6), on the other hand, states that during seasons of frequent thunder storms, this source of injury is common in Arkansas. The injured spots are circular, with the first dead plants appearing in the center. Affected plants do not always die at once, but frequently linger in a wilted state for several weeks. Such spots according to Elliot (6) are frequently mistaken for Texas root rot spots. Plants which die early from lightning injury show no peculiar symptoms. However, those which succumb later exhibit an injured area at the surface of the soil, above which the stem of the plant has enlarged and below which, although the root may still be alive, there has been no growth; these are the marks that distinguish it from Texas root rot injury, the symptoms of which are given on page 13.

Wilt. This disease is mostly confined to the sandy soils and sandy loams in Texas as contrasted to the Texas root rot disease, which is mostly found in the black, waxy, and compact soils. Wilt is caused by a fungus, *Fusarium vasinfectum* Atk., which lives in the soil and infects the plants through the young rootlets and penetrates the main root, stem, petioles, and even leaves. The causal organism invades the interior fibrovascular or water-carrying vessels of the plant, cutting off the water supply from the soil and causing a sudden wilting of the foliage, a frequent reviving over night or during rainy weather, and a gradual slow dying of the entire plant. The diseased leaves drop off at the least touch, leaving a bare stalk, which may remain green a long time, and even send out new sprouts. Outwardly, there are no visible symptoms of this disease except the wilting, which is very pronounced in dry weather. However, when one splits open lengthwise the roots and stem of an affected plant, the interior woody portions of both roots and stems are found to be darkened, a condition indicating the presence of the causal organism. This, then, distinguishes the Fusarium wilt from Texas root rot; the latter attacks the roots only, and never any parts of the plant above ground. Furthermore, the Fusarium wilt fungus lives over winter in the soil and on dead remnants of the cotton plants, which is not the case with the causal organism of Texas root rot.

HOSTS AFFECTED.

In studying the life history of any plant parasite, one must determine its range of host. This is equally important from a practical point of view when we consider methods of control.

In order to definitely determine the range of hosts which were susceptible or resistant to Texas root rot, our attention was given to growing and testing out as many of the economic crops as we could obtain through limited funds. Many of the ornamentals were secured through the cooperation of the United States Department of Agriculture. The tests on forest and shade trees were carried out in cooperation with the State Forester, Mr. E. O. Siecke, who was kind enough to furnish the material. Most of the tests reported in Table 3 are based on five years' studies and observations beginning with 1917 and continuing and including the season of 1922. The degree of susceptibility or resistance as indicated in Table 3 is expressed in letters. *A* denotes complete resistance; *B,* fifteen per cent. susceptible; *C,* fifteen to thirty per cent. susceptible; *D,* thirty to sixty per cent. susceptible; *E,* sixty to ninety per cent. susceptible; *F,* ninety to one hundred per cent. susceptible. It should be added that this scale is only relative and is intended merely as a guide. These trials, before furnishing an absolute guide, should be carried on during a period of several more years, and cover larger percentages. It is, of course, probable, that after several more years of study and observations, some of the hosts indicated as resistant may prove to be slightly susceptible or very susceptible. In this case, our present conception of their susceptibility or apparent resistance may have to be modified when these hosts are tested for a longer period of time. This is especially true with trees and shrubs. In this connection it will not be out of place to cite an illustration with the peach. For twelve years a number of peach trees grew in an orchard at Substation No. 5 at Temple, Texas. In this same orchard, we grew for the last seven years cotton, which every year died from Texas root rot, whereas the peach trees there remained healthy. Early in the summer of 1922, four peach trees suddenly turned pale, the fruit failing to develop, the foliage shedding prematurely, and by the end of the season the trees were dead. Two were dug out, and a close examination with the naked eye and under the microscope revealed the presence of *Phymatotrichum omnivorum*, and another coarse yellow sterile fungus on the dead roots. The question arises as to which of these fungi killed the peach trees. From this it is evident that it is necessary to grow trees and shrubs for a large number of years in sick land before we can definitely classify them as to resistance to Texas root rot.

Table 3. Relative resistance or susceptibility of various hosts to Texas root rot.

Common name	Scientific name	Relative resistance or susceptibility
Family Aceraceae.		
Box Elder	*Acer negundo*	C
Maple (sugar)	*Acer saccharinum*	D
Maple (Chinese)	*Acer saccharinum chinensis*	C
Family Amarantaceae.		
Amaranth	*Amaranthus tricolor*	A
Alternanthera	*Alternanthera spp*	A
Coxcomb	*Celosia cristata*	A
Pigweed, tall	*Amaranthus retroflexus*	A
Pigweed, Red Root	*Amaranthus hybridus*	A
Spiny Amaranth	*Amaranthus spinosus*	A
Family Amaryllidaceae.		
Daffodil	*Narcissus bulbocodium*	A
Tuberose	*Polianthes tuberosa*	A
Family Ambrosiaceae.		
Cocklebur	*Xanthium commune*	D
Cocklebur	*Xanthium strumarium*	C
Ragweed	*Ambrosia artemisiaefolia*	C
Family Ampelideae.		
Grape	*Vitis vinifera*	C
Family Anacardiaceae.		
Pistache, Chinese	*Pistache chinensis*	D
Family Apocynaceae.		
Oleander	*Nerium lauriforme*	A
Periwinkle	*Vinca minor*	A
Family Araceae.		
Dasheen	*Colocasia spp*	A
Family Araliaceae.		
Sarsaparilla vine	*Aralia nudicaulis*	B
Family Asclepiadaceae.		
Milkweed	*Asclepias speciosa*	A
Family Begoniaceae.		
Catalpa	*Catalpa speciosa*	C
Family Cactaceae.		
Cactus, all varieties	*Opuntia spp*	A
Family Cannaceae.		
Canna, edible	*Canna edulis*	A
Canna, ornamental	*Canna spp*	A
Family Caprifoliaceae.		
Elder Berry	*Sambucus canadensis*	B
Honeysuckle	*Lonicera spp*	A

Table 3. Relative resistance or susceptibility of various hosts to Texas root rot —Continued.

Common name	Scientific name	Relative resistance or susceptibility
Family Caryophyllaceae.		
Carnation	*Dianthus caryophyllus*	A
Chickweed	*Cerastium vulgatum*	A
Pink	*Dianthus spp*	A
Family Chenopodiaceae.		
Beets, all varieties	*Beta vulgaris*	C to D
Lamb's Quarter	*Chenopodium album*	C
Russian Thistle	*Salsola pestiveri*	A
Spinach	*Spinacia oleracea*	C to D
Swiss Chard	*Beta sp*	D
Family Cichoriaceae.		
Prickly Lettuce	*Lactuca scariola*	D
Sow Thistle	*Sonchus asper*	B
Family Compositae.		
Artichoke, Jerusalem	*Helianthus tuberosus*	C
Artichoke, Globe	*Cynara scolymus*	C
Cosmos	*Cosmos spp*	A
Daisy, Shasta		A
Lettuce, Big Boston	*Lactuca sativa*	B
Lettuce, Prize Head	*Lactuca sativa*	B
Rosin Weed	*Grindelia squarrosa*	A
Salsify	*Tragopogon porrifolius*	D
Sunflower, Russian	*Helianthus annuus*	D
Sunflower, Wild	*Helianthus petiolaris*	C
Thistle, Canada	*Carduus arvensis*	A
Thistle, Common	*Carduus lanceolatus*	A
Family Coniferae.		
Arbor vitae	*Thuja orientalis*	A to B
Cypress, Smooth	*Cupressus glabra*	C
Pine	*Pinus spp*	C
Pine, Chinese	*Pinus chinensis*	C
Family Convulvulaceae.		
Cypress vine	*Ipomoea quamoclit*	A
Ivy-leaved Morning Glory	*Ipomoea hederacea*	C
Moonflower	*Ipomoea grandiflora alba*	A
Small-flowered pink Morning Glory	*Ipomoea trichocarpa*	B to C
Sweet Potato	*Ipomoea batatas*	E
Family Cornaceae.		
Dogwood	*Cornus Florida*	C
Family Cruciferae.		
Alyssum, Sweet	*Alyssum odoratum*	A
Broccoli, Early Large White	*Brassica sp*	B
Brussels Sprouts, Improved Long Island	*Brassica sp*	B
Cabbage	*Brassica oleracea*	B
Cauliflower	*Brassica oleracea, var. Botrytis*	B
Collard, Georgia or Southern Creole	*Brassica sp*	B
Horseradish		D
Kale	*Brassica oleracea*, var. *Acephala*	B
Kohl Rabi	*Brassica oleracea*, var *Caulo-Rapa*	B
Mustard, Southern Giant, Curled	*Brassica Japonica*	B
Mustard, Chinese	*Brassica Juncea*	B
Nasturtium, Tall	*Tropaeolum majus*	A
Nasturtium, Dwarf	*Tropaeolum minus*	A
Radish	*Raphnus sativus*	B
Rape, Dwarf Essex	*Brassica napus*	B
Stock	*Matthiola incana*	A
Turnip, all varieties	*Brassica rapa*	B
Watercress	*Roripa nasturtium*	A
Family Cucurbitaceae.		
Citron	*Citrullus sp*	A
Cucumber, Small Gherkin	*Cucumis anguria*	A
Cucumber, Klondike	*Cucumis sativus*	A
Cassaba, Honey Dew Melon	*Cucumis melo*	A
Muskmelon, Texas Cannonball	*Cucumis melo*	A
Muskmelon, Burrell's Gem	*Cucumis melo*	A
Muskmelon, Rockyford	*Cucumis melo*	A
Pumpkin, Mammoth King	*Cucurbita pepo*	A
Pumpkin, Green Striped Cushaw	*Cucurbita pepo*	A

Table 3. Relative resistance or susceptibility of various hosts to Texas root rot —Continued.

Common name	Scientific name	Relative resistance or susceptibility
Family Cucurbitaceae—Continued.		
Pumpkin, Big Four	*Cucurbita pepo*	A
Squash, Giant Summer Crookneck	*Cucurbita pepo*	A
Squash, Patty Pan	*Cucurbita pepo*	A
Watermelon, all varieties	*Citrullus vulgaris*	A
Family Cupuliferae.		
Chestnut, American Sweet	*Castanea sativa*	C
Oak, Scrub	*Quercus, sp*	B
Oak, Bur	*Quercus macrocarpa*	B
Oak, Water	*Quercus nigra*	A
Oak, Live	*Quercus virginiana*	A
Oak, Post	*Quercus minor*	B
Family Cyperaceae.		
Chufas or Earth Almond	*Cyperus esculentis*	A
Nut Grass	*Cyperus spp*	A
Sedges	*Carex spp*	A
Family Dioscorea.		
Yam, Tropical	*Dioscorea sp*	E
Yam, Tropical	*Dioscorea sp*	D
Family Ebenaceae.		
Persimmon, Native	*Diospyros virginiana*	C
Persimmon, Japanese	*Diospyros Kaki*	C
Family Euphorbiaceae.		
Castor Bean	*Ricinus communis*	D
Castor Bean, Ornamental	*Ricinus, spp*	D
Snow-on-the-mountain	*Euphorbia marginata*	A
Spurge, Flowering	*Euphorbia corollata*	A
Spurge, Spotted	*Euphorbia cyparissias*	A
Tallow Tree	*Sapium sebriferum*	D
Wood, Oil Tree, Chinese	*Aleurites fordii*	D
Family Geraniceae.		
Geranium	*Geranium spp*	A
Geranium, Wild	*Geranium carolianum*	A
Family Ginkgoaceae.		
Ginkgo Tree, Japanese	*Ginko bialoba*	D
Family Graminae.		
Barley	*Hordeum sativum*	A
Broom Sedge	*Andropogon virginicus*	A
Cheat or Chess	*Bromus secalinus*	A
Corn, all varieties	*Zea Mays*	A
Corn, Broom	*Andropogon sorghum* var. *technicus*	A
Durra	*Andropogon sorghum*	A
Emmer	*Triticum sativum* var. *dicoccum*	A
Grass, Barnyard	*Echinochloa crusgalli*	A
Grass, Bermuda	*Capriola dactylon*	A
Grass, Broom	*Bromus enermis*	A
Grass, Crab	*Digitaria sanguinalis*	A
Grass, Fescue	*Festuca elatior*	A
Grass, Foxtail	*Setaria viridis*	A
Grass, Johnson	*Sorghum halepense*	A
Grass, Pigeon	*Setaria glauca*	A
Grass, Mesquite	*Hilaria penchroidea*	A
Grass, Rhodes	*Chloris gayana*	A
Grass, Sudan	*Andropogon sorghum* var. *sudanensis*	A
Grass, Wire	*Paspalum distichum*	A
Grass, Witch	*Panicum capillare*	A
Kaoliang	*Andropogon sorghum*	A
Kafir	*Andropogon sorghum*	A
Millet	*Chaetochloa italica*	A
Milo	*Andropogon sorghum*	A
Oats, cultivated	*Avena sativa*	A
Rye	*Secale cereale*	A
Rice	*Oryza sativa*	A
Sand-bur	*Cenchrus tribuloides*	A
Shallu	*Andropogon sorghum*	A
Sorghum	*Andropogon sorghum*	A
Sorgo	*Andropogon sorghum*	A
Spelt	*Triticum sativum* var. *spelta*	A
Sugar Cane	*Saccharum officinarum*	A
Wheat	*Triticum vulgare*	A
Wild Oat	*Avena fatua*	A

Table 3. Relative resistance or susceptibility of various hosts to Texas root rot —Continued.

Common name	Scientific name	Relative resistance or susceptibility
Family Grossulariaceae.		
Currant	*Ribes rubrum*	A
Gooseberry	*Ribes grossularia*	B
Family Hamamelidaceae.		
Gum	*Liquidambar styraciflua*	D
Gum, Formosa	*Liquidambar formosa*	D
Family Iridaceae.		
Crocus	*Crocus spp*	A
Gladiolus	*Gladiolus spp*	A
Iris	*Iris spp*	A (?)
Family Juglandaceae.		
Pecan	*Hicoria pecan*	A
Walnut, Black	*Juglans nigra*	E
Walnut, Japan	*Juglans sieboldii*	C
Family Labiatae.		
Basil, Sweet	*Ocimum basilicum*	A
Catnip	*Nepeta cataria*	A
Mint	*Mentha spicata*	A
Sage	*Salvia officinalis*	A
Savory, Summer	*Satureia hortensis*	A
Family Leguminosae.		
Acacia	*Acacia nerifolia*	E
Alfalfa	*Medicago sativa*	D
Alfalfa, German	*Medicago sp*	B
Bean, all garden varieties	*Phaseolus vulgaris*	C to D
Bean, Frijole	*Phaseolus sp*	D
Bean, Jack	*Dolichos lablab*	C
Bean, Japanese Sword	*Canavalia gladiata*	B
Bean, Mexican Pinto	*Phaseolus sp*	E
Bean, Mung	*Phaseolus radiatus*	B
Bean, Tepary	*Phaseolus latifolius*	C
Bean, Velvet, var. Osceola	*Stizolabium sp*	A
Bean, Velvet, var. Speckled	*Stizolabium sp*	B
Bean, Velvet, var. Bush	*Stizolabium sp*	B
Bean, Velvet, var. 100 Day	*Stizolabium sp*	B
Bean, Velvet, var. Extra Early	*Stizolabium sp*	B
Bean, Velvet, var. Bunch	*Stizolabium sp*	B
Cowpea	*Vigna sinensis*	D
Clover, Black Medic	*Medicago lupulina*	C
Clover, Yellow Sweet	*Melilotus officinalis*	C
Clover, Sweet White	*Melilotus alba*	C
Clover, Burr	*Medicago obicularis*	B
Guar	*Cyamopsis tetragonoloba*	A to B
Locust, Black	*Robinia pseudoacacia*	B
Locust, Honey	*Gleditsia triacanthos*	B
Pagoda Tree, Japanese	*Sophora Japonica*	E
Partridge Pea	*Casia chamaecrista*	C
Pea, Garden	*Pisum sativa*	A to B
Peanut	*Arachis hypogea*	B to C
Soybean, Ito San	*Glycine hispida*	E
Soybean, Duggar	*Glycine hispida*	E
Soybean, Japanese Black	*Glycine hispida*	E
Vetch	*Vicia spp*	A
Sweet Pea	*Lathyrus odoratus*	A to B
Wild Vetch	*Vicia angustifolia*	C
Family Liliaceae.		
Asparagus, Early Argentueil	*Asparagus officinalis*	A
Asparagus, Palmeto	*Asparagus officinalis*	A
Garlic, all varieties	*Allium sp*	A
Garlic, Wild	*Allium canadense*	A
Hyacinth	*Hyacinthus orientalis*	A
Leek	*Allium sp*	A
Lily	*Lilium longiflorum*	A
Lily, Calla	*Araceae spp*	A
Onion, Red Creole	*Allium sp*	A
Onion, Silverskin	*Allium sp*	A
Onion, Denver's Yellow	*Allium sp*	A
Onion, Crystal Wax	*Allium sp*	A
Onion, Shallot Evergreen	*Allium sp*	A
Onion, Egyptian, Winter	*Allium sp*	A
Onion, Wild	*Allium vinale*	A
Tulip	*Tulipa spp*	A
Yucca	*Yucca filamentosa*	A

Table 3. Relative resistance or susceptibility of various hosts to Texas root rot —Continued.

Common name	Scientific name	Relative resistance or susceptibility
Family Magnoliaceae.		
Magnolia	*Magnolia grandiflora*	A
Tulip Tree	*Liriodendron tulipefera*	B
Family Malvaceae.		
Althea	*Hibiscus syriacus*	C
Bladder Ketmia	*Hibiscus trionum*	B
Cotton	*Gossypium spp*	D
Hollyhock	*Althea rosea*	B
Mallow, High	*Malva sylvestris*	D
Mallow, Low	*Malva rotundifolia*	D
Okra, White Velvet	*Hibiscus esculentis*	D
Okra, Dwarf Green	*Hibiscus esculentis*	D
Sida	*Sida hederacea*	C
Sida	*Sida spinosa*	C
Star Mallow	*Malvastrum coccinum*	B
Velvet Leaf	*Abutilon avicennae*	B
Family Meliaceae.		
China Berry Tree	*Melia azedarach*	C
Family Moraceae.		
Fig	*Ficus carica*	D
Mulberry	*Morus tartarica*	D
Osage Orange	*Toxylan pomiferum*	A
Family Myctaginaceae.		
Four-O'Clock	*Mirabilis Jalapa*	A
Family Myriaceae.		
Crape Myrtle	*Myrica cerifera*	A
Family Myrtaceae.		
Pomegranate	*Pumica granatum*	A
Family Oleaceae.		
Ash, American White	*Fraxinus americana*	D
Ash, Green	*Fraxinus lanceolata*	B
Privet	*Ligustrum spp*	D
Family Oxalidaceae.		
Oxalis	*Oxalis bowiei*	A
Sorrel, Wood	*Oxalis violacea*	A
Sorrel, Sheep	*Rumex acetosella*	A
Family Polemoniaceae.		
Phlox	*Phlox drummondii*	A
Family Polygonaceae.		
Rhubarb	*Rheum officinale*	E
Family Primulaceae.		
Primrose	*Primula vulgaris*	A
Family Ranunculaceae.		
Larkspur	*Delphinium, sp*	A
Family Rhamnaceae.		
Jujube, T. S. 5095	*Zizyphus sativa*	C
Jujube, T. S. 36854	*Zizyphus sativa*	C
Jujube, T. S. 38245	*Zizyphus sativa*	C
Jujube, T. S. 22686	*Zizyphus sativa*	D
Jujube, T. S. 38249	*Zizyphus sativa*	D
Family Rosaceae.		
Apple	*Pyrus malus*	D
Blackberry, Dallas	*Rubus sp*	A
Dewberry, Austin Mays	*Rubus sp*	A
Dewberry, Louisiana	*Rubus sp*	A
Dewberry, Haupt	*Rubus, sp*	A
Peach	*Prunus persica*	B
Pear	*Pyrus communis*	E
Raspberry, Cordial	*Rubus strigosus*	D
Rose	*Rosa spp*	C
Spiraea	*Spiraea spp*	B
Strawberry, Lady Thomson	*Fragaria chiloensis*	A
Strawberry, Aroma	*Fragaria chiloensis*	A
Strawberry, Klondike	*Fragaria chiloensis*	A

Table 3. Relative resistance or susceptibility of various hosts to Texas root rot —Continued.

Common name	Scientific name	Relative resistance or susceptibility
amily Rubuceae.		
Cape Jasmine	*Gardenia veitchii*	A
amily Salicaceae.		
Poplar, Carolina	*Populus eugenia*	D
Poplar, Lombardy	*Populus nigraitalica*	D
Poplar, Norwegian	*Populus sp*	C
Willow	*Salix nigra*	B
amily Sapindaceae.		
Balloon Vine	*Cardiospermum halicacabum*	A
amily Scrophulariaceae.		
Snapdragon	*Antirrhinum majus*	A
amily Solanaceae.		
Buffalo-Bur	*Solanum rostratum*	A
Bull Nettle	*Solanum elaeangifolium*	A
Eggplant, Spineless	*Solanum melongena*	C
Pepper, Bull Nose	*Capsicum annum*	C
Pepper, Pimento	*Capsicum annum*	C
Pepper, Chinese Giant	*Capsicum annum*	C
Pepper, Ruby King	*Capsicum annum*	C
Pepper, Long Red Cayenne	*Capsicum annum*	C
Petunia	*Petunia sp*	A
Potato (Irish) all varieties)	*Solanum tuberosum*	A
Tobacco	*Nicotiana tabacum*	A
Tomato	*Lycopersicum esculentum*	B
amily Sterculiaceae.		
Varnish Tree, Chinese	*Sterculia platanifolia*	D
amily Tamaricaceae.		
Tamarisk, Common	*Tamarix gallica*	C
amily Ulmaceae.		
Elm, Cork	*Ulmus racemosa*	D
Elm, Native	*Ulmus virginiana*	A
Elm, American White	*Ulmus Americana*	B
Hackberry	*Celtis occidentalis*	A
Hackberry, Chinese	*Celtis chinensis*	A
amily Umbelliferae.		
Anise	*Pimpinella anisum*	A
Carrot, all varieties	*Daucus carota*	D to E
Chervil	*Anthriscus cerefolium*	A
Dill	*Anethum graveolens*	A
Fennel, Italian	*Foeniculum vulgare*	A
Fennel, Sweet	*Foeniculum officinale*	A
Parsley, Plain	*Petroselinum hortense*	C to D
Parsley, Double Curled	*Petroselinum hortense*	D
Parsley, Curled	*Petroselinum hortense*	C to D
Parsnip, Imperial Hallow	*Pastinaca sativa*	D
amily Urticaceae.		
Hemp, Kymington	*Cannabis sativa*	D
amily Vaccinaceae.		
Cranberry, Small	*Vaccinium oxycoccus*	A
Cranberry, Large	*Vaccinium macrocarpon*	A
amily Valerianceae.		
Corn, Salad	*Valerianella olitaria*	A
amily Violaceae.		
Pansy	*Viola tricolar*	A
Violet	*Viola odorata*	A

IS THERE A DIFFERENCE IN RESISTANCE IN DIFFERENT VARIETIES?

It has already been shown in Table 3 that certain hosts seem to be resistant, while others are either slightly or entirely susceptible to the Texas root rot disease. During the course of this work, we felt it necessary to determine if possible whether or not there actually exists a definite resistance in different varieties of the same species and genus. Accordingly, tests were made with various field crops, chief of which were cotton, okra, and certain legumes. In referring to Table 4, one sees that of the cotton varieties tested during 1919, which was really a very favorable year for Texas root rot, it seems that there is probably a difference in resistance of some of the cotton varieties. This, however, cannot be stated with certainty unless these trials are repeated for a number of years, which, because of lack of funds and lack of sufficient land, we were forced to discontinue for the present at least. What is true of cotton seems also to apply to the legumes tested, as shown in Table 4.

Table 4. Susceptibility of some legume and cotton varieties—1919.

Host and name of variety	Total per cent root rot	Host and name of variety	Total per cent root rot
Cotton		Legumes	
Bank Account	43	Cowpea (Groit)	31
Matchless (extra early big boll)	37	Cowpea (Upright)	40
Broadwell's Double-jointed	40	Cowpea (Clay)	33
Allen's Express	46	Cowpea (Iron crossed with black-eyed pea)	37
Early King	30	Cowpea (Iron crossed with whip-poor-will)	34
Sure Crop	65	Cowpea (Red Ripper)	45
Hasting's Upright	55	Cowpea (Brabham)	45
Union Big Boll	55	Cowpea (Iron)	38
Belton-Rowden	55	Cowpea (New Era)	31
Belton-Rowden	80	Soy-bean (Ohio grown)	60
Rowden	60	Soy-bean (Ito San)	75
Cleveland	65	Soy-bean (Ebony)	90
Cook's Silk	70	Yokahoma Bean	18
Mebane	43	Velvet Bean	15
Mebane	40	Befri (Origin, British India)	22
Peterkin	38	Guar	1
Cleveland Big Boll	34	Peanuts (Tenn. Red)	23
Boykin	45	Peanuts (Spanish)	13
Cotton (Belton)	51	Peanuts (Valencia Improved)	16

As concerns the fruit trees, there seems to be no difference in susceptibility between various varieties. Trials made with five different varieties of pears and six varieties of apples seem to show that they are all equally susceptible and that fruit trees when planted usually begin to die the very first year they are put out. Dying becomes more pronounced as the years succeed each other and as the dead trees are replaced by healthy ones the following season. This is clearly indicated in Tables 5 and 6, which are self-explanatory and which show that wherever a pear or an apple tree dies from the Texas root rot disease no other pear or apple tree should follow in the same place until all living carriers are eliminated, as it will likely die either the same season in which it it put out, or after two or three years at the most.

Table 5. Susceptibility of pears to Texas root rot.

Name of variety	Plat and No. of tree	Year planted	Year killed	Year killed	Year killed	Year killed
Kieffer	1	1917	1919*	1920*	1921	....
Kieffer	2	1917	1919*	1920*	1921	....
Kieffer	3	1917	1919*	1920*	1921	....
Kieffer	4	1917	1919*	1920*	1921	....
Kieffer	5	1917*	1918*	1919*	1920*	1921
Kieffer	6	1917*	1918*	1919*	1920*	1921
Kieffer	7	1917*	1918*	1919*	1920*	1921
Kieffer	8	1917*	1918*	1919*	1920*	1921
Kieffer	9	1917	1919*	1920*	1921*	....
Kieffer	10	1917*	1919*	1920*	1921*	1921
Kieffer	11	1917*	1921	....	....	....
Kieffer	12	1917	1919*	1920*	1921	....
Kieffer	13	1917	1919*	1920*	1921	....
Kieffer	14	1917	1921	....	....	....
Kieffer	15	1917	1919*	1920*	1921	....
Kieffer	16	1917	1920*	1921	....	....
Kieffer	17	1917	1919*	1920*	1921	....
Kieffer	18	1917*	1919*	1920*	1921	....
Bartlett	1	1917	1919*	1920*	1921	....
Bartlett	2	1917	1918*	1921	....	....
Bartlett	3	1917	1918*	1919*	1920*	1921*
Bartlett	4	1917	1919*	1921	....	....
Seckel	1	1917	1918*	1919*	1920*	1921*
Seckel	2	1917	1920*	1921	....	....
Seckel	3	1917	1919*	1920*	1921	....
Seckel	4	1917	1921	....	....	....
Garber	1	1917	1918	1919*	1920*	1921
Garber	2	1917	1919*	1920*	1921	....
Garber	3	1917	1918*	1919*	1920*	1921
Garber	4	1917	1918*	1919*	1920*	1921
Duchess	1	1917	1918*	1919*	1920*	1921*
Duchess	2	1917	1919*	1920*	1921	....
Duchess	3	1917	1919*	1920*	1921	....
Duchess	4	1917	1919*	1920*	....	....

*Trees died that year and were replaced by the same variety the following spring.

Table 6. Susceptibility of apples to Texas root rot.

Name of variety	Plat and No. of tree	Year planted	Year killed	Year killed	Year killed	Year killed
Arkansas Black	1	1917	1918*	1919*	1920*	1921
Arkansas Black	2	1917	1918*	1919*	1920*	1921
Arkansas Black	3	1917	1918*	1919*	1920*	1921
Arkansas Black	4	1917	1918*	1919*	1920*	1921
Arkansas Black	5	1917	1919*	1920*	1921	....
Arkansas Black	6	1917	1919*	1920*	1921	....
Ben Davis	1	1917	1919*	1920*	1921	....
Ben Davis	2	1917	1921	....	....	....
Ben Davis	3	1917	1918*	1919*	1920*	1921
Ben Davis	4	1917	1919*	1920*	1921	....
Ben Davis	5	1917	1919*	1920*	1921	....
Ben Davis	6	1917	1918*	1919*	1920*	1921
Summer Queen	1	1917	1918*	1919*	1920*	1921
Summer Queen	2	1917	1919*	1920*	1921	....
Summer Queen	3	1917	1918*	1919*	1920*	1921
Summer Queen	4	1917	1918	1919*	1920*	1921
Summer Queen	5	1917	1919	1920*	1921	....
Summer Queen	6	1917	1921	....	....	....
Kinard Choice	1	1917	1919*	1920*	1921	....
Kinard Choice	2	1917	1919*	1920*	1921	....
Kinard Choice	3	1917	1919*	1920*	1921	....
Kinard Choice	4	1917	1918*	1919	1920*	1921
Kinard Choice	5	1917	1918*	1919	1920	1921
Kinard Choice	6	1917	1918*	1919*	1920*	....
Red June	1	1917	1919*	1920*	1921	1921
Red June	2	1917	1918*	1919*	1920*	1921
Red June	3	1917	1919*	1920*	1921	....
Red June	4	1917	1918*	1919*	1920*	1921
Red June	5	1917	1918*	1919*	1920*	1921
Red June	6	1917	1919*	1920*	1921	....
Yellow Transparent	1	1917	1919*	1920*	1921	....
Yellow Transparent	2	1917	1918*	1919*	1921	....
Yellow Transparent	3	1917	1919*	1920*	1921	....
Yellow Transparent	4	1917	1918*	1919*	1920*	1921
Yellow Transparent	5	1917	1919*	1920*	1921	....
Yellow Transparent	6	1917	1920*	1921	....	....

*Trees died that year and were replaced by the same variety the following spring.

It should be added that where the pear and apple varieties were planted as indicated in Tables 5 and 6, cotton was grown between the trees for a number of years in succession, and each year the cotton in the same orchard died from the Texas root rot. Furthermore, none of the living cotton roots were pulled out, but were allowed to remain in the soil during the winter; thus the Texas root rot fungus had a chance to pass over winter on those cotton roots which escaped summer infection and which remained alive during the winter months. Likewise, no attempt was made to kill out the roots of the small-flowered pink morning glory (*Ipomoea trichocarpa*). From these roots evidently the Texas root rot fungus passed over to the roots of the pear and apple trees.

ARE THERE ANY RESISTANT STRAINS?

Cotton growers are well aware of the fact that where the Texas root rot disease is very prevalent in any one cotton field the disease usually works in more or less definite spots, sometimes killing every plant within the infected area. At other times, however, there are healthy plants standing up here and there in close proximity to plants that have died of infection. Frequently it is seen that when several cotton plants grow together in the same hill one may remain alive while all the others near or next to it will die from the Texas root rot disease. It, therefore, occurred to the writers that there might possibly be a certain inherent resistance in those individual cotton plants which seem to stand up while others succumb. Accordingly, a large quantity of seed from individual cotton plants apparently resistant was selected and planted in a field known to be badly infected with the Texas root rot disease. Side by side with that, seeds from unselected plants were planted in the same field as checks for comparison. These tests were carried on for a period of four years with the result, apparently, that the plants from the selected strains were no more resistant than those that came from the check or unselected plants. On the other hand, the amount of root rot in both selected and resistant strains seemed to have been determined primarily by the amount of rainfull during the season. This is clearly shown in Table 7, which indicates that during 1918, which was a dry year, there was practically no root rot present in either of the strains of cotton whether coming from seeds of healthy but non-selected plants, or those coming from seeds of plants killed by root rot, or those which were selected for apparent resistance. Likewise, during 1919, which was a very wet summer, the amount of root rot depended primarily upon the rainfall, and upon the incidental appearance of root rot spots where the selected and unselected cotton seed were planted.

From Table 7, it seems evident that it is apparently useless to try to select a cotton which is altogether immune to the disease. However, inasmuch as there seems to be certain cotton plants or strains which do stand up and escape root rot infection during the summer months, it becomes therefore apparent that it may be possible to select such strains as are able to withstand the disease the longest time during the season. In other words, those strains which become infected very late in the season may be those worthy of promise, in the sense that cotton strains may be developed through selection that would take the root rot very late, in which case the crop would practically mature and be unhurt by the disease.

Table 7. Susceptibility of selected cotton strains.

Source of seed for planting	Year	Total per cent. root rot Sept. 25.
Belton cotton—healthy plants	1918	None
Belton cotton—killed by root rot	1918	None
Belton cotton—apparently resistant	1918	None
Mebane cotton—healthy plants	1918	None
Mebane cotton—plants killed by root rot	1918	None
Mebane cotton—apparently resistant	1918	None
Rowden cotton—healthy plants	1918	None
Rowden cotton—plants killed by root rot	1919	None
Rowden cotton—apparently resistant	1918	None
Belton cotton—healthy plants	1919	80
Belton cotton—killed by root rot	1919	37
Belton cotton—apparently resistant	1919	33
Belton cotton—apparently resistant	1919	60
Belton cotton—healthy plants	1919	20
Mebane cotton—healthy plants	1919	24
Mebane cotton—plants killed by root rot	1919	43
Mebane cotton—apparently resistant	1919	17

DOES A SUSCEPTIBLE CROP ONE YEAR INFLUENCE THE AMOUNT OF ROOT ROT IN ANOTHER SUSCEPTIBLE CROP THE NEXT YEAR?

It has been observed repeatedly that year in and year out certain crops seem to be more susceptible to the Texas root rot disease than others. For instance, sweet potatoes when grown in infected land will yield a larger percentage of diseased hills than a similar field planted to cotton. The reason, it seems, is probably the fact that when plants of a certain crop are grown close together in the same hill, as is the case with the sweet potato, carrots, and beets, which are planted close in the row, they are more susceptible to root rot than plants which require more spacing. With this in mind, it was desirable to determine what would be the effect of planting cotton, for instance, following a very susceptible crop like the sweet potato. Although this test was carried out during 1917 and 1918, both very dry years, in which cotton root rot was very limited, it was nevertheless found that a very susceptible crop like the sweet potato decidedly increased the root rot in cotton when the latter followed the sweet potatoes, but that was apparently not the case when sweet potatoes followed cotton. This is well shown in Table 8, which is self-explanatory. From this table it is seen that the sweet potato in 1917 in the trial plat showed a total of 41 per cent. infection from root rot. In 1918, when cotton followed in place occupied by sweet potatoes in 1917, the total per cent. of root rot was 52 as compared to 22 per cent. for the cotton check in 1917, and 5 per cent. for the cotton check in 1918. Likewise, when cotton was grown in an experimental plat in 1917, the total per cent. of root rot that year was only 14. When this same place was occupied by sweet potatoes in 1918, the total per cent. of root rot that year was 14, indicating that there was no increase of root rot in sweet potatoes due to the cotton previously grown in the same plat. While the figures in Table 8 are at best only indicative, they seem to have a practical application. The up-to-date cotton grower will take every precaution to prevent planting his cotton after those crops which are known to be highly susceptible to root rot. Of such crops may be mentioned the sweet potato, alfalfa, or sweet clover, which are excellent carriers of the Texas root rot during the winter months.

Table 8. Effect of root rot from one susceptible crop one year on another susceptible crop the following year.

Host	Year	Date counted, per cent root rot						Total per cent root rot
		June 25, 1917	July 10, 1917	July 30, 1917	Aug. 15 1917	Sept. 10, 1917	Oct. 1, 1917	
Sweet potato........ (Nancy Hall)	1917	None	3	6	7	12	13	41
		June 25, 1918	July 10, 1918	July 30, 1918	Aug. 15, 1918	Sept. 10, 1918	Oct. 1, 1918	
Cotton (Belton).....	1918	2	5	8	10	12	15	52
		June 25, 1917	July 10, 1917	July 30, 1917	Aug. 15, 1917	Sept. 10, 1917	Oct. 1, 1917	
Cotton (Check)..... (Belton)	1917	None	None	1	4	8	9	22
		June 25, 1918	July 10, 1918	July 30, 1918	Aug. 15, 1918	Sept. 10, 1918	Oct. 1, 1918	
Cotton (Check)..... (Belton)	1918	None	None	None	1	2	2	5
		June 25, 1917	July 10, 1917	July 30, 1917	Aug. 15, 1917	Sept. 10, 1917	Oct. 1, 1917	
Cotton (Belton)....	1917	None	None	1	2	5	6	14
		June 25, 1918	July 10, 1918	July 30, 1918	Aug. 15, 1918	Sept. 10, 1918	Oct. 1, 1918	
Sweet potato....... (Nancy Hall)	1918	1	1	5	3	2	2	14

CONDITIONS FAVORING OR RESTRICTING THE SPREAD OF TEXAS ROOT ROT.

From a practical consideration it is necessary that we have information on the conditions which favor the spread or restriction of the Texas root rot disease. Various observations and studies were made in order to determine more or less definitely what these conditions were. These studies were made on cotton and also on a small scale on the okra. Whether the same results would apply to other crops, especially trees, as they are subject to the Texas root rot disease, is as yet difficult to foretell.

Effect of Climate on Texas Root Rot. Climatic conditions are important factors in restricting or increasing the spread of the Texas root rot disease. Other things being equal, the disease is more prevalent in some years than in others. This prevalence or absence seems to a great extent determined not only by soil conditions, but also to a large extent by climatic conditions during the summer season and by the number of winter carriers permitted to live over in the soil. Repeated observations and statements by progressive farmers have indicated that the damage from the Texas root rot disease, other things being equal, is far more serious during wet than during dry seasons (see Tables 9, 10, and 12). Percentages of root rot counts were made by the writers in several cotton and okra fields during a period of six years with the result that the average of these counts clearly indicates the greater preponderance of root rot during a wet summer over the dry one. This is shown in Table 9, which is a typical sample of wet years. During the dry season of 1918, the percentage of root rot with okra varied from one to three per cent., and in 1919, a wet season, the percentage of root rot varied from 66 to 83 per cent. What is true with okra also holds with cotton and other crops of a similar root system.

Table 9. Root rot as affected by seasonal differences.

Host	Year	Total per cent of root rot Sept. 30.
Okra (White Velvet)	1918	2
Okra (Perkin's Long Pod)	1918	1.5
Okra (Dwarf Green)	1918	3
Okra (Dwarf White)	1918	2
Okra (Kleckley's Favorite)	1918	1
Okra (White Velvet)	1919	66
Okra (Perkin's Perfect, Long Pod)	1919	82
Okra (Dwarf Green)	1919	75
Okra (Dwarf White)	1919	66
Okra (Kleckley's Favorite)	1919	79
Okra (Kleckley's Giant)	1919	83

Effect of Irrigation on Texas Root Rot. It has already been indicated in Table 9 that the Texas root rot disease is far more prevalent and more serious during a wet summer than during a dry one. Rains during June and July invariably bring out more root rot than if these two months were comparatively dry. This, then, seems to indicate that the presence of moisture during these months is an important factor in favoring a better root system and hence in insuring underground contact, which seems to favor the spread of the Texas root rot disease. In order to make more certain of this, experiments were carried out during several years with a view of determining the effect of irrigation in favoring or restricting Texas root rot during dry and wet summers. The irrigations were tried on okra and cotton, both of which are susceptible hosts. From one to four irrigations were given in order to determine whether frequent waterings will mean increased percentages of the disease. The results are indicated in Table 10. From this table it is seen that in 1918, which was a dry year, the okra check which had no irrigation showed a total of only 6 per cent. of Texas root rot that year and likewise the cotton check with no irrigation, a total of 2 per cent. of root rot. On the other hand, one irrigation increased the total percentage of root rot on okra to 15 per cent. and on cotton to 6 per cent. Three irrigations increased the total percentage of root rot in okra to 23 and in cotton to 25 per cent. Four irrigations increased the total percentage of root rot in okra to 49 and in cotton to 17, apparently, a decrease over the three irrigations in cotton. Nevertheless, it is very evident that during a dry year when moisture is artificially added to the soil, Texas root rot increases in proportion as the number of irrigations is increased. Similarly, in 1919, which was a wet year, the check plat of okra which received no irrigation gave a total percentage of 66⅔ per cent. of root rot, whereas one watering increased the total percentage of root rot to 83 per cent. This clearly indicates that even in a wet year when root rot is prevalent, the addition of more water in the form of irrigation will make it still more so. From these experiments it seems plainly established that moisture is one of the important factors in favoring the spread of Texas root rot.

Table 10. Effect of irrigation on root rot.

Host	Number and date of irrigations	Date counted, per cent root rot							Total per cent root rot
		Year	June 25, 1918	July 19, 1918	July 30, 1918	Aug. 15, 1918	Sept. 10, 1918	Oct. 10, 1918	
Okra (White Velvet)	No irrigation (Check)	1918	None	None	None	None	5	1	6
Cotton (Belton)	No irrigation (Check)	1918	None	None	None	None	None	2	2
Okra (White Velvet)	One Irrigation June 25	1918	None	5	8	None	1	1	15
Cotton (Belton)	One Irrigation June 25	1918	None	None	2	3	None	1	6
Okra (White Velvet)	Three irrigations—June 25, July 15, Aug. 5	1918	None	10	2	3	3	5	23
Cotton (Belton)	Three irrigations—June 25, July 15, Aug 5	1918	None	None	None	5	5	15	25
Okra (White Velvet)	Four irrigations—June 25, July 15, Aug. 5, Aug. 30	1918	None	10	15	15	5	4	49
Cotton (Belton)	Four irrigations—June 25, July 15, Aug. 5, Aug. 30	1918	None	None	2	5	5	5	17
Okra (Kleckley's Giant)	No irrigation (Check)	1919	None	None	None	31	None	35	66
Okra (Kleckley's Giant)	One irrigation	1919	None	1	22	22	None	38	83
Okra (Kleckley's Giant)	Two irrigations	1919	None	18	14	56	12	None	100
Okra (Kleckley's Giant)	Three irrigations	1919	None	None	10	30	20	40	100

Effect of Temperature on Texas Root Rot. That air temperature, and more especially the soil temperature, is an important factor in favoring infection by certain plant diseases, has been demonstrated by several workers. It became evident that it was necessary to determine the effect of both the air and the soil temperatures on the possible increase or decrease of the Texas root rot disease. Accordingly, soil thermometers measuring 1, 3, 6, 12, 24, 36, and 48 inches were installed at Substation No. 5, Temple, Texas. These thermometers (Fig. 15, b) were placed in the same field where most of the experimental work was carried out, and the readings taken three times a day. Likewise, and in addition to outdoor and soil temperatures, the daily and the monthly precipitations were also taken into consideration. The recording of the soil temperatures began in 1917 and was continued during 1918, 1919, 1920, 1921, 1922, and will be continued in the future as a soil temperature project. Since these data are to be published elsewhere, they will be referred to only indirectly. Because of limited space, we have compared and studied the soil temperatures and precipitation data of July, August, and September during the dry year of 1918, with similar months of the wet year of 1920. This was done for the purpose of tracing the relationship, if any, of soil temperatures to the prevalence or absence of Texas root rot. These studies are summarized in Table 11. Briefly stated, the temperatures for July, August, and September during a dry year such as 1918 at a soil depth of one to three inches were much hotter on the whole than the outdoor temperatures during the same dates in these three months. This is evidently due to the fact that the black waxy soils in Texas are capable of absorbing heat and holding it. On the other hand, as we go down deeper, the temperature decreases considerably, especially at the depths of 36 and 48 inches, but not enough to considerably cool the soil at these depths. In contrasting the data for a dry year in 1918 with those of a wet year in 1920 as shown in Table 11, one will see that the outdoor and the soil temperatures are lower in a wet season than is the case in a dry summer. This is no doubt due to the cooling effect of the rain. Furthermore, it has been observed repeatedly that infection in most cases first begins at the tip end of the root system and gradually works up to the laterals, where it spreads to adjacent roots which happen to touch those of infected plants. This, then, would seem to indicate that moisture and a temperature varying from 70 to 78 degrees, as it occurs at a depth of 24 to 36 inches during a wet year, is most favorable for infection. On the other hand, during a dry year the temperatures for 36 and 48 inches during July to September are 5 to 15 degrees higher, and this probably checks infection or retards the activity of the causal organism. This would perhaps seem to indicate that the deeper soil temperatures, together with moisture, are important factors in determining the severity of the disease each season. This, of course, is to be verified and duplicated on indoor soil temperature boxes in the greenhouse where moisture and temperatures are under control.

Table 11. Highest and lowest maximum and minimum soil temperatures for July, August and September during 1918 and 1920

Year	Month	Outdoor		1 inch		3 inches		6 inches		12 inches		24 inches		36 inches		48 inches		Precipitation in inches
		Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	
1918	July................	91 to 105	62 to 77	97 to 110	78 to 89	95 to 104	84 to 94	96 to 99	89 to 93	90 to 94	89 to 93	86 to 90	86 to 89	83 to 87	82 to 86	79 to 83	79 to 83	0
1920	July................	88 to 100	67 to 75	89 to 102	68 to 89	87 to 99	74 to 85	84 to 95	79 to 89	82 to 89	81 to 89	80 to 86	79 to 84	79 to 82	78 to 82	75 to 80	75 to 80	3.66
1918	August..............	94 to 105	65 to 79	97 to 106	77 to 92	93 to 103	83 to 90	91 to 98	88 to 92	91 to 93	89 to 93	89 to 92	89 to 90	86 to 88	86 to 88	84 to 88	83 to 85	0.07
1920	August..............	76 to 101	63 to 75	78 to 101	72 to 84	79 to 97	74 to 85	81 to 95	77 to 85	81 to 88	80 to 85	81 to 85	81 to 84	80 to 83	80 to 83	79 to 80	79 to 80	10.41
1918	September...........	69 to 104	41 to 78	69 to 102	55 to 85	71 to 99	55 to 88	72 to 96	71 to 90	78 to 91	76 to 91	81 to 90	80 to 89	82 to 88	80 to 87	82 to 85	82 to 85	1.42
1920	September...........	73 to 97	42 to 75	81 to 89	58 to 83	81 to 89	64 to 81	81 to 87	69 to 82	81 to 85	78 to 83	81 to 83	80 to 82	80 to 81	80 to 81	79 to 79	79 to 79	5.76

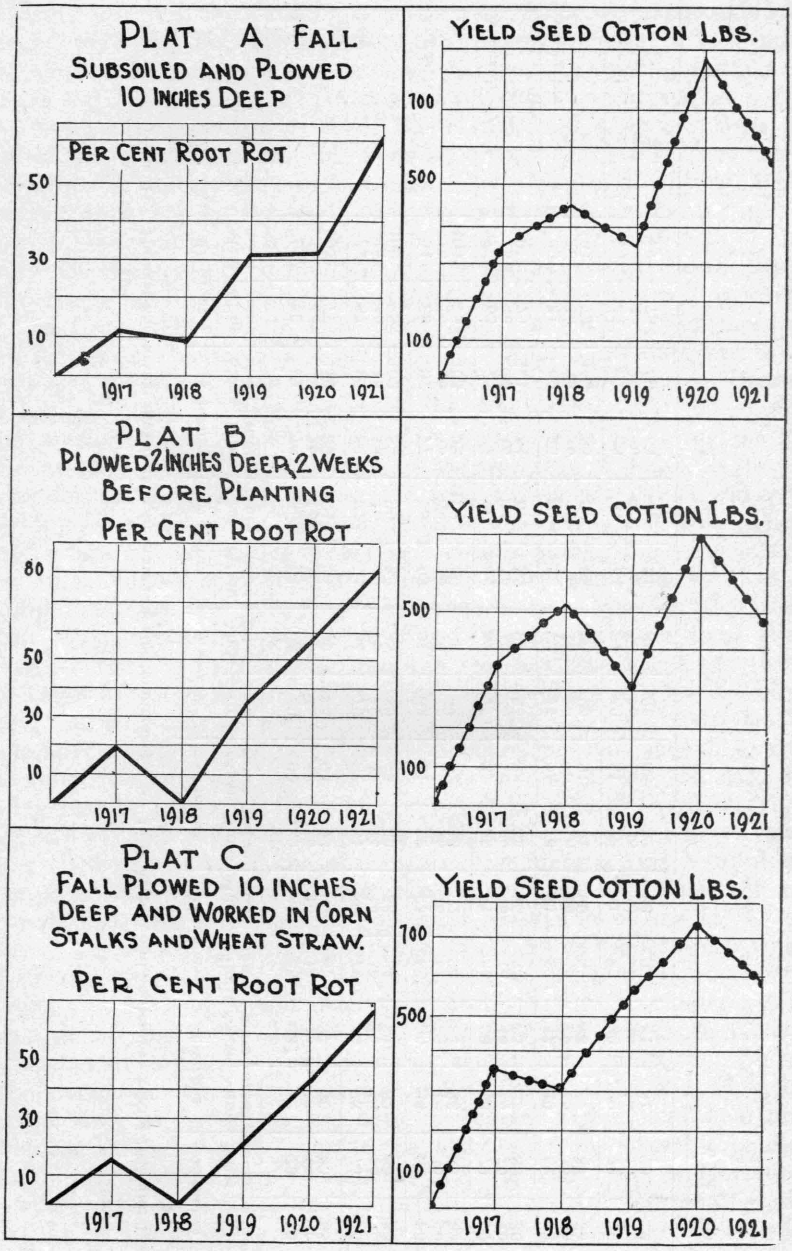


FIGURE 4.

a, b, c. Effect of fall and spring plowing on the control of Texas root rot of cotton.

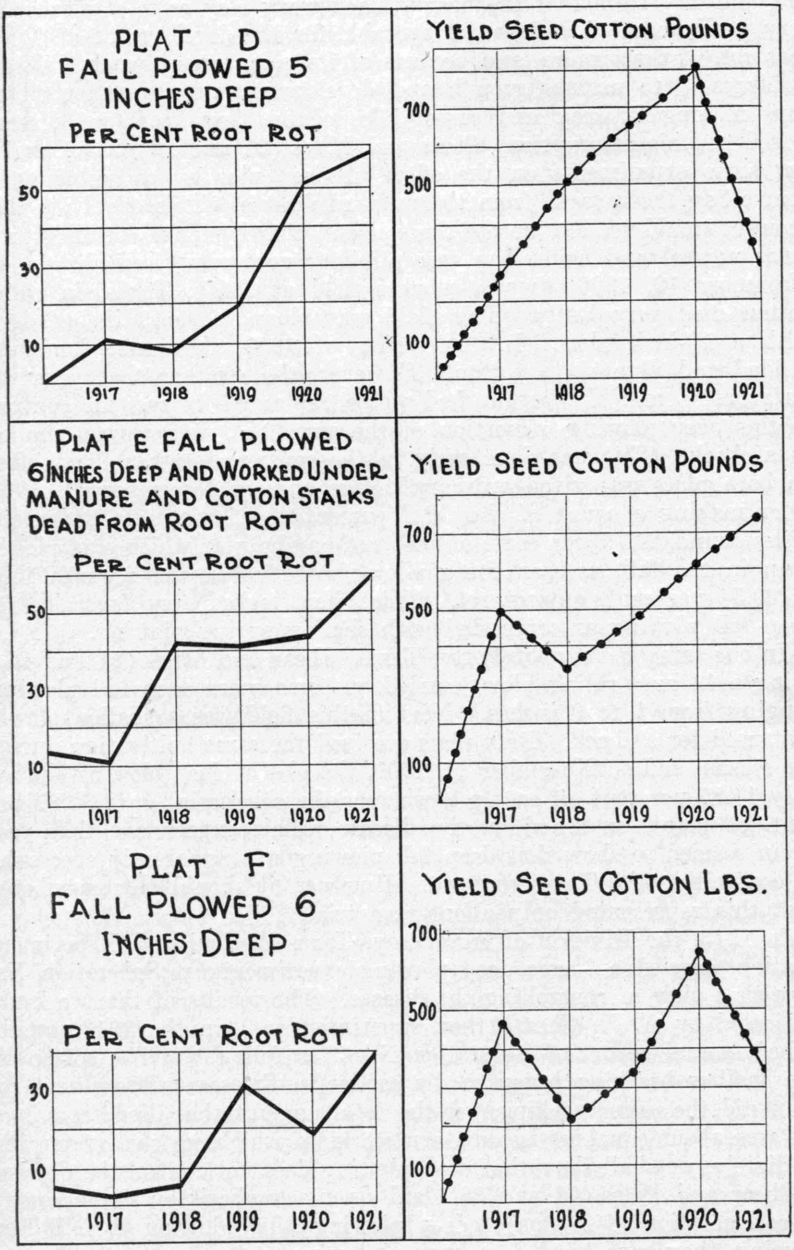


FIGURE 5.

d, e, f. Effect of fall plowing on the control of Texas root rot of cotton.

Effect of Deep Fall Plowing on Texas Root Rot. Shear and Miles (21 and 22) state that the heavy, black waxy clay soils of Texas are very poorly aerated and hence favorable for the development of Texas root rot. Furthermore, and because of its compactness, such soils are unfavorable to normal growth and development of the cotton plant, thus making it weak and susceptible to the Texas root rot disease. Based on this assumption, Shear and Miles (21 and 22) have carried out some experiments on the effect of deep plowing on reducing or controlling the ravages from the root rot disease. This operation they thought would tend to aerate the soil and thereby make cotton growth more normal and hence less susceptible to root rot. Accordingly, on November 12, 1906, they selected a field at Petty, Texas, in which cotton died very badly. This field was plowed 7 to 9 inches deep, with a 10-inch plow. In the spring of 1907, this same land was bedded and planted to cotton. However, the weather that year was unfavorable and the cotton had to be replanted twice. In contrast to this deep plowing, a portion of the same field was plowed shallow as a check. This was done early in the spring of 1907. The cotton on both plats was given ordinary tillage and on November 11, 1907, after making a count of the total percentage of root rot, Shear and Miles found 26.79 per cent. of root rot on the plat which was plowed deep in the fall, and on the shallow-plowed check there was a total of 69.54 per cent. of root rot. This, then, looked very favorable for deep fall plowing as contrasted with shallow spring plowing.

In the same vicinity of Petty, Texas, Shear and Miles (21 and 22), using a 14-inch riding plow, carried on some more deep fall plowing, ranging from 7 to 9 inches. Next to this field was a shallow-plowed plat used for a check. Both plats received the same cultivation during the season, and on November 11, 1907, the plat of deep plowing showed only 14.87 per cent. of root rot, whereas the check plat gave 57.87 per cent. of plants as killed by the disease. This experiment that year again seemed to show that deep fall plowing was apparently successful in controlling the Texas root rot. However, it should be remembered that this represented only a one-year trial.

In 1913, the Division of Agronomy, Texas Agricultural Experiment Station, carried on some deep plowing experiments at Substation No. 5, with a view of controlling the disease. The results of this work are indicated by A. K. Short (then superintendent) in the 1913 unpublished annual report of Substation No. 5 as follows: "The cotton on the shallow breaking began to die earlier in the season from root rot than did the deep breaking, yet the total amount that died from root rot was about equal." In our own work, to which we shall refer immediately, we shall show that deep plowing does not control the disease.

Shear and Miles (21 and 22) laid strong emphasis on the necessity of soil aeration by means of deep plowing. In addition to fall deep plowing, they have tried deep spring plowing and subsoiling. The results were not as favorable as for deep fall plowing. That this should be the case is not at all surprising since, as we shall show later, the effect of soil aeration through deep plowing does not seem to be a factor in controlling Texas root rot. Deep plowing as such fails to control the disease as long as the cotton roots are not killed as a result of the plowing and they remain alive during the winter months. This is substantiated by the fact that Shear and Miles (21 and 22) did not obtain favorable results with deep spring plowing because in this case the cotton roots had wintered over in the soil, remaining alive and thus carrying over the root rot fungus. When this was followed by deep spring plowing, most of the cotton roots which remained alive were not probably killed outright and quickly. Furthermore, no reference is made by Shear and Miles about the living susceptible weed roots which probably remained in that soil and which, undoubtedly, also helped to carry the root rot fungus and in this way defeat the benefit from deep spring plowing. Gilbert (8) states that the root rot fungus seems to grow best, and hence the Texas root rot disease is most severe where soil aeration is poorest. The idea of soil aeration accomplished through deep plowing gained considerable headway among practical growers, as they seemed to believe that this practice, together with crop rotation, might eventually eradicate the root rot disease. Unfortunately, this has not proved to be so in most cases, and the reason will become more apparent as we refer to our discussion on the life history studies of the causal organism.

There seems no doubt but that immediately after a heavy rain the black waxy soils of Texas become compacted and probably lack sufficient ventilation. However, it should be remembered that during the least dry spell these same soils crack in all sorts of directions and these cracks frequently vary in width from one to five inches and extend to a depth of from five to ten feet and more. Under these circumstances the soil as well as the cotton roots receive the very maximum of aeration. This condition often prevails during July and August, the two months in which Texas root rot is at its height. We have already indicated that frequent showers during June and July are very favorable to the later spread of the disease, irrespective of whether the soil has been plowed deep during the previous fall or not.

In order to definitely test out the effect, if any, of deep plowing on the possible control of Texas root rot, experiments were carried out for a period of five years. It was believed that a one-year test would not be conclusive inasmuch as we shall show immediately that the seasons, whether dry or wet, have everything to do with the results obtained, which seem to be independent of the manner or the time in which the plowing is done. The plowing experiments were carried out in the Station orchard at Temple. In this orchard, Texas root rot was very prevalent, for cotton and apple trees were known to die there every year previous to 1917. The field was divided in six plats of four rows each and of about one-tenth acre in area. The method of plowing and results obtained are indicated in Table 12 and Figs. 4 and 5. The various plowing operations were carried on in the same plats for a period of five years so as to obtain uniform and reliable data. For instance, the subsoiling and 10-inch fall-plowing experiment was carried on there from 1917 to 1921, inclusive. The same was true with the other plats in which other plowing methods were tried and in which no attempt was made to really kill the cotton roots or the roots of the weed carrier, *Ipomoea trichocarpa,* by uprooting and exposure to the air. The results obtained are shown in Table 12. The summers of 1917 and 1918 were both very dry; hence the percentage of Texas root rot in Plat A was very small. On the other hand, during 1919, 1920, and 1921, all of which were three wet summers, the percentages of Texas root rot varied from 57 in 1919 to 32 in 1920 and 62 in 1921. Had we carried on this experiment during 1917 and 1918 and stopped there, we should have been forced to come to the erroneous conclusion that 10-inch deep fall plowing, together with subsoiling, undoubtedly reduces the amount of root rot to a minimum. However, just as soon as the same experiment was continued on the same plat three more years, which were fortunately three wet seasons and favorable for the disease, there apparently was as much root rot as there was in Plat B (check), or in Plats C, D, E, and F as shown in Table 12. A word of explanation is here necessary, and this would also apply to all the plats indicated in this table. During the dry summers of 1917 and 1918, the fall plowing resulted, no doubt, in killing out a large percentage of the cotton roots and those of the weed *Ipomoea trichocarpa,* thus reducing to a minimum the number of carriers during the winter months. On the other hand, during 1919, 1920, and 1921, all of which were three wet seasons, the soil during the time of the fall plowing was wet or moist, and this meant that although it was plowed deep and the cotton roots and perennial weeds were stirred up, the plowing did not dislodge or expose them to the air. This meant that these roots remained alive during the winter months, encouraging a large number of winter carriers. With plenty of moisture during the following summer seasons, it naturally resulted in more root rot in spite of the deep fall plowing. From this and from a study of Table 12, it is safe to conclude that neither fall plowing whether 10, 6, or 5 inches deep, or spring plowing 2 inches deep will control root rot if the plowing, no matter when done, does not kill out the winter carriers. Furthermore, a dry summer, that is, lack of rain during June, July, or August, will result in the greatest reduction of Texas root rot, due to the fact that the spread of the disease is interfered with because of lack of contact of a poorly developed root system of the cotton or of the other weed carriers.

Table 12. Effect of deep plowing on Texas root rot.

Plat No. and method of plowing	Year	Date		Date of root rot count	Per cent root rot per acre	Total yield seed cotton per acre
		Plowed	Planted			
A	1917	Dec. 10, 1916	April 20, 1917	Sept. 12, 1917	11	374
	1918	Nov. 25, 1917	May 11, 1918	Oct. 1, 1918	8	457
Subsoiled and fall plowed 10 inches deep.	1919	Dec. 5, 1918	April 9, 1919	Oct. 1, 1919	32	370
	1920	Nov. 5, 1919	April 20, 1920	Oct. 1, 1920	32	792
	1921	Dec. 1, 1920	May 2, 1921	Oct. 11, 1921	62	525
B	1917	April 5, 1917	April 20, 1917	Sept. 12, 1917	21	385
	1918	April 28, 1918	May 11, 1918	Oct. 1, 1918	0	526
Shallow spring plowing 2 inches deep.	1919	Mar. 25, 1919	April 9, 1919	Oct. 1, 1919	35	332
	1920	April 5, 1920	April 20, 1920	Oct. 1, 1920	57	594
	1921	April 17, 1921	May 2, 1921	Oct. 11, 1921	82	451
C	1917	Dec. 10, 1916	April 20, 1917	Sept. 12, 1917	17	374
Fall plowed 10 inches deep, stalks and straw worked in at rate of 5 tons per acre	1918	Nov. 25, 1917	May 11, 1918	Oct. 1, 1918	0	315
	1919	Dec. 5, 1918	April 9, 1919	Oct. 1, 1919	22	530
	1920	Nov. 10, 1919	April 20, 1920	Oct. 1, 1920	41	726
	1921	Dec. 1, 1920	May 2, 1921	Oct. 11, 1921	66	544
D	1917	Dec. 10, 1916	April 20, 1917	Sept. 12, 1917	11	385
	1918	Nov. 25, 1917	May 11, 1918	Oct. 1, 1918	8	510
Fall plowed 5 inches deep.	1919	Dec. 5, 1918	April 9, 1919	Oct. 1, 1919	25	653
	1920	Nov. 10, 1919	April 20, 1920	Oct. 1, 1920	51	803
	1921	Dec. 1, 1920	May 2, 1921	Oct. 11, 1921	59	291
E Fall plowed 6 inches deep, worked in manure at rate of 10 tons per acre and cotton stalks at rate of 5 tons per acre.	1917	Dec. 10, 1916	April 20, 1917	Sept. 12, 1917	17	517
	1918	Nov. 25, 1917	May 11, 1918	Oct. 1, 1918	20	345
	1919	Dec. 5, 1918	April 9, 1919	Oct. 1, 1919	19	473
	1920	Nov. 11, 1919	April 20, 1920	Oct. 1, 1920	49	605
	1921	Dec. 1, 1920	May 2, 1921	Oct. 11, 1921	47	726
F	1917	Dec. 10, 1916	April 20, 1917	Sept. 12, 1917	22	484
	1918	Nov. 25, 1917	May 11, 1918	Oct. 1, 1918	8	202
Fall plowed 6 inches deep.	1919	Dec. 5, 1918	April 9, 1919	Oct. 1, 1919	36	353
	1920	Nov. 10, 1919	April 20, 1920	Oct. 1, 1920	37	660
	1921	Dec. 1, 1920	May 2, 1921	Oct. 11, 1921	34	357

Effect of Humus on Texas Root Rot. In order to test out the effect of humus on Texas root rot, two plats, C and E (see Table 12) were chosen in connection with the experiments on deep plowing. Plat C was fall-plowed ten inches deep and had corn stalks and wheat straw worked into it at the rate of five tons per acre. This treatment was carried on for a period of five years from 1917 to 1921, inclusive. The object of this experiment was to determine whether the addition of humus to the same plat during a period of five years will increase root rot. If this proved to be the case, we would have a lead as to whether the causal organism is capable of living over from year to year on the humus in the soil. From Table 12, it is seen that this is not apparently the case, since the increase or decrease of Texas root rot depends not on the humus, but rather on the amount of rainfall during the summer seasons, that is, little during 1917 and 1918, and considerable during 1920. Likewise, when barnyard manure and cotton stalks which had died from Texas root rot were added for a period of five years to Plat E (see Table 12), the results obtained were practically the same as in Plat C. From the data in Table 12, and from numerous other observations it is safe to assume that the causal organism of root rot does not apparently maintain itself as a saprophyte on the organic matter in the soil. This is fully supported by other studies on the life history of the Texas root rot fungus.

Effect of Date of Planting on Texas Root Rot. There seems to be no evidence in literature that anyone has ever tried to determine the effect of the date of planting of cotton or any other of the susceptible hosts on the prevalence or absence of Texas root rot. Farmers have repeatedly stated to the writers that when cotton is planted late it actually dies less from root rot. In order to test this out two hosts were selected, namely, the guar, a highly resistant legume, and the cotton, a very susceptible host. The results of these trials are shown in Table 13. From this table it is seen that the date of planting seems to be a factor in influencing the disease. Hence the guar, when planted early, April 22, 1921, showed at the end of the season 3 per cent. of root rot, but when it was planted late, July 15 of that same year, there was only a trace of the disease.

In referring to Table 13, one sees that although the earliest plantings of guar gave the highest percentage of root rot, nevertheless these plantings also gave the highest yield in total pounds of seed per acre; that is, the first plantings, on April 22, with a high total of 3 per cent. root rot, yielded 206 pounds per acre as compared to the late planting, which was made July 15 of that same year, and which showed only a trace of root rot, yielded 78 pounds of seed per acre. As far as the guar is concerned, it seems, therefore, evident that the heavier yields from the early planting have counterbalanced the loss from root rot, which, in this respect, was really negligible as compared to the reduced yields of the later-planting dates.

Table 13. Effect of date of planting on Texas root rot.

Name of variety	Date planted	Per centage of root rot Sept. 19, 1921	Yield, pounds per acre
Cotton			
Mebane*	May 6, 1921	68	366.600
Mebane*	May 17, 1921	43	568.230
Mebane*	May 25, 1921	37	645.280
Mebane*	June 7, 1921	24	491.530
Bennett†	May 6, 1921	54	439.920
Bennett†	May 17, 1921	32	678.210
Bennett†	May 25, 1921	34	653.400
Bennett†	June 7, 1921	13	443.630
Snowflake‡	May 6, 1921	48	476.580
Snowflake‡	May 17, 1921	22	623.220
Snowflake‡	May 25, 1921	34	484.000
Snowflake‡	June 7, 1921	24	302.500
Guar	April 22, 1921	3	206.250
Guar	May 17, 1921	1.5	173.250
Guar	June 6, 1921	0.5	117.875
Guar	June 28, 1921	0.10	110.000
Guar	July 5, 1921	0.10	119.125
Guar	July 10, 1921	0.25	81.125
Guar	July 15, 1921	Trace	78.375

*Early maturing. †Medium maturing. ‡Late maturing.

From further reference to Table 13, it is seen that with the cotton, the Mebane, an early-maturing variety, the earliest date of planting, May 6, 1921, actually gave a larger percentage of root rot, i. e., 68 per cent., as compared to the later-date planting June 7, 1921, which only showed 24 per cent. of root rot. Furthermore, in referring to

Table 13, one sees that the lowest yield in seed cotton was obtained from the earliest date of planting, which may account for the larger percentage of root rot. Furthermore, with a later date in planting, that is, May 17, there was a reduction in the percentage of root rot to 43, and an increase of seed cotton per acre amounting to 568 pounds. Likewise, during the third date of planting, which was May 25, the percentage of root rot was decreased further to 37 per cent. and at the same time the yield of seed cotton per acre was increased to 645 pounds. Finally, in the last planting, which was June 7, the percentage of root rot was decreased to 24 per cent. and the yield also was decreased to 491 pounds. It seems, therefore, that the highest yield with the Mebane was obtained during the third planting of May 25 with also a reasonable decrease in root rot. From Table 13, it is also seen that the same practically holds true with the Bennett, which is a medium-maturing cotton, and the Snowflake, a late variety. Here the highest yields obtained were from the second planting, which was May 17. In summarizing Table 13, one concludes that with all varieties tested, the highest percentage of root rot actually coincides with the earlier dates of planting and that the lowest percentage of root rot follows the later dates of planting. As far as the yields of seed cotton per acre are concerned, the highest yields are obtained after the second or third dates of planting. These results should not be considered as conclusive, since they represent only one year's trial, and at best are only suggestive. However, these results may serve as a guide until further research is carried on,—something to which we are planning to give considerable attention during the next few years.

Effect of Clean Culture and Crop Rotation on Texas Root Rot. Pammel (15) was undoubtedly the first to indicate that certain weeds may be carriers of the Texas root rot disease. This, however, was merely conjecture, as no experimental data were offered to substantiate these claims. However, on this supposition, Pammel (15) argues that in order to control the Texas root rot disease, it is necessary not only to rotate the crops, but to keep out all obnoxious weeds. In this work, we can definitely state that the Texas root rot disease is carried over not only on living cotton roots during the winter months, but also on the roots of certain susceptible perennial weeds which appear periodically in the black lands. This will be referred to more fully under life history studies on page 72.

Likewise, the first to have recommended crop rotation as a means of controlling root rot was Pammel (15), who states, "I think from a practical point of view, proper methods of rotation of crops is the best way to destroy the fungus. Not only has this been shown in field studies, but the practical growers of the state are nearly unanimous on this point." Shear and Miles (21 and 22) also lay stress on crop rotation as a means of controlling Texas root rot. They recommend a three-year rotation consisting of corn, wheat, and cotton. This rotation was tried out at Terrell, Texas, in 1904, 1905, and 1906. Shear and Miles (21 and 22) found that this rotation reduced root rot, but did not entirely eliminate it, as there were still present certain definite root rot spots. Heald (9) claims that a one-year rotation, that is, cotton following corn, will materially reduce the disease. Youngblood (34) states that where cotton root rot is prevalent a three-year rotation may be effective and he recommends the following: (a) corn with cowpeas planted between the rows at the last cultivation; (b) cotton; (c) oats followed by cowpeas which are sown broadcast. Another rotation suggested by Youngblood (34) is: grow alfalfa about three years on the land until it is killed out by the root rot disease; then follow with wheat, corn, oats, and cotton. The Division of Agronomy of the Texas Agricultural Experiment Station has for years carried on rotation experiments with a view to increase the yields of cotton, and to eliminate Texas root rot. All of this work was done at Substation No. 5 at Temple, Texas. Part of this work was done by former Superintendent A. K. Short, and later by his successor, the junior writer. In referring to Tables 14 and 15, one will see that rotation increased the yields of cotton and materially reduced the disease in the cotton. However, rotation has not definitely controlled Texas root rot for the reason that the idea of clean culture with a view of eliminating susceptible winter weed carriers was not experimentally intended to be carried out.

Table 14. Effect of rotation on the control of root rot of cotton.

Year	Kind of rotation in years	Series No.	Acre No.	Root Rot: Date counted	Root Rot: Per cent	Total yield pounds seed cotton per acre	Average per cent root rot	Average yield pound seed cotton
1915	4	1	C 11–20	August 17	4.58	696.22		
1919	4	1	C 11–20	October 20	10.00	708.11		
1916	4	1	B 11–20	October 25	6.00	961.71	Eight 4-year rotations 9.37	Eight 4-year rotations 823.27
1920	4	1	B 11–20	October 25	10.00	2022.57		
1917	4	1	E 11–20	October 1	18.71	548.62		
1921	4	1	E 11–20	September 19	20.07	451.00		
1918	4	1	D 11–20	September 30	0.00*	422.95		
1922	4	1	D 11–20	October 24	5.64	774.98		
1915	4	2	B 21–30	August 17	4.31	689.35		
1919	4	2	B 21–30	October 20	8.50	689.20		
1916	4	2	A 31–40	October 25	2.00	808.95	Eight 4-year rotations 3.81	Eight 4-year rotations 775.89
1920	4	2	A 31–40	October 25	6.00	1477.18		
1917	4	2	A 21–30	October 1	2.50	764.64		
1921	4	2	A 21–30	September 19	3.00	748.33		
1918	4	2	A 11–20		0.00*	366.24		
1922	4	2	A 11–20	October 24	0.21*	663.26		
1915	4	5	C 21–30	August 17	1.47	617.72		
1919	4	5	C 21–30	October 20	12.00	627.68	Six 4-year rotations 6.29	Six 4-year rotations 608.95
1920	4	5	F 17–20	October 25	9.50	1275.00		
1917	4	5	D 21–30	October 1	8.00	326.90		
1921	4	5	D 21–30	September 19	1.50	572.00		
1922	4	5	C 35–40	October 24	5.31	234.43		
1918	3	3	C 1–10		0.00*	205.56		
1921	3	3	C 1–10	September 19	0.10*	880.00		
1916	3	3	B 1–10	October 25	5.00	915.74	Seven 3-year rotations 4.58	Seven 3-year rotations 743.21
1919	3	3	B 1–10	October 20	12.00	865.00		
1922	3	3	B 1–10	October 24	0.00*	453.15		
1917	3	3	A 1–10	October 1	3.00	502.44		
1920	3	3	A 1–10	October 25	12.00	1380.62		
1918	3	4	F 1–10	September 25	0.75*	176.34		
1921	3	4	F 1–10	September 19	12.23	792.00		
1916	3	4	E 1–10	October 25	3.00	851.81	Seven 3-year rotations 8.49	Seven 3-year rotations 792.01
1919	3	4	E 1–10	October 20	18.00	973.40		
1922	3	4	E 1–10	October 24	8.74	609.84		
1917	3	4	D 1–10	October 1	8.74	507.37		
1920	3	4	D 1–10	October 25	8.00	1633.33		
1917	3	7	A 91–100	October 1	1.5	400.12		
1920	3	7	A 91–100	October 25	12.0	1510.00		
1918	3	7	A 81–85	September 25	1.0*	210.37	Seven 3-year rotations 7.85	Seven 3-year rotations 612.52
1921	3	7	A 81–85	September 19	15.0	828.75		
1916	3	7	A 71–80	October 25	7.5	392.32		
1919	3	7	A 71–80	October 20	15.0	495.11		
1922	3	7	A 71–80	October 24	2.99	450.99		

Table 15. Effect of non-rotation on Texas root rot of cotton.

Year	Acre No.	Root Rot		Total yield pounds seed cotton per acre	Average per cent root rot	Average yield pounds seed cotton per acre
		Date counted	Per cent			
1916	C 33	October 25	28.5	516.79		
1917	C 33	October 1	14.54	289.37		
1918	C 33	September 25	8.50	98.59		
1919	C 33	October 20	45.00	555.31	7 non-rotations 19.77	7 non-rotations 451.40
1920	C 33	October 25	37.50	612.50		
1921	C 33	September 19	3.00	700.00		
1922	C 33	October 24	1.40	387.30		
1916	F 14	October 25	32.00	510.03		
1917	F 14	October 1	17.43	335.00		
1918	F 14	September 25	5.25	117.18		
1919	F 14	October 20	60.00	316.87	7 non-rotations 39.19	7 non-rotations 355.49
1920	F 14	October 25	55.00	668.75		
1921	F 14	September 19	78.00	175.00		
1922	F 14	October 24	26.70	365.60		
1919	G 1–20	October 20	28.00	....		
1920	G 1–20	October 25	96.00	760.70	4 non-rotations 48.63	3 non rotations 557.59
1921	G 1–20	September 19	56.00	511.50		
1922	G 1–20	October 24	14.55	400.57		
1916	A 61–70	October 25	15.00	1012.70		
1917	A 61–70	October 1	6.68	366.43		
1918	A 61–70	September 20	8.00	392.50		
1919	A 61–70	October 20	28.00	451.83	7 non-rotations 24.03	7 non-rotations 552.12
1920	A 61–70	October 25	44.50	696.00		
1921	A 61–70	September 19	58.33	482.33		
1922	A 61–70	October 24	7.76	463.06		

Texas farmers have, of course, practiced crop rotation with the hope of reducing or controlling the Texas root rot disease of cotton. No matter where tried, nor how persistent, crop rotation has not always given the results which were claimed for it. We do not intend to give the impression that we are condemning the idea of crop rotation. However, from our life history studies as seen on page 72, we are now able to explain why this practice has not in the majority of cases given the results which it was hoped it would give and where, in the light of our own studies, success may take the place of failure. Perhaps the only plausible explanation of this failure is the fact that wherever crop rotation was religiously practiced, one important factor was unconsciously overlooked, or neglected, namely, clean culture. We shall herein discuss on page 89 the fact that where clean culture is not practiced, a chance is given to certain susceptible perennial weeds to carry over the root rot fungus on the living roots during the winter months. It is this fact, which until now, has not been definitely known, that may explain the failure of crop rotation. We shall now refer to various types of crop rotation advocated or practiced which have not given the desired results and we shall point out the probable cause of the failure. We have stated that Heald (9) recommended a one-year rotation of corn and cotton. This rotation has actually been tried out by many farmers with varying results. In most cases, however, where weeds are not thoroughly killed out, there is as much root rot after the corn as if that crop had not been grown. For this reason this system of rotation is generally condemned by many. Anyone who is familiar with the methods in vogue in Texas in producing a corn crop will realize that the farmer usually goes to the trouble to prepare the land and keep the crop fairly clean as long as he can penetrate with his tools and work it. However, as soon as the corn is made and the ears mature, the field is left to itself without further attention or cultivation. The result is that nearly all of the corn fields in Texas become a veritable weed garden immediately after the last cultivation and beginning with the ripening of the corn crop. The corn is thus left in the field sometimes until late in the fall, when it is harvested and nothing further done to the field until the following spring. If there is any doubt about this, let anyone go into the average corn field during the summer, fall, or winter months and see if he cannot find there one or more types of susceptible weeds, especially the cocklebur, Xanthium spp., in various stages of dying from the Texas root rot and also numerous instances of living roots of perennial weeds, especially *Ipomoea trichocarpa,* which carries over the causal organism during the winter months.

To support the above contention, we shall cite a specific illustration. On October 24, 1922, an average corn field was picked out in Bell County, Texas. Counts were made of the number of cocklebur plants in the field which were alive and those which died from Texas root rot. The results of this count are shown in Table 16, which is self-explanatory.

Table 16. Cockleburs in a corn field.

Condition of plants	Row No. 1	Row No. 2	Average	Per cent
Total	109	77	93.0	100.0
Died from Texas root rot	49	14	31.5	33.8
Alive	60	63	61.5	66.2

Cases of unsuccessful three-year rotations may be mentioned—oats or wheat, corn, and cotton. Here again, the failure may be traced to a lack of clean culture in the rotation system. For instance, as soon as the oats or wheat is harvested, the stubble is generally plowed up and the land is not planted to a crop until the following year, when it is planted to corn. This fallow stubble land, as is frequently the case, becomes overrun by a number of susceptible weeds which maintain the Texas root rot organism during the summer, fall, and winter months. This is especially true of *Ipomoea trichocarpa,* the roots of which remain alive in the soil and sprout with the least moisture. Furthermore, the corn crop the second year, likewise, furnishes sufficient weed flora to carry the Texas root rot to the cotton the third year.

Believing that a three-year rotation is not always effective in controlling root rot, farmers in many cases have practiced a four-year rotation with the hope of reducing the ravages from the Texas root rot disease, but with no better results. In a four-year rotation such as: (a) cowpeas; (b) corn; (c) wheat, and (d) cotton, the causes of failure at control may be explained as for the other rotations. To begin with, cowpeas planted during the first year are highly susceptible to Texas root rot. After the cowpeas are harvested, and the vines turned under, there are usually enough susceptible weeds left over to perpetuate the root rot fungus during the winter months. Likewise, during the second year the weeds which are permitted to thrive after the last cultivation of the corn and those found the third year on the wheat stubble are sufficient to maintain the disease for the cotton crop the fourth year of the rotation.

There may be any number of crop rotations practiced, but whenever the question of clean culture is overlooked, and by this we mean a clean culture not only during the period in which the crop is grown, but also clean culture of the fallow land during the fall and winter months, the system of rotation practiced may be a failure or give only partial results under root rot conditions.

Effect of Lime or Sulphur on Texas Root Rot. Claims are frequently made by farmers and fertilizer concerns that lime or sulphur when used alone or in combination act as a check to the disease. In order to determine the effect of the two elements, a cooperative experiment was undertaken with the Division of Agronomy, this Division testing its effect on the growth and production of seed cotton per acre and the Division of Plant Pathology and Physiology studying the effect of these applications on the possible control of the Texas root rot disease. The object in this experiment was to determine the effect, if any, of soil acidity or alkalinity on the Texas root rot and as brought about by the applied lime or sulphur. The amounts used and the results obtained during the last three years are indicated in Tables 17, 18, and 19. It should be added that the years 1920 and 1921 were both favorable for the Texas root rot because of the prevalent showers during June and July. On the other hand, during 1922 there was a scarcity of rainfall during these two months, resulting in little root rot.

Table 17. Effect of sulphur on Texas root rot.

Year	Acre No.	Plat	Amount in pounds per acre	Per cent root rot per acre	Total yield in pounds of seed cotton per acre
		1	Check	20	496.0
1920	At Cater's farm	2	Sulphur 100	28	608.0
		3	Sulphur 100	24	632.0
		4	Sulphur 600	18	776.5
		1	Check	81.6	720.0
		2	Sulphur 1,000	63.4	1380.5
		3	Sulphur 500, acid phosphate 400	74.4	960.2
		4	Sulphur 25	83.3	600.0
1920	G 1–20	5	Check	96.0	760.7
		6	Sulphur 50, acid phosphate 400	72.4	900.0
		7	Acid phosphate 400	85.4	680.2
		8	Sulphur 50	82.4	940.7
		9	Check	92.8	684.2

*Yield data furnished by the Division of Agronomy, Texas Agricultural Experiment Station. (See also Reynolds, E. B., and Leidigh, A. H. Sulphur as a fertilizer for cotton. Soil Science 14: 435–440, 1922.)

Table 18. Effect of lime or sulphur on Texas root rot.*

Year	Acre No.	Plat No.	Amount in pounds per acre	Per cent root rot per acre	Total yield in pounds of seed cotton per acre
1921	G 1–20	1	Check	30	792
		2	Lime 500	26	660
		3	Sulphur 500	35	550
		4	Lime 500, sulphur 500	53	418
		5	Lime 2,500	61	396
		6	Check	75	374
		7	Sulphur 2,500	98	27.5
		8	Lime 2,500, sulphur 2,500	69	24.05
		9	Lime 5,000	70	108.62
		10	Sulphur 5,000	89	110
		11	Check	82	286
		12	Lime 5,000, sulphur 5,000	73	275
		13	Lime 10,000, sulphur 10,000	45	396
		14	Sulphur 10,000	28	396
		15	Lime 10,000	26	484
		16	Check	24	594
1921	E 1–10	1	Check	33	558
		2	Lime 500	24	864
		3	Sulphur 500	17	800
		4	Lime 500, sulphur 500	16	880
		5	Lime 2,500	13	887.5
		6	Check	16	880
		7	Sulphur 2,500	12	704
		8	Lime 2,500, sulphur 2,500	7	770
		9	Lime 5,000	5	902
		10	Sulphur 5,000	4	704
		11	Check	13	748
		12	Lime 5,000, sulphur 5,000	16	671
		13	Lime 10,000	8	814
		14	Sulphur 10,000	12	638
		15	Lime 10,000, sulphur 10,000	9	792
		16	Check	....	682

*Yield data furnished by Division of Agronomy, Texas Agricultural Experiment Station.

Table 19.—Effect of lime or sulphur on Texas root rot.*

Year	Acre No.	Plat No.	Amount in pounds per acre	Per cent root rot per acre	Total yield in pounds of seed cotton per acre
1922	G 1-20	1	Check	8.2	539.0
		2	Lime omitted	9.1	506.0
		3	Sulphur 500	16.3	453.6
		4	Lime omitted, sulphur 500	32.6	410.9
		5	Lime omitted	19.8	401.2
		6	Check	10.5	346.2
		7	Sulphur 2,500	21.4	269.2
		8	Lime omitted, sulphur 2,500	16.1	273.2
		9	Lime omitted	23.9	262.2
		10	Sulphur 5,000	22.4	266.6
		11	Check	23.9	326.9
		12	Lime omitted, sulphur 5,000	20.9	295.6
		13	Lime omitted	4.6	380.6
		14	Sulphur 10,000	0.9	345.4
		15	Lime omitted, sulphur 10,000	1.4	336.6
		16	Check	0.9	390.2
1922	E 1-10	1	Check	20.6	622.82
		2	Sulphur 50	27.5	589.16
		3	Sulphur 100	20.2	655.16
		4	Sulphur 200	19.7	634.04
		5	Sulphur 300	11.5	700.70
		6	Check	8.2	683.32
		7	Sulphur 400	4.0	619.08
		8	Sulphur 500	3.0	689.04
		9	Sulphur 1,000	1.1	630.30
		10	Sulphur 1,500	7.3	619.08
		11	Check	2.1	642.40
		12	Sulphur 2,000	2.3	617.32
		13	Sulphur 2,500	2.9	513.70
		14	Sulphur 3,000	4.7	457.16
		15	Sulphur 4,000	1.3	423.06
		16	Check	3.5	490.82
1922	C D E 01-010	1	Check	14.3	615.88
		2	Sulphur 50	15.3	620.28
		3	Sulphur 100	10.8	526.43
		4	Sulphur 200	28.3	442.11
		5	Sulphur 300	29.3	479.51
		6	Check	24.0	436.25
		7	Sulphur 400	18.8	408.39
		8	Sulphur 500	43.7	291.81
		9	Sulphur 1,000	38.8	278.75
		10	Sulphur 1,500	12.6	291.81
		11	Check	3.3	289.61
		12	Sulphur 2,000	4.1	397.39
		13	Sulphur 2,500	2.8	194.29
		14	Sulphur 3,000	9.0	173.76
		15	Sulphur 4,000	3.6	261.75
		16	Check	2.4	252.95

*Yield data furnished by Division of Agronomy, Texas Agricultural Experiment Station.

In carefully studying Tables 17 to 19 one sees that neither lime nor sulphur has controlled or reduced the Texas root rot in cotton. It should be remembered, however, that these tests are not as yet final, as there is a possibility that the amount of sulphur used was not as yet sufficient to overcome the soil alkalinity and render it sufficiently acid to control the disease. In fact, acidity tests of the treated plats carried out by Mr. Reynolds of the Division of Agronomy bear this out. This means that these experiments must be carried on for several more years before we can adopt or discard the use of sulphur in the control of the Texas root rot. As to the lime, its use in this connection has been discontinued during 1922. Lime has apparently no effect in increasing or diminishing the disease.

EFFECT OF FERTILIZER AND INOCULATED SULPHUR ON TEXAS ROOT ROT.

From time to time, claims were made that the application of certain fertilizers to infected land will materially help to reduce the ravages of the root rot disease. Pammel (15) states a case near Brenham, Texas, in which two infected acres were heavily top-dressed with manure with the result that the percentage of the dead cotton decreased decidedly. He further cites a case where the use of cotton seed meal resulted not only in the production of a bale of cotton per acre, but it materially helped to reduce the Texas root rot disease. Likewise, he tried out various fertilizers or fungicides as agents in controlling Texas root rot, which were as follows: kainit, chloride of potash, sulphate of magnesium, cotton seed meal, chloride of lime, sulphate of iron, alum, copper sulphate, sodium chloride, white arsenic, verdigris, lac-sulphur, carbolic acid, lime, salt and lime, lime and copper sulphate (dry), lime and copper sulphate (solution), sodium chloride and kainit. Of all these, not a single one tried was able to check the root rot, with the exception perhaps of the chloride of lime. However, where this was used, very little cotton was produced. Curtis (3), too, recommends the application of salt and coal oil (kerosene) in controlling Texas root rot in cotton or alfalfa. As to the amount of salt to use, he advises that enough should be applied to the young plants to make the surface of the treated soil thoroughly white in appearance. As for the coal oil, he recommends that a sufficient amount be used to thoroughly drench the treated land. While we have not tried out the use of either salt or coal oil, it is very doubtful if they will control root rot when used in small doses, and when used in excess, plant growth may be prohibited altogether.

Table 20. Effect of fertilizer on Texas root rot.*

Year	Acre No.	Plat No.	Amount in pounds per acre	Per cent root rot per acre	Total yield in pounds of seed cotton per acre
1921		1	Nitrate of soda 160	78	145
		2	Nitrate of soda 80	67	80
		3	Acid phosphate 400	33	490
		4	Acid phosphate 200	29	440
		5	Lime 10,000, manure 20,000	22	540
		6	Manure 20,000	34	490
1922	C 35–40	1	Check	4.3	302.77
		2	Guano 300	2.0	256.85
		3	Nitrate of soda 100	2.7	235.67
		4	Sulphur 300	1.9	168.30
		5	Sulphur, Toyah Valley, 400	3.1	160.30
		6	Brown Ore 200 A. P.	4.5	161.42
		7	Brown Ore 200 A. P.	4.8	160.05
		8	Manure 14,000	6.4	203.50
		9	Inoculated agricultural sulphur 400	12.8	142.17
		10	Check	10.6	166.10

*Yield data furnished by the Division of Agronomy, Texas Agricultural Experiment Station.

Fertilizer experiments during the last two years carried on by the writers in cooperation with the Division of Agronomy of this Station have not yielded anything definite. In referring to Table 20, one is convinced of the necessity of carrying on these experiments for a number of years before reaching definite conclusions. The data obtained so far are conflicting and inconclusive.

Effect of Soil Disinfectant on Texas Root Rot. Mention has already been made of the work of Pammel (15) in trying out various chemicals and their effect as soil sterilizers with but little or no results. The writers realize that no amount of soil treatment by chemicals would be possible or practical on a large scale. However, when we consider the great damage occasioned by Texas root rot disease to various outdoor ornamentals, it becomes evident that some standard soil disinfectant may be practical on a small scale. Since we had no steam facilities at Substation No. 5, it was decided to try out the effect of formaldehyde, chlorophol, and Seed-O-San. The formaldehyde was used during 1921 and 1922 at the rate of one pint in twenty gallons of water and the solution was applied at the rate of two gallons per square foot. The soil treated was protected by a wooden frame, and ten days after treatment okra was planted, since this host is extremely susceptible to the root rot disease. A check plat which was untreated was also sown to okra next to and adjoining the formaldehyde-treated plat. The chlorophol and the Seed-O-San were used at the rate of one pound in twenty gallons of water, and tried during 1922 only. From Table 21, it is seen that during 1921, the formaldehyde apparently reduced considerably the percentage of the disease. However, it should not be taken as conclusive since this only represented one year's trials. Nevertheless, these results are interesting in the sense that the treated plat actually showed a decided decrease in the disease compared to the check. This work will be duplicated for several more years and tried on various crops with root systems which penetrate more or less deeply into the soil. On the other hand, the treatments with the chlorophol and Seed-O-San during 1922 did not show anything because there was no root rot on the treated and check plats. But it was evident that the proportions of one pound in twenty gallons was strong, as it stunted the growth of the okra and reduced the yield in pods.

Table 21. Effect of soil disinfectants on Texas root rot.*

Year	Plat No.	Kind of soil disinfectant used	Per cent root rot per plat, Nov. 15	Yield in pounds of okra per plat
1921	1	Check	49	....
	2	Formaldehyde	5	....
1922	1	Check	0	15.75
	2	Chlorophol	0	6.00
	3	Seed-O-San	0	8.50
	4	Formaldehyde	0	12.50

*Yield data furnished by the Division of Agronomy, Texas Agricultural Experiment Station.

IS A TEXAS ROOT ROT SPOT PERSISTENT FOR A NUMBER OF YEARS.

Farmers frequently claim that as far as cotton is concerned, a root rot spot one year does not necessarily mean the reappearance of the same spot the following year. Duggar (4) states, "In a field grown two or more years to cotton, one notices the disappearance of some of the small spots of the previous year." Scofield (19), in his work on dead spots of cotton in Texas, likewise found that a root rot spot one year does not necessarily mean a root rot spot another year if the same susceptible host is grown on that land. The writers have studied this question for a period of five years with the result that we can safely corroborate the statements of the workers mentioned above. In general, it is safe to state that a root rot spot one year does not necessarily mean a root rot spot another year (compare Fig. 6, a and b), if a susceptible host is grown again on that same land the following year. However, it must be further added that the reason for this is undoubtedly the fact that the disease is able to kill out all susceptible hosts grown in any one spot during any one year. If, for instance, in any given cotton root rot spot, all the cotton is killed out as is usually the case, and if in addition all other annual and perennial susceptible weeds are also killed out, leaving no winter carriers, then the same spot will certainly not reappear the following year, no matter what favorable weather conditions may prevail. On the other hand, as it sometimes happens, some of the cotton plants or susceptible hosts are not all killed out in a spot; in which case there will be winter carriers, and a root rot spot one year will reappear again the following year, given a favorable climatic condition for the disease. From this it becomes more evident that the causal fungus does not apparently live over in the soil, because if it did, it would maintain itself indefinitely there. Furthermore, a root rot spot would last as long as a susceptible crop was grown there.

CAUSE OF THE TEXAS ROOT ROT DISEASE.

Various Claims. Practically every cotton grower has at one time or another entertained certain ideas of his own regarding the cause of the Texas root rot disease. Even today, there are quite a few growers who believe that the trouble is caused by alkali in the soil. As seen in Table 22, soil analyses of various root rot spots do not show that there is enough alkali in those spots to be responsible for the dying of the cotton grown there. From Table 22 it is, therefore, very evident that the alkali theory is untenable. The work of Stewart (24) seems to indicate that cotton will stand a considerable amount of alkali and will even grow when the water table is within a short distance of the surface of the land. The chief ill effect of alkali on cotton is that it causes the seed to germinate poorly. However, those seeds which do germinate grow fairly well and seem to produce normal plants and normal yields.

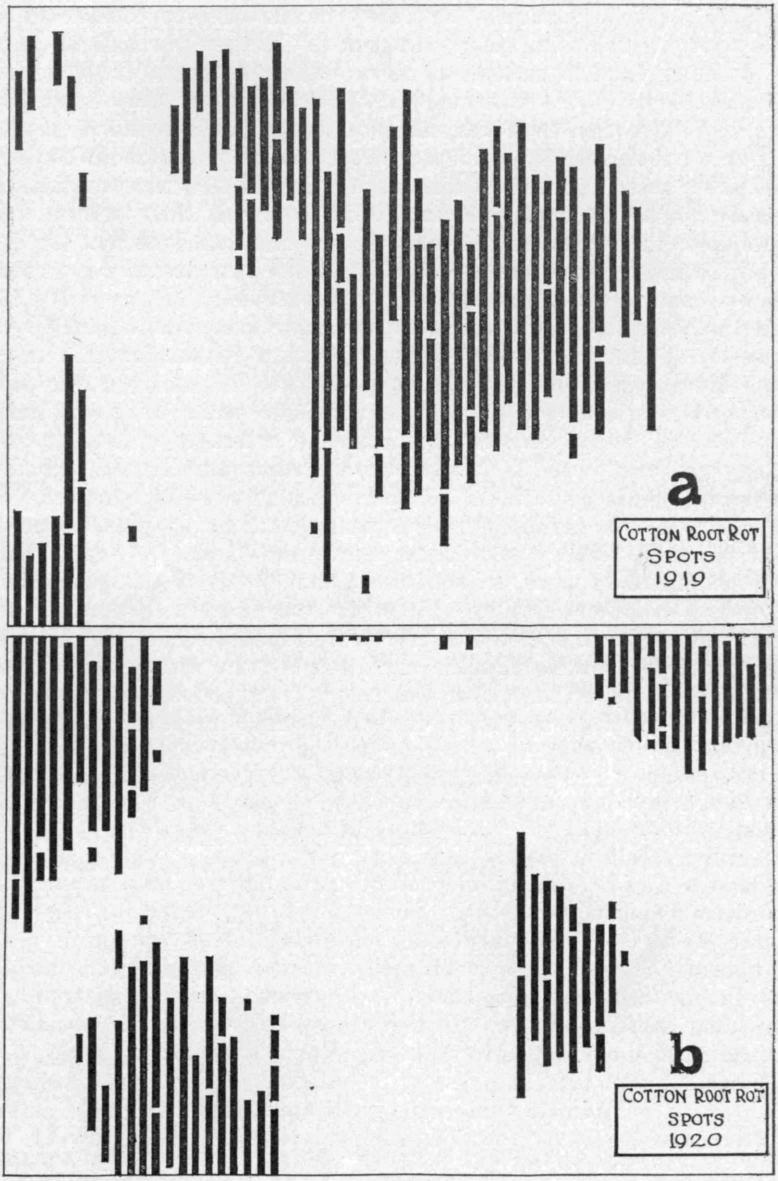


FIGURE 6.

a and b. Comparing a root rot spot during 1919 and 1920, both of which years were favorable for the disease. The black lines represent dead cotton plants in the rows.

Table 22. Chemical analyses of soil from root rot spots.*

Sample No.	Origin of spots	Per cent Nitrogen	Active phosphoric acid parts per million	Active potash parts per million	Acid consumed per cent.	Soluble salts parts per million
2	Okra dying from root rot....	0.153	21.3	375.0	100.0	107
Subsoil to No. 2	Subsoil to No. 2............	0.143	16.9	287.5	100.0	82
3	Healthy okra plant.........	0.152	17.5	295.0	100.0	61
Subsoil to No. 3	Subsoil to No. 3...........	0.128	9.4	88.7	100.0	81
4	Apple tree dying from root rot.....................	0.156	22.5	376.9	100.0	70
Subsoil to No. 4	Subsoil to No. 4............	0.157	16.9	276.2	100.0	70
5	Healthy apple tree..........	0.137	17.7	273.1	100.0	39
Subsoil to No. 5	Subsoil to No. 5............	0.129	12.5	278.7	100.0	67
6	Healthy cotton plant.......	0.140	26.3	268.1	100.0	78
Subsoil to No. 6	Subsoil to No. 6............	0.143	34.4	138.7	99.7	50
7	Cotton plant dying from root rot.....................	0.134	14.8	225.0	99.7	38
Subsoil to No. 7	Subsoil to No. 7............	0.175	16.9	118.7	100.0	20
9	Dead grape killed by root rot.....................	0.112	6.8	159.3	100.0	31
Subsoil to No. 9	Subsoil to No. 9............	0.110	5.0	63.7	100.0	45
10	Healthy grape.............	0.113	5.6	174.3	100.0	34
Subsoil to No. 10..........	Subsoil to No. 10...........	0.100	5.0	48.7	100.0	48

*These analyses were made by Dr. G. S. Fraps, Chief Chemist of the Texas Agricultural Experiment Station.

Pammel (15) refers to claims by growers that the Texas root rot disease is brought about by soil acidity—probably sulphuric acid in the heavy black lands. This acid is believed to be formed by the decomposition of iron sulphate present in the soil. Through the influence of sunlight and air, the iron sulphate is brought up to the surface by the cultivator or the plow. Through the action of air and sunlight, it is finally transformed into free sulphuric acid, which kills the plants. Such acid spots, it is claimed, grow wider and wider as the iron sulphate increases. Experiments by Pammel (15), however, show that cotton may tolerate as much as 2½ per cent. solution of iron sulphate without dying. It might be interesting to further add that some growers believe that when the land is plowed wet the plants in that land will die from the root rot disease. Others claim that Texas root rot is brought about when cultivation of the cotton is suddenly stopped for two or three weeks and this is followed by heavy rains, and the land is worked when still wet. Others still believe that the rains during June and July are directly responsible for the dying of the cotton. For this reason, it is not uncommon to find people claiming that an overflow in heavy, bottom lands will cause the Texas root rot disease.

FUNGOUS NATURE OF THE DISEASE.

Pammel (15) was the first to have suspected and to believe that *Phymatotrichum omnivorum* (*Ozonium omnivorum*) was the cause of the Texas root rot disease of cotton, as he states that "It has been amply proved that Ozonium (Phymatotrichum) is the cause of root rot. (*Experimental proof not stated.*) It is universally admitted that where the disease is once established, cotton will die year in and year out unless checked. If sweet potatoes, grapes, mulberries, apples,

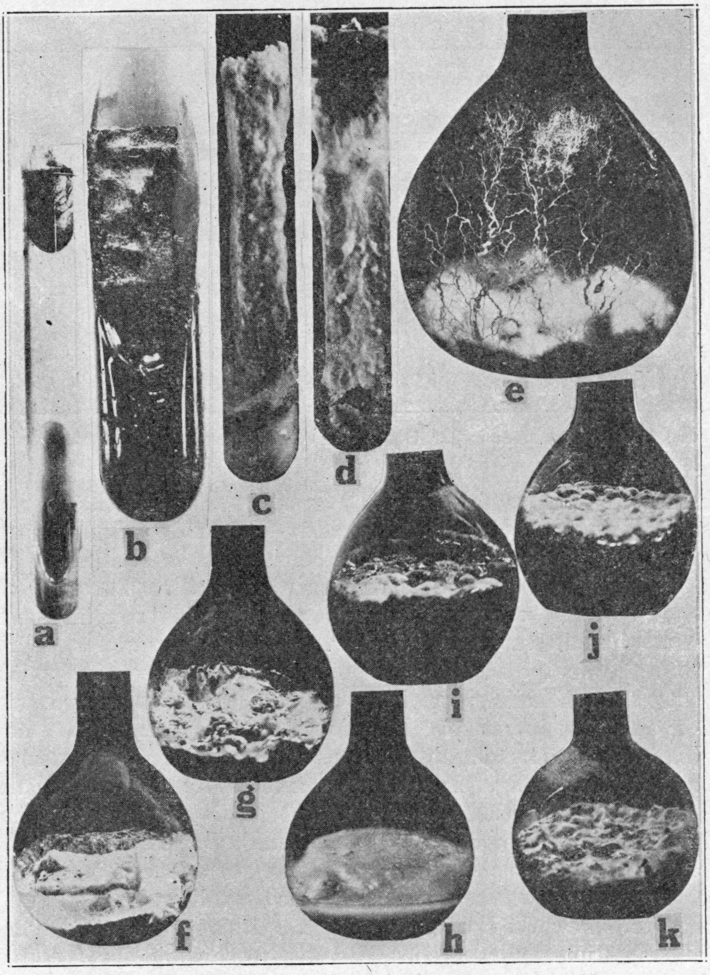


FIGURE 7.

a. Showing method of isolating *Phymatorrichum omnivorum* by dropping in a surface sterilized section of freshly infected cotton root into a sterile tube slant of agar agar. b. Same as *a,* two weeks later, showing growth of the causal organism. c. Test tube cultture of *P. omnivorum* on sterilized mulberry stem. d. Same as *c,* two weeks older, showing sclerotia formation at the mouth end. e. Showing strand formation on glass wall of a culture of *P.* omnivorum. f. *P. omnivorum* grown on sterilized slices of Irish potato. g. On sweet potato slices. h. On potato starch. i. On navy beans. j. On rice. k. On crushed cotton seed (*e* to *k,* cultures grown in 500 c.c. Ehrlmayer flasks).

chinaberry trees, cowpeas, and other susceptible crops will follow each other, they will all die in the same way and from the same cause, namely, Ozonium." We shall soon show that Pammel was correct in his belief of the fungous nature of Texas root rot.

Isolation of Phymatotrichum Omnivorum. It has already been mentioned that Pammel (15) strongly suspected that Ozonium (*Phymatotrichum omnivorum*) was the cause of the Texas root rot disease. He attempted to grow the organism on artificial media, but without success, as he would nearly always wind up with contamination of a varied mycological flora, consisting of such fungi as Tricothecium, Verticillium, Cladosporium, species of Mucor, and putrefying bacteria, but no Ozonium. Atkinson in writing to Curtis (3) states, "I am trying to obtain a pure culture of Ozonium, but I find it much more difficult to transplant with success." However, be it said to the credit of Atkinson (1) that he was the first to have succeeded in growing *Phymatotrichum omnivorum* in pure culture by adopting the following rather crude method. He first secured fresh material of infected cotton stalks from Texas, and then rinsed the roots of these plants in distilled water. He then cut the roots into small pieces and placed them on sterilized filter paper which was lying on sterile sand in a moist chamber. In a few days, the Ozonium (Phymatotrichum) strands grew out from the infected tissue over the paper on the sterilized slides. He then took bits of sterilized cotton roots and placed them in contact with the advancing hyphae. When the hyphae started to grow on the sterilized bits of cotton roots they were transferred to various media. That Atkinson (1) grew the fungus on culture media there seems no doubt. However, the senior writer in duplicating this method found it very tedious and not always reliable, as secondary infection would readily get in in spite of the greatest precaution.

Not only did Atkinson have difficulty in isolating the Ozonium (Phymatotrichum) fungus in pure culture, but Duggar (4) states that "The organism is none too readily isolated." Shear (20) and Shear and Miles (21 and 22) do not state whether or not they have ever grown Ozonium in pure culture. However, Miles has written to one of us stating that he had no trouble whatsoever in growing *Phymatotrichum omnivorum* in pure culture.

The first attempt by the senior writer met with considerable disappointment. In fact, during 1917 and 1918, it is doubtful if we ever had the organism growing pure on media. However, and after discarding numerous methods, we adopted Atkinson's method of isolation, but modified it as follows: Freshly infected cotton plants were secured from Temple, Texas, and immediately shipped to College Station. These plants after arriving at destination, were carefully washed in running tap water to remove every trace of soil particles, and the tops cut off and discarded. These roots were then cut up into small pieces and everything discarded except bits one-half inch long, which were taken from the area immediately adjoining the healthy tissue, and consisting of partly healthy and partly diseased tissue. These pieces were then disinfected for one-half minute in an ordinary test tube in a solution made up of equal parts of 1-1000 mercuric chloride and 50 per cent. alcohol. The disinfectant was then drawn off and the pieces of root tissue washed four times in sterilized water to remove all traces of the disinfectant. After this each piece of the root tissue thus treated was inserted in a slanted tube of solidified sterilized agar agar media. (Fig. 7, a.) After three to five days the Ozonium would grow out on the surface from the tissue within (Fig. 7, b); then on the agar slant. It was necessary, each time, to make a large series of cultures before the organism was finally obtained. During each attempt 100 to 300 tube cultures were thus made, and out of these, on an average, only 5 per cent. gave a growth of *Phymatotrichum omnivorum.* From these tubes the fungus was then transferred to other tubes of sterilized agar agar media or to various vegetable media (Fig. 7, c to k) and in this way and by repeated transfers, accompanied by microscopical examinations, it was made certain that the *Phymatotrichum omnivorum* fungus was isolated pure.

Once a pure culture of *Phymatotrichum omnivorum* is obtained, it may be transferred to practically all sorts of sterile media consisting of agar agar or of cooked vegetables, etc.

We have already mentioned the difficulty met with, especially by beginners, when attempts are made to isolate *Phymatotrichum omnivorum* in pure culture. In this connection, it should be added that the writers were not able to isolate the causal organism from any susceptible roots which had been dead more than two or three weeks.

ARTIFICIAL INOCULATION.

Pammel (15) not only desired to isolate the causal organism, but he also tried some artificial inoculations with the hope of proving that the Ozonium (*Phymatotrichum omnivorum*) was the cause of the Texas root rot disease. Pammel (15) noticed that plants that died from the Texas root rot disease were always superficially covered by threads of the causal fungus. However, since he found it difficult to isolate the organism, he, of course, did not prove its parasitism. Duggar (4) states, "It seems that no successful inoculation experiments have been reported with this fungus (*Phymatotrichum omnivorum*). During two seasons, I have attempted to transfer the disease to potted cotton plants in the greenhouse. Diseased roots of cotton and alfalfa showing an abundance of the fungus were placed beneath the soil in contact with the healthy roots of half-grown plants. In every case, the fungus failed to spread and after a few months seemed to be dead." Duggar (5), in a further attempt to carry on artificial inoculations, writes, "It should be said that no inoculations carried out in the greenhouse up to the present have given positive results. As a source of infection, I have employed (a) diseased cotton roots, fresh from the field (showing the Ozonium in abundance); (b) fresh conidia of *Phymatotrichum omnivorum,* and (c) cultures from diseased roots." It thus seems that although various workers have considered *Phymatotrichum omnivorum* to be the cause of the Texas root rot disease, yet this was only merely through circumstantial evidence, as proof was still lacking.

The circumstantial evidence of the fungous nature of Texas root rot may be summarized as follows: (a) *Phymatotrichum omnivorum* from its field behavior does not seem to be a wound parasite, but seems to be able to penetrate its host either by breaking through the cell wall of the epidermis or through some lenticle. (b) From our own studies we believe that *Phymatotrichum omnivorum* is unable to subsist on dead plants or on organic matter in the soil. At least, it cannot do so through its fungus threads only. On the other hand, it lives and thrives continuously on live susceptible roots which it infects during the summer months, and on living but dormant susceptible roots during the winter months, indicating its probable parasitic nature. (c) *Phymatotrichum omnivorum* always seems to start from a given center of infection and progresses in a definite way killing healthy plants as the fungus spreads and reaches out to the roots of adjoining healthy plants. (d) When a susceptible host is killed by the so-called Texas root rot disease, the typical fungus threads of *Phymatotrichum omnivorum* are always present and can be seen even with the naked eye on the affected roots. (e) Affected plants die progressively, one by one, and in the same ratio as the mycelium of *Phymatotrichum omnivorum* is able to reach out from the infected plant which overlaps and touches the roots of another adjoining healthy, susceptible host. (f) All susceptible plants when infected exhibit symptoms common to all. (g) *Phymatotrichum omnivorum* seems to kill its host by means of an enzyme. This is evidenced by the fact that there is always a dark area preceding the area in which the Phymatotrichum fungus is found. This dark area as far as has been tested, seems to be sterile, that is, free from fungus hyphae. (h) Young plants may die without affecting adjacent plants while older plants with a better developed root system generally die progressively within a few days from the outbreak of the infection of the first plant due no doubt to an overlapping of the root system.

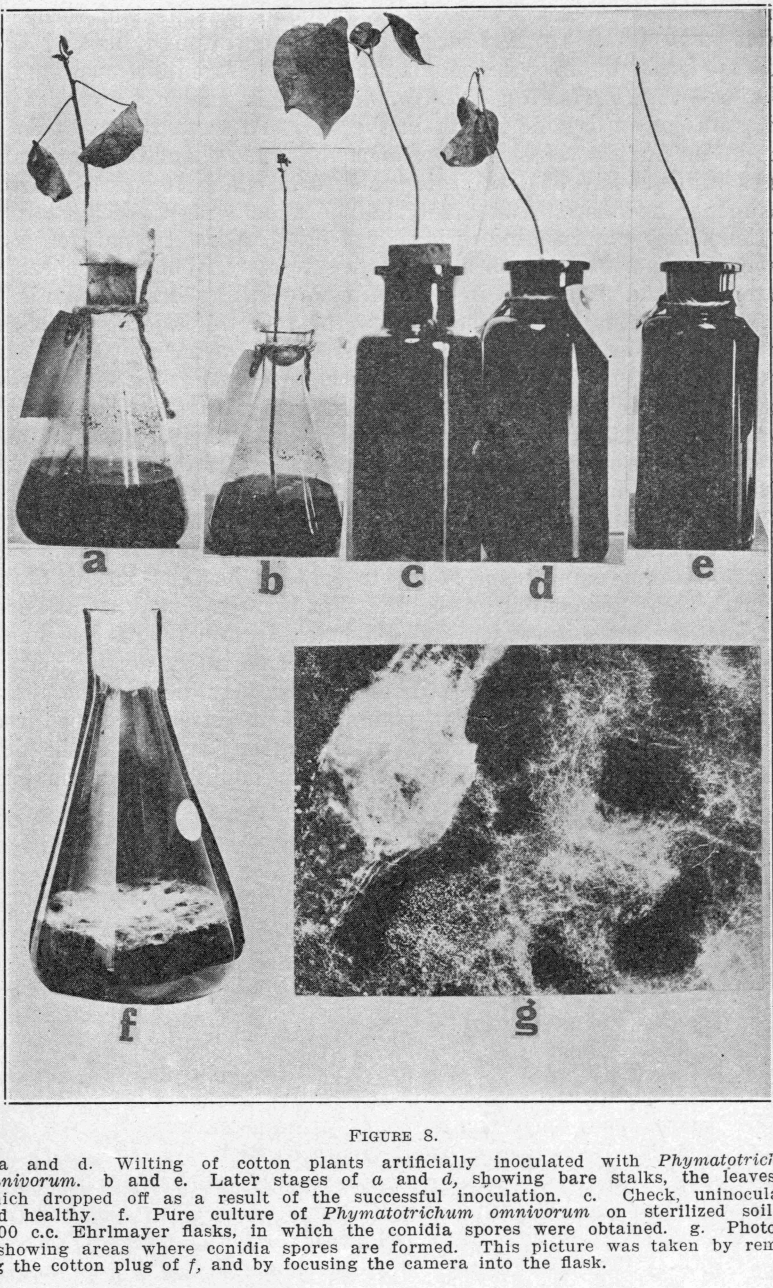


FIGURE 8.

a and d. Wilting of cotton plants artificially inoculated with *Phymatotrichum omnivorum*. b and e. Later stages of *a* and *d,* showing bare stalks, the leaves of which dropped off as a result of the successful inoculation. c. Check, uninoculated and healthy. f. Pure culture of *Phymatotrichum omnivorum* on sterilized soil in 1000 c.c. Ehrlmayer flasks, in which the conidia spores were obtained. g. Photo of *f* showing areas where conidia spores are formed. This picture was taken by removing the cotton plug of *f,* and by focusing the camera into the flask.

Table 23. Unsuccessful inoculation experiments.

Date Inoculated	Place of Inoculation	Method of inoculation	No. of plants inoculated	Results
Aug. 4, 1918	Substation No. 5	Placed roots of freshly-infected cotton plants near roots of healthy scratched plants and covered with soil	15	No infection
Sept. 7, 1918	Substation No. 5	Placed roots of freshly-infected cotton plants near roots of healthy scratched plants and covered with soil	32	No infection
July 7, 1919	Substation No. 5	Placed freshly-infected beet roots near healthy scratched cotton roots and moistened with sterile water	17	No infection
July 15, 1919	College Station Greenhouse	Placed freshly-infected cotton roots near healthy scratched cotton roots growing in galvanized tank in steam sterilized soil and moistened with sterilized water	48	No infection
July 15, 1919	College Station Greenhouse	Checks	10 checks	No infection
July 15, 1919	College Station Greenhouse	Placed freshly-infected beet roots near cotton roots growing in galvanized tank in steam sterilized and moistened with sterilized water	52	No infection
Sept. 5, 1920	College Station Greenhouse	Placed bits of mycelium from a tube (pure culture) *Phymatotrichum omnivorum* near healthy scratched cotton roots growing in galvanized tanks in steam sterilized soil and moistened with sterilized water	43	No infection
Sept 5, 1920	College Station Greenhouse	Check	10 checks	No infection

Unsuccessful Inoculations. In 1918, 1919, and 1920, the senior writer attempted to carry out inoculation experiments on cotton grown both in the field at Temple, Texas, and in the greenhouse, but with negative results (see Table 23). Soil collected directly from spots where cotton died in the field was shipped from Temple, Texas, to College Station and placed in six galvanized tanks of a capacity each of 4x3x2½ feet. Cotton was then planted in all the six tanks during 1918, 1919, and 1920. The methods of inoculation and the negative results obtained are indicated in Table 23, which is self-explanatory.

Successful Inoculations. Our new method of inoculation was as follows: Transfers of pure cultures of *Phymatotrichum omnivorum* were made on pieces of sterilized stems of either mulberry or cotton roots in tubes. After ten days from the time of the original transfers, the fungus grew very luxuriantly on these vegetable plugs in the tubes (Fig. 7, c and d). At the same time cotton plants six weeks old which were more or less woody, apparently healthy, and fairly well developed were carefully washed in running tap water, without bruising any parts of the plant; then the roots were quickly dipped into a solution consisting of equal parts of 50 per cent. alcohol and 1-1000 mercuric chloride, and again dipped in sterilized water to remove all traces of the disinfectant. Each of these plants was then planted, singly in bottles (Fig. 8, a and c) which contained steam-sterilized soil. The bottles (Fig. 8, c) were closed with a cork, the center of which was burned out by a hot iron rod to permit the ready introduction of the root of the cotton plant above mentioned (Fig. 9, a). Eight bottles were thus planted each with one individual cotton plant and permitted to remain for four weeks until we were fully satisfied that the transplanted cotton plants were fully alive and had actually developed new roots and leaflets, the older foliage in most cases having dropped off through the shock of transplanting. On December 30, 1921, actively-growing pure cultures of *Phymatotrichum omnivorum* on either sterilized mulberry stems or cotton roots were used for inoculation purposes (Fig. 7, c and d). One tube was used to inoculate one bottle at a time. Under aseptic conditions, the entire mulberry stem or cotton root, as the case might have been, containing vigorous growth of *Phymatotrichum omnivorum,* was taken out from the tube and introduced into the bottle in which the healthy plant grew. This was done by carefully removing the perforated cork of the bottle, which slid back with ease on the cotton stem (Fig. 9, a). Then a pure culture of *Phymatotrichum omnivorum* that had been grown on a sterilized mulberry stem in a test tube (Fig. 7, c) was introduced into the bottle and placed on the soil at the foot of the cotton plant (Fig. 9, a). With a sterilized cool glass rod, this culture was gently pressed into the soil and the cork of the bottle closed again. Six bottles with six cotton plants were thus inoculated and two were left as checks. On January 3, 1922, wilting (Fig. 8, a and d) of all the inoculated plants became evident. On January 4, wilting of the inoculated plants was very pronounced. On January 5, the leaves began to shrivel. On January 10, the leaves of all inoculated plants dropped off (Fig. 8, b and e). When the inoculated plants were examined, they were all found to be killed and the foot end of the inoculated plant was overrun by Ozonium threads, whereas the two checks remained alive (Fig. 8, c) and remained so for five months, when they were used for other experimental purposes. Three of the inoculated plants were then chosen with a view of recovering the original fungus used for inoculation. The method employed was similar to that described for isolating the organism from infected plants secured from the field (see page 57). The results of the re-isolations were positive to the extent that out of 25 tube cultures made of the roots of these three inoculated plants, 14 yielded growth of *Phymatotrichum omnivorum.* The others did not show any growth whatsoever.

Not content with the first series of inoculations, it was decided to duplicate the experiments. Accordingly, on January 3, 1922, eight more healthy cotton plants, five weeks old, were secured and planted in sterilized soil in bottles, the same method being used here as was used in the first inoculation experiment. On February 3, 1922, four of the plants in the bottles were inoculated, the same method being used as was described in the first experiments, and four were left as checks. On February 6, all inoculated plants began to wilt, and on February 9 all inoculated plants were dead, exhibiting the typical root rot symptoms as found in the field, whereas the checks remained alive. As in the first series of inoculations, the fungus was again recovered. From these artificial inoculation experiments, it was proved for the first time that not only Pammel, but all the other workers referred to in this work, were correct in assuming that *Phymatotrichum omnivorum* is the true cause of the so-called Texas root rot disease of cotton and all other susceptible hosts. These inoculation experiments seem to prove that *Phymatotrichum omnivorum* is the cause of Texas root rot.

Natural Methods of Field Infection. We have already stated above that we have been able to induce artificial infection by placing the inoculum near the foot of a non-injured healthy cotton root. This would indicate that *Phymatotrichum omnivorum* is not necessarily a wound parasite. Duggar (5) believes that field infection is probably effected by penetration of the mycelium in the lenticles of the cotton roots. He further states that in all cases of infection, a depression of the bark on the root is immediately noticed, which would indicate the area of penetration of the organism into the root tissue.

We have fixed and imbedded in paraffin over 150 specimens of cotton roots as well as sweet potato roots which show early stages of natural infection in the field. These imbeddings were made with the hope of finally sectioning and staining them so as to make out whether infection is by means of fungus hyphae penetrating through lenticles in the roots, or through actual breaking through the epidermal cell wall. However, we have not as yet been able to section and stain these specimens; hence these must be reserved for future work. Like Duggar (5), we have noticed time and again on okra, cotton, sweet potatoes, castor bean, and many other susceptible hosts that during early infections, there first appear slight depressions where freshly infected root touches the living healthy root and where the fungus threads of *Phymatotrichum omnivorum* bridge over from a recently infected host to a neighboring, adjacent healthy one. This depression is probably due to enzymic activity which the causal organism secretes before actually penetrating the host. This, however, is to be further verified by careful study. Repeated field observations on cotton seem to indicate two methods of infection: (a) The first method is that in which the main tap root is first affected. In this case the tap root usually comes into contact with some infected roots of a susceptible weed host in the soil. Once the tap root is infected, the disease spreads and advances upward, encroaching on nearly all the lateral roots and sometimes working up one or two inches above ground on the foot of the plant. (b) The second method is that in which one or more lateral roots are first attacked and the fungus gradually works and spreads downward to the main tap root and to the other laterals. In this case, infection of the laterals usually begins when roots of a healthy cotton plant which happen to touch the laterals of a neighboring cotton plant recently infected by the Texas root rot disease. This is the common occurrence in the field during the summer months. Whether infection starts first at the tap root or with the laterals, the infected herbaceous host succumbs and is completely dead within two or three days after infection. With trees, it probably must require weeks and may be months before the causal organism is able to attack and to invade the great mass of the entire root system.

NAME OF THE CAUSAL ORGANISM.

Pammel (14) was the first to describe and to name the fungus of the Texas root rot disease as *Ozonium auricomum* Link. Curtis (3), quoting a letter from Professor G. F. Atkinson, then of the Alabama Agricultural Experiment Station, states (Atkinson's statement): "The fungus was determined by Pammel as *Ozonium auricomum,* but I have my doubts about that being the proper determination and I think also that Pammel has." It is thus seen that Atkinson was practically the first to question Pammel's correctness in naming the fungus of the Texas root rot disease. Shear (20), like Atkinson, did not think that Pammel's Ozonium found in Texas was the same as the *Ozonium auricomum* which is very prevalent in Germany. Fortunately, Shear (20) after his trip to Berlin and examining Link's type of *Ozonium auricomum,* convinced himself that this fungus was quite different from the one found by Pammel in Texas. Consequently, Shear renamed Pammel's Ozonium *Ozonium omnivorum* (Pammel) Shear. According to Shear (20) both *Ozonium auricomum* and *O. omnivorum* slightly resemble each other in color but differ markedly in every other respect. *Ozonium auricomum* produces mycelium, which is more loose and lacks entirely the slender tapering branches which arise at right angles and which are so characteristic of *Ozonium omnivorum.* According to Shear (20), *Ozonium omnivorum* is a species universally prevalent in the black lands of Texas, and furthermore, that *Ozonium auricomum* is also present in this state probably as a saprophyte. The writers have as yet been unable to find *Ozonium auricomum.* Suffice it to say that the above species is distinct from *Ozonium omnivorum* and, even if present in Texas, does not seem to be connected in any way with the true Texas root rot disease. It should be further added that *Ozonium omnivorum* is the name given to the sterile stage of this fungus.

CONIDIA SPORE STAGE.

Plant pathologists and mycologists in studying plant pathogens always endeavor to work out and to connect up the various possible spore stages which the organism may have. This is not only valuable from a systematic point of view, but is of utmost importance in studying the life history of the parasite and the various methods with which it perpetuates itself. With reference to the Texas Ozonium, Pammel (15) believed it to be connected with some spore-forming Pyrenomycete. He based his conclusions on observations of infected sweet potato specimens on which he found typical Ozonium mycelium as well as numerous black perithecia-like bodies. Shear and Miles (21 and 22) state that the root rot fungus is suspected on strong circumstantial evidence of producing one or more spore stage forms through which it may be spread about broadcast. However, they neither described or named any such spore stages. Thornber (27) was really the first one to have met with and described a fruiting stage of *Ozonium omnivorum,* which occurred on affected alfalfa plants, but which he did not name. The following is his own statement: "It develops continuously on the ground along the outer margin of the zone of dying plants and immediately above the matted fungus mycelium which develops on the surface of the ground during hot, moist periods from July to September or October. This fruiting stage is developed and matures in the course of a few days, after which it disappears. It first appears as a flattened cushion-like filamentous mass varying in extent of about 2 to 10 or more inches in diameter, and about one-fourth inch in thickness. When young, it is creamy white in color, surrounded by a series of white radiating hyphae. With age it becomes light yellowish brown and soon breaks up into a fine powdery spore mass which imparts to the immediate area a characteristic fawn color. Near the cushion is found the characteristic Ozonium mycelium. Among this mycelium appear hyphae whose branches thicken at the extremities and the spores develop laterally and terminally, singly and in clusters. The spores are smooth, nearly colorless, globose to ovate. The spores range from 10 to at least 36 to the conidiophore, and these are growing over the entire swollen portion of the conidiophore. The spores measure about $4\frac{1}{2}$ to 7 microns in diameter. The conidiophores are about $14\frac{1}{2}$ to 25 microns in diameter."

Among the many other claims in connecting Ozonium with various fruiting stages of fungi, may be mentioned that of Schroeter, who believed that some species of Ozonium developed into *Coprinus radians*, one of the common toad stools. Penzig (16) believed that Ozonium developed into a species of Coprinus which he named *Coprinus intermedius*. Saccardo (17) and Winter (32) believed that Ozonium was connected with *Agaricus deliquescens*. Duggar (5) found the same conidial form in the field which Thornber had already found and described, but without naming it. Duggar decided that this conidial form belonged to the Hyphomycete group and to the genus Phymatotrichum, which he named *P. omnivorum* (Shear) Duggar. Duggar (5) connected up the genetic relationship of *Ozonium omnivorum* with *Phymatotrichum omnivorum* on the following observations: (a) the presence in the conidial layer of hyphae and strands (bearing conidia) found to be identical with the characteristic mycelium on the roots of affected plants; (b) the identity in artificial culture of a mycelium originating, on the one hand, on diseased roots and on the other, on the germination of the conidia as found in the field. It is thus seen that full evidence was lacking, because it was necessary to produce the Phymatotrichum stage from a pure culture of *Ozonium omnivorum* which was previously isolated from an infected plant in the field. This Duggar has not done. Duggar, however, was correct in his assumption that the *Phymatotrichum omnivorum* fungus was the conidial spore stage of Ozonium, because the senior writer was able to produce the conidiospore stage in a pure culture grown on steam-sterilized soil in a flask in the laboratory. Of six such flasks, one developed the typical *Phymatotrichum omnivorum* stage (Fig. 8, f and g).

In the field, the conidia spores were at first formed on conidiophores at irregular intervals, which usually arise as short assurgent branches. The conidia are formed at the tip end of the swollen conidiophores. Later, spores are formed on any swollen branch of the various hyphae strands. Finally, spore production appears to involve practically the

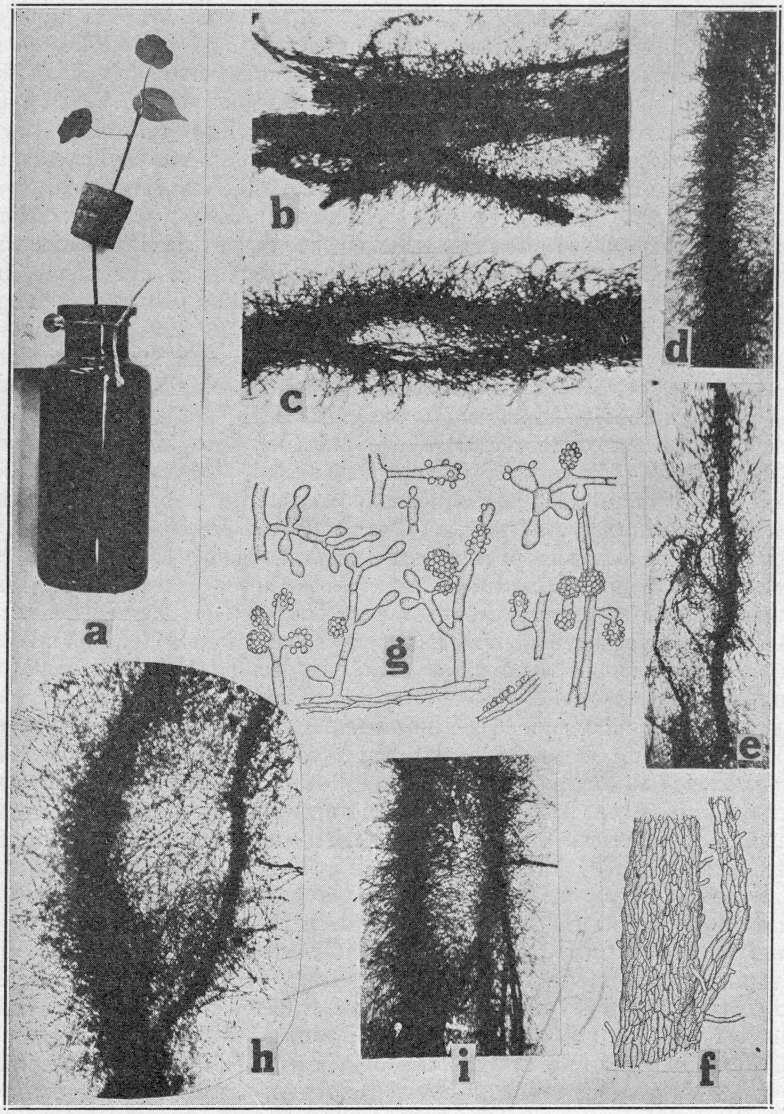


FIGURE 9.

a. Showing method of growing cotton plant in sterilized soil in bottle. The cork stopper is perforated and slides on the cotton stem without bruising it. To introduce the inoculum, the cork is moved up, and then pushed down again. b, c, d, h. and i. Photomicographs of typical strands of Phymatotrichum as found on infected plants in the field. g. Conidia spores of *P. omnivorum*. f. Drawing of a strand to show structure and relationship of both young and old threads (f. and g. after Duggar).

whole mass of mycelium. This then winds up in a pulverulent mass of conidia which are carried away by the wind. The conidia are sessile, or at best are formed on what may appear as minute sterigma.

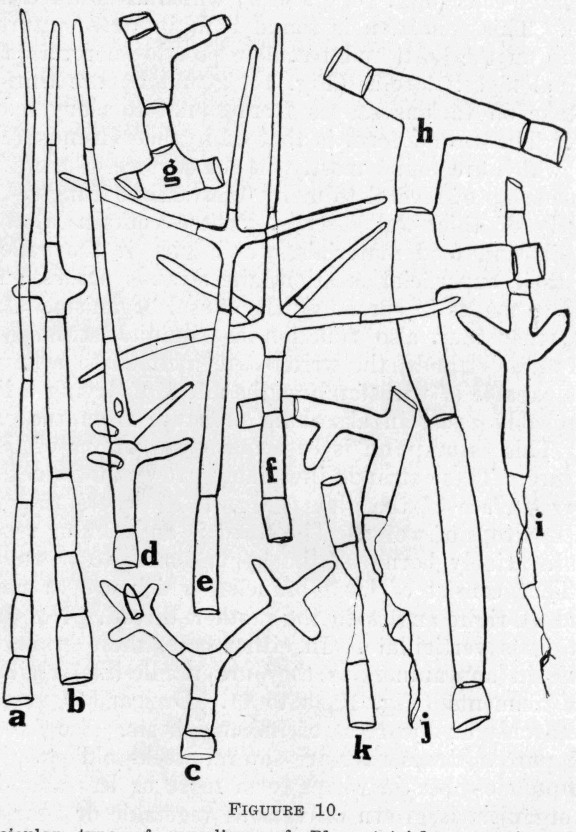
MORPHOLOGY OF PHYMATOTRICHUM OMNIVORUM.

From a scientific consideration, the morphology of this organism is interesting, because such a knowledge helps to distinguish it from other closely related species. Our morphological studies, with but few exceptions, bear out Duggar's (5) description. *P. omnivorum* appears in five different forms. The first form is that of Rhizoctonia-like hyphae, made up of large cells (Fig. 10, g and h) which are formed in a stroma-like cushion. This condition is found both in pure culture (Fig. 11, a and b) and on the host, and resemble pseudo-sclerotia (Fig. 11, b). The individual mycelial cells (Fig. 10, g and h) are thin-walled and frequently take on various shapes from round to elongated, hyalin to deep yellow. The second form is that of hyphae strands (Fig. 9, b to f, h, and i) which are found mostly on the surface of the affected host. These are made up of several to many anastamized fungus threads consisting largely of thick-walled cells. These contain what appear to be various oils and food materials, which give it the yellowish color. Because of their superficial location, the strands act as an anchor to the host and as means in spreading the causal organism. According to Duggar (5), they may also function as conidial stroma. From the structure of these strands, the writers are inclined to believe that they not only are capable of withstanding the effect of drying a little longer, but they probably assist in absorbing moisture from the exterior surroundings. This assumption is based on observations of the organism in pure culture. These strands invariably grow out from the substrata on the inner surface of the glass (Fig. 7, e) where they are usually surrounded by drops of water. The third is an acicular type, which on the host is invariably borne on the hyphae strands or on the pseudo-sclerotia. They consist of loose branches which are in pairs, that is, opposite and at right angles to the mother thread. Not infrequently, too, branching is verticillate. In either case, these branches are very characteristic in appearance, as they are needle-like, rigid, and taper to very fine filaments (Fig. 10, a to f). Duggar (5) states that this type is found only on the roots of infected hosts. We have repeatedly found it in pure cultures that are several weeks old covering the surface of the pseudo-sclerotia which form more or less abundantly when the causal organism is grown on various vegetable or agar agar media. However, this acicular type of mycelium does not seem to be present in young cultures nor on the strands which are abundantly formed on the glass surface in culture media. The writers firmly believe that the function of the acicular type of mycelium is to serve as anchors of attachment of the hyphae strands on the root of the host which they penetrate. The anchoring in this case is due to the penetration of these acicular branches into the host tissue. When numerous acicular branches meet, as they frequently do, they unite and form new secondary hyphae strands. The fourth is that of conidia spores (Fig. 9, g), which are formed at irregular intervals in the field and in pure culture (Fig.

8, f and g). The morphology of the conidial spore stage (Fig. 9, f and g) was fully described by Duggar and bears no repetition here. Fifth, the senior writer has on one occasion met in pure culture with what appeared to be an immature ascus stage which failed to mature. Likewise, Shear in a recent letter to us stated that he found another spore stage of *Ozonium omnivorum,* the nature of which was not disclosed.

PHYSIOLOGY OF PHYMATOTRICHUM OMNIVORUM.

In the study of any plant disease which is induced by parasitic bacteria or fungi, it is always helpful to study not only the disease itself,



FIGUURE 10.

a to f. Acicular type of mycelium of *Phymatotrichum omnivorum.* g and h. Rhizoctonia-like hyphae of *P. omnivorum.* i, j and k. Showing method of breaking down of individual cells of mycelial strands. This is quite common in pure culture and on the host.

but also the behavior of the causal organism. Such studies may frequently throw new light on the limitations of the parasite and usually open the way for promising methods of control. Our studies on the physiology of *Phymatotrichum omnivorum* are as yet incomplete and will form part of a future publication. As a preliminary statement, however, it might be said that when this fungus is handled by beginners it is difficult to isolate. However, when once obtained in pure culture, it will grow on a variety of food.

Of the many kinds of media used, we found that it grows well on cooked beans, cooked rice, cooked Irish and sweet potatoes, cooked crushed cotton seed, mulberry stems, cotton stems, and roots, rose stems, chinaberry stems, and okra stems (Fig. 7, e to k; Fig. 11, a to e). It also grows well on soil agar,* bean agar, and potato agar. On vegetable plugs, especially on sterilized stems of cotton, okra, rose or mulberry, growth in each case is slow, but later copious, white at first, forming a dense mat which seldom arises more than two or three mm. above the substratum and is never fluffy in appearance on the vegetable plug itself. The same is true when this fungus is grown on the other media mentioned; that is, growth at first is very slow, but after ten to fifteen days it becomes rapid and white at first, gradually turning yellowish-gray, with numerous pseudo-sclerotia-like bodies, formed singly or in large masses, flat or slightly raised. When grown on bean or potato agar media,† the pseudo-sclerotia appear as fluffy masses of mycelium scattered here and there, which are at first white, becoming yellowish-gray with age, and formed above the substratum and held by aerial mycelial branches.

One of the peculiar characteristics of *Phymatotrichum omnivorum* in pure culture is the fact that on certain media it secretes black liquid drops (Fig. 7, i), which vary in amount with the media used. On ordinary cooked beans, for instance, or on crushed cotton seed, the black liquid drops become so numerous and abundant as to inundate the surface of the culture. Another peculiarity of this fungus is the fact that it produces considerable water of condensation, which collects on the surface of the interior wall of the glass, and this surface becomes immediately invaded by hyphal strands which grow out from the substratum and cover the sides of the glass. These strands assume various forms of tree-like structure (Fig. 7, e). The fungus frequently attempts to produce pseudo-sclerotia on the strands on the glass, but these seldom develop to the same extent as they do on the substratum.

Phymatotrichum omnivorum grows very poorly on sterilized soil (Fig. 11, c to be compared with a, b, d, and e), and in liquid media. It grows fairly well on potato starch, on which it forms a shiny, glossy layer which is flat and compact. After two or more weeks of growth, the starch is broken down and a copious amount of liquid formed in the glass, the substratum changing color and becoming slightly yellowish to light ochraceous.

We do not as yet know the conditions necessary for the development of the conidial stage in pure culture. As already stated, page 67, we have met with but one instance of conidia and that was in a pure culture grown on sterilized soil in 1000 c.c. Ehrlmayer flask (Fig. 8, f and g). Conidia have also been obtained very sparingly on cultures

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*Made of 1000 c.c. soil broth decoction and 30 grams agar agar.

†In every case where agar agar was added to the medium 30 grams of it was used to each 1000 c.c. of the liquid broth.

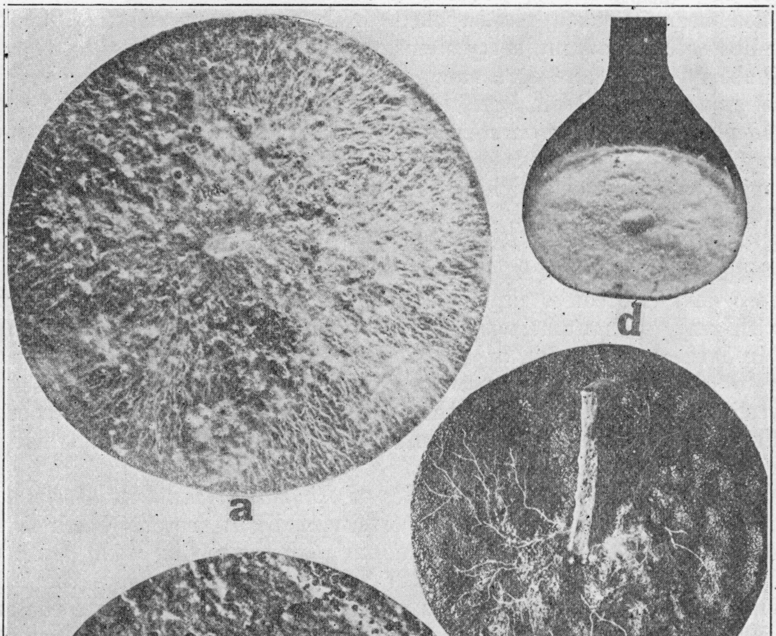

FIGURE 11.

a. Pure culture of *Phymatotrichum omnivorum,* three weeks old, grown on soil agar, showing strands, and beginnings of pseudo-sclerotia formation. b. Same as *a,* but two weeks later, showing nature of flat growth with darkish flat pseudo-sclerotia. c. *P. omnivorum* grown on steam-sterilized soil showing meager growth of scattered surface strands. (a, b, c, grown in 1000 c.c. Ehrlmayer flasks, the walls of which were broken off to make the photographs.) d. *P. omnivorum* grown on bean agar, and e. Grown on white potato agar.

grown on various agar media, but in these cases the production of spores was very meager indeed.

One fact remains very pertinent in connection with the conidia of *Phymatotrichum omnivorum*, and that is, that a satisfactory method of germinating them is still wanting. Duggar (5) states, "Germination in any particular medium has been on the whole erratic." We have made several attempts at germinating conidia spores, fresh material being secured from Professor Brown of the Arizona station, with practically negative results in every attempt. Various ways were adopted: some of the spores were plated out in agar agar media and others were inoculated in Van Tiegheim hanging drop cells in liquid broth made of soil decoction, in sugar solution, etc., with not a single instance showing germination. Professor Thornber of the Arizona station, in corresponding with the writer under date of December 21, 1921, states, "I made a careful study of these (conidia) as best I could and tried in every way possible to germinate them, but without success." Professor Brown of the Arizona station, in a letter dated December 13, 1921, states, "I have made about ten cultures on nutrient agar and none of the spores germinated." Dr. Shear in a letter dated February 28, 1922, states: "We have never had much success in germinating these spores. In fact, I am not sure that we ever actually demonstrated their germination. Whatever growth we got might perhaps have arisen from bits of hyphae." We have purposely referred to these statements of other workers to show that there must be some fundamental requirement or condition favoring the conidia spores in nature, where they probably do germinate. This much is evident, that without being able to germinate the conidia, we cannot definitely explain their function.

It should be stated that in growing *Phymatotrichum omnivorum* in pure culture, we have tried vegetable plugs as tube cultures, agar agar media in petri dishes and on sterilized plant material. We found that after a comparatively short time—say five or eight weeks,—the causal organism would dry up in tube cultures and more especially in petri dishes. However, when grown in Ehrlmayer flasks, whether using plant material or agar agar, we have been able to maintain the fungus alive in the flasks for over six months without resorting to fresh transfers. We found that a 500 c.c. Ehrlmayer flask answered the purpose well. When agar agar was used, we placed 300 c.c. of the media in each flask, and when vegetable material was used, 100 to 200 grams. We have not, as yet, definitely determined how long *Phymatotrichum omnivorum* will retain its viability in old cultures and whether it loses its power of infection when grown on artificial media for one or more generations. These are phases to be worked out in the future.

A further peculiarity of the *P. omnivorum* fungus is that the hyphal cells readily break down and die through plasmolosis of the cell content. This is also met with under pure culture conditions when the older growth dies and is superseded by new cells (Fig. 10, i, j and k).

EFFECT OF THE TEXAS ROOT ROT DISEASE ON THE HOST.

Mention has already been made on page 63 that, as a result of the first penetration and invasion of the causal organism, wilting begins and after twenty-four to forty-eight hours the epidermis and the cambium layer of the roots and the foot end of the affected plant become softened and in time may peel off readily. Shear and Miles (21) and Stevens (23) state that the fungus destroys the rootlets and the external surface of the roots, invading the fibro-vascular system. The writers believe that the causal organism first invades the cambium layer, which results in the killing of the affected root. From the cambium, the fungus continues to work inward into the fibro-vascular bundles and the pith. Dying of the host results after the tap root and most of the secondary roots and rootlets have been invaded.

MYCOLOGICAL FLORA ISOLATED FROM INFECTED DEAD COTTON ROOTS.

Mention has already been made of the fact that a pure culture of *Phymatotrichum omnivorum* may be obtained from freshly infected cotton plants. However, as soon as the host has been thoroughly killed after a period of ten to fifteen days, the causal organism disappears and a rich mycological flora takes its place. The following fungi have been repeatedly isolated by us from dead cotton roots after the *Phymatotrichum omnivorum* had disappeared: Fusarium; a species of Dendryphium, identified by Miss A. E. Jenkins of the United States Department of Agriculture, as *D. cladosporoides,* Ell. and Ev.; *Cephalothecium roseum; Tricothecium roseum;* Penicillium sp.; *Aspergillus glaucus; Penicillium glaucum;* a species of Sphearopsis; a species of Alternaria; and a species of Verticillium.

LIFE HISTORY STUDIES.

From previous discussions, it is evident that nearly every phase of the Texas root rot disease, especially as it concerns practical methods of control are based on a thorough knowledge of the life history of *Phymatotrichum omnivorum.* In connection with these studies, it became apparent that control methods depended on a solution of the following phases:

IS PHYMATOTRICHUM OMNIVORUM A STRICT PARASITE, A SAPROPHYTE, OR A SEMI-PARASITE?

Pammel (14) believed that *Phymatotrichum omnivorum* might probably maintain itself from year to year as a saprophyte on dead organic matter. His conclusions were based on field observations at Independence, Texas, where a number of cotton fields were badly infected with the Texas root rot disease during 1888. These same fields were devoted to corn in 1887. Since corn was not a susceptible host, Pammel reasoned that the causal organism must have lived over in the soil or dead organic matter as a saprophyte. Furthermore, he believed that the *Phymatotrichum omnivorum* fungus might probably live even on the dead corn stalks and roots. This, however, is not true, and we suggest that the reason cotton dies in the fields where corn grew the year previous is that, as is generally the case, susceptible weed hosts are nearly always present in the corn field and around the fences (Fig. 12, a to c, and Fig. 13, a), and these weeds may maintain the causal organism until the following year when cotton follows corn.

In order to definitely determine whether or not *Phymatotrichum omnivorum* remains viable on dead cotton or other susceptible hosts after they are killed by it, a series of experiments were undertaken with a view of ascertaining whether or not it is possible to isolate the fungus from affected plants which were killed and remained dead in the field for various lengths of time. Of the many cultures carried out, only the 1921 data are given and these practically bear out the results of culture work during 1919 and 1920. From Table 24, it is evident that *Phymatotrichum omnivorum* seems to die with the eventual death of its host, since at no time were we able to isolate a fresh viable culture from dead cotton plants or any other susceptible host after it had been killed by the disease more than ten to twenty days. Similar results are further emphasized in Tables 25 and 26.

Table 24. Longevity of Phymatotrichum on undisturbed dead plants in the field.

Source of material	Date cultured	Per cent tubes showing viable Phymatotrichum
Freshly infected cotton roots	July 15, 1921	10
Cotton roots killed by root rot and remaining for 26 days undisturbed in the field	July 15, 1921	0
Freshly infected cotton roots	Sept. 23, 1921	9
Cotton roots killed by root rot and remaining for 40 days undisturbed in the field	Sept. 23, 1921	0

DOES PHYMATOTRICHUM OMNIVORUM LIVE OVER IN THE SOIL?

In referring to the literature on *Phymatotrichum omnivorum,* one finds occasional statements to the effect that the causal organism of the Texas root rot disease does live over in the soil. Thompson and Wood (26) claimed that the causal organism of root rot of cotton (referring to Phymatotrichum root rot) is capable of living over in the soil from year to year. However, no experimental data were given to support this statement. Duggar (5) in speaking of the strand hyphae of *Phymatotrichum omnivorum* states, "They are also more or less sclerotial and are doubtless an important factor in the persistence of the fungus in the soil." It is true that *Phymatotrichum omnivorum* does produce on the host and in pure culture sclerotia-like bodies. These, however, are much of the nature of pseudo-sclerotia, and do not seem to be able to survive during the winter months on a dead host or in the soil. All our evidence on hand tends to show that *Phymatotrichum omnivorum* is unable to live as such in the soil as ordinary mycelium without the presence of a living host. If this were not so, a root rot spot one year would invariably mean a root rot spot another year if a susceptible host were grown again on that same spot. We have already referred on page 53 to the fact that very

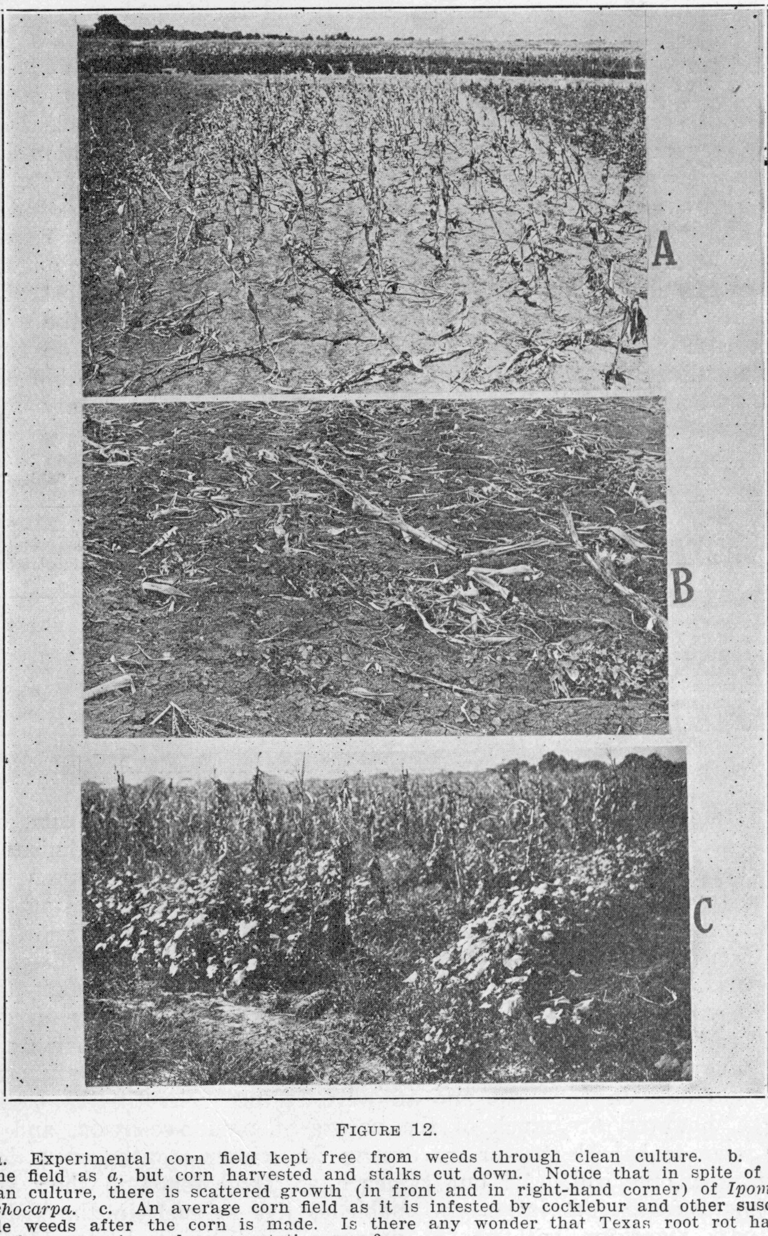

FIGURE 12.

a. Experimental corn field kept free from weeds through clean culture. b. The same field as *a*, but corn harvested and stalks cut down. Notice that in spite of the clean culture, there is scattered growth (in front and in right-hand corner) of *Ipomoea trichocarpa*. c. An average corn field as it is infested by cocklebur and other susceptible weeds after the corn is made. Is there any wonder that Texas root rot hangs on where corn is used as a rotation crop?

frequently a root rot spot one year is not necessarily a root rot spot another year, if every susceptible host, including weeds, happened to be killed out by the disease in that spot during the previous year. Those who have studied the Texas root rot disease as it affects alfalfa

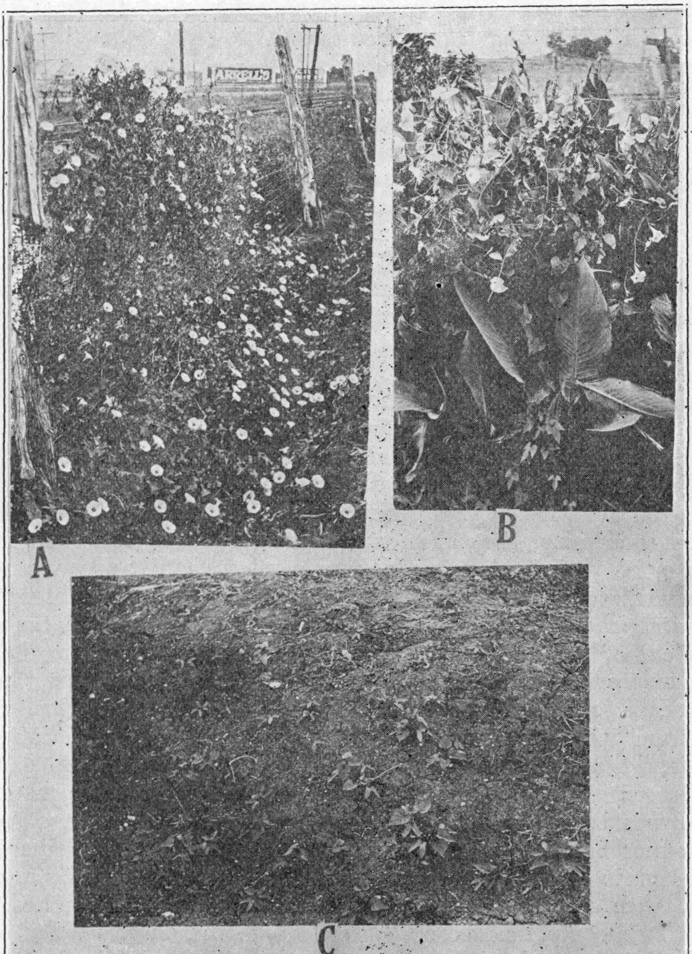

FIGURE 13.

a. Small-flowered Pink Morning Glory (*Ipomoea trichocarpa*) trailing on fences. In this way the survival of this weed is doubly insured, namely, by producing large quantities of seed, and through its fleshy undisturbed perennial roots in the soil. b. *Ipomoea trichocarpa* trailing on cannas and acting as a carrier of Texas root rot in the flower garden. c. View of a portion of a plowed up wheat stubble. One good rain after the plowing of the stubble land caused the *Ipomoea trichocarpa* to sprout from pieces of roots of this weed unharmed by the previous wheat crop.

are familiar with the fact that a root rot spot increases in area as the years succeed each other. In this way there is not a single living alfalfa plant in the interior, although the disease spreads gradually from the interior of the spot to the outer periphery. Furthermore, in order to minimize the losses from this disease, alfalfa growers are in the habit of re-sowing the dead spots in order to obtain some kind of a fair yield. Immediately, and as soon as this spot is re-sown, the plants remain healthy and alive for nearly two years until the disease begins to work and crowd in from the exterior of the spot into the interior. If *Phymatotrichum omnivorum* could live in the soil independent of any living host, the reseeded alfalfa would have died the same year. As a further evidence, we might cite the following observation. Ordinarily, we assume that when cotton is grown for a number of years on the same land that the Texas root rot disease would become worse from year to year. This, however, does not seem to be the case. On permanent cotton, and for a period of years, weather conditions being favorable, the disease fluctuates. If it begins mildly, it winds up with a high percentage of root rot and then gradually lessens. On the other hand, when the disease reaches the peak, it ends with very little root rot in the same field and then again increases. The reason seems obvious, because when the disease is at its highest during the summer, it generally succeeds in killing out not only most of the cotton but also the winter weed carriers, which naturally reduces the root rot to a minimum the following summer. This is well shown in Table 15 and in Fig. 14. It, then, seems pretty well evident that *Phymatotrichum omnivorum* does not apparently live in the soil without the presence of a living host. Even under pure culture conditions, the causal organism grows far better on nutrient media or on various sterilized vegetable plugs than it does on sterilized or unsterilized soil. In order to definitely determine whether or not *Phymatotrichum omnivorum* does or does not live over in the soil independent of a living host, it was decided to try to isolate the causal organism from the soil taken directly from badly infected spots in which the disease is very active and near cotton plants which had recently died from infection. This soil was secured from Substation No. 5, Temple, Texas, and brought into the laboratory within two days after it had been collected and was immediately cultured. The method employed was as follows: One gram of soil was placed in a sterilized eight-ounce baby bottle to which was added 50 c.c. of sterilized water equivalent to 1/50. The bottle was corked with a flamed stopper and shaken with an electric revolving apparatus for thirty minutes. Then with a sterile pipette, one c.c. of the 1/50 solution was taken out and placed in another sterilized baby bottle which contained 20 c.c. of sterilized water. This made a dilution equivalent to 1/100, that is, one gram of soil diluted in 1/100 c.c. of water. Again with a sterile pipette one c.c. of the original 1/50 was now put in a sterilized baby bottle which contained 200 c.c. of sterilized water, making a dilution of 1/1000, that is, one gram of soil to 1/1000 c.c. of water. This, then, gave two dilutions, one of 1/100 and the other 1/1000, both of which were plated out in agar media in the ordinary way and poured into sterilized petri dishes, some of which received an addition of one drop of a 5 per cent. lactic acid to prohibit bacterial growth while others were made without the acid. The plates from the 1/100 dilution were marked *A* and the plates from the 1/000 dilution were marked *B*. Over 5000 such soil isolations were made of both series, A and B, and at no time were we able to find in even a single instance, growth of *Phymatotrichum omnivorum*. If this fungus lives in the soil, it would seem probable that from so large a series of soil platings we certainly would obtain at least a small percentage with viable cultures, but we did not. It is, of course, conceivable that strands of

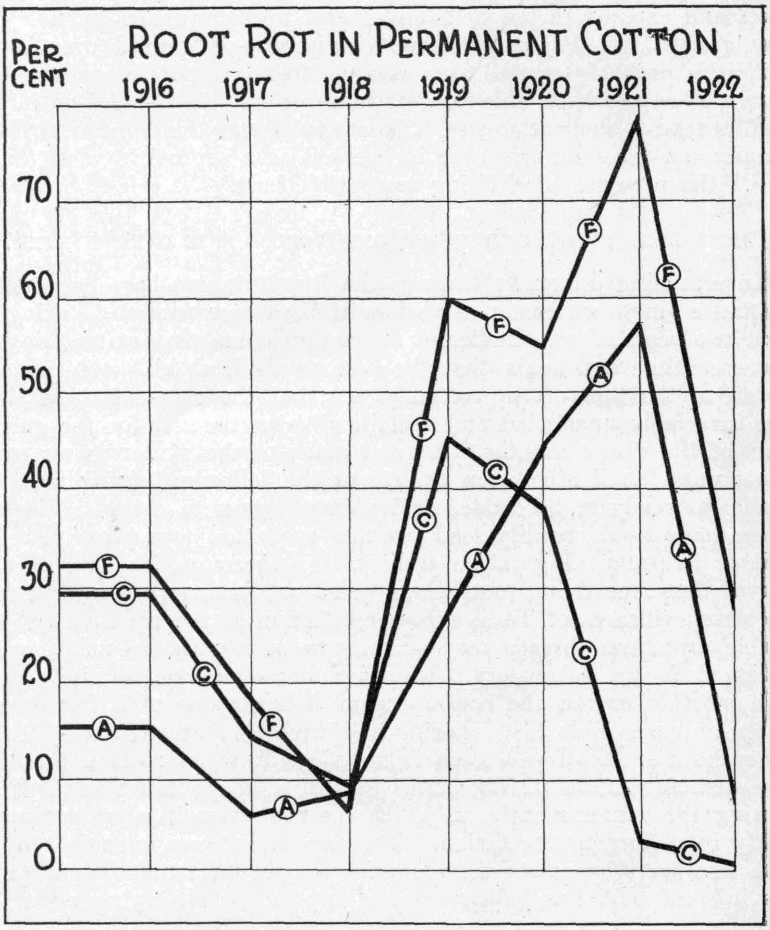

FIGURE 14.

Graph showing the rise and fall of Texas root rot in permanent cotton from 1916 to 1922, inclusive. F represents plat No. F14; C represents plat No. C33; and A represents plat No. A61-70.

Phymatotrichum omnivorum are occasionally found in the soil, especially on the surface, in connection with conidia spores, but these undoubtedly are strands which have been broken when pulled from the infected host, or strands which grew from the roots of an affected host which launched out in search of a neighboring host. From our own observations, we have never yet been able to find viable strands of

Phymatotrichum omnivorum in the soil unless they were directly attached to an infected host or within its immediate neighborhood. This, then, seems pretty strong evidence that *Phymatotrichum omnivorum* does not probably live in the soil as viable fungus mycelium without the presence of a living host. Neither is it apparently capable of living over in the soil as pseudo-sclerotia. Cultures of affected cotton roots showing the presence of these bodies as found on the dead roots and exposed in the field for several weeks or more did not yield any growth. If *Phymatotrichum omnivorum* is carried over in the soil, it is probably carried over as some form of spore stage which we have not as yet been able to determine or to verify. Unless further studies tend to show otherwise, it is safe to assume that *Phymatotrichum omnivorum* does not live over in the soil as a saprophyte, but that it needs the presence of a living susceptible host.

HOW DOES PHYMATOTRICHUM OMNIVORUM LIVE OVER WINTER?

In searching diligently through the literature, we have been unable to find a single statement as to how it lives over winter. During the first two years of our studies of *Phymatotrichum omnivorum*, we have observed time and again that the first severe frost kills 100 per cent. of all of the tops of the cotton plants, but the roots of these plants are invariably unaffected and remain alive in the soil for the greatest part of the winter months. A great many of the wintered-over cotton roots were found alive even as late as the following spring when the land was ready to be bedded and planted again to cotton. Likewise, these roots would readily send out new roots and tops when placed in soil or in water (Fig. 15, a and c). Furthermore, we have also observed that such living roots when pulled out during the winter months do show evidences of Texas root rot infection at the tip ends and that viable mycelium threads may actually be seen with the naked eye or cultured in the laboratory. In order, therefore, to definitely establish whether or not the causal organism is capable of living over on roots of susceptible hosts during the winter months, it was decided to make a series of isolations from infected cotton roots not only in the summer months during active growth of the cotton plant, but also during the winter months in which the roots remain alive but apparently in a dormant condition. The experiment was intended to find out whether *Phymatotrichum omnivorum* would remain alive (a) if its infected host was pulled out and exposed to air-drying under laboratory conditions; (b) when the infected host is pulled out from the ground and exposed to air-drying of outdoor conditions, and (c) when the susceptible roots of a living host remain in the field undisturbed during the winter months. This latter experiment especially has a practical application inasmuch as it is customary among tenant farmers, especially negroes, to leave their cotton fields undisturbed after the last picking of the cotton and to plow up that field very late in the winter, or just before planting time the following spring.

Table 25. Viability of Phymatotrichum omnivorum as influenced by exposure of infected cotton roots to indoor conditions.

Date when pulling infected roots	Date when culturing material in laboratory	Per cent of tubes showing Phymatotrichum	Date when pulling infected roots	Date when culturing material in laboratory	Per cent of tubes showing Phymatotrichum
July 10, 1921	July 15, 1921	11.2	Nov. 17, 1921	Mar. 15, 1922	0
July 10, 1921	July 30, 1921	2.4	Nov. 26, 1921	Nov. 30, 1921	9.6
July 10, 1921	Aug. 10, 1921	0	Nov. 26, 1921	Dec. 29, 1921	0
Aug. 15, 1921	Aug. 19, 1921	8.8	Nov. 26, 1921	Jan. 18, 1922	0
Aug. 15, 1921	Aug. 29, 1921	4	Nov. 26, 1921	Feb. 15, 1922	0
Aug. 15, 1921	Sept. 16, 1921	0	Nov. 26, 1921	Mar. 15, 1922	0
Sept. 19, 1921	Sept. 23, 1921	6.4	Dec. 3, 1921	Dec. 7, 1921	4
Sept. 19, 1921	Oct. 2, 1921	4	Dec. 3, 1921	Dec. 14, 1921	3.2
Sept. 19, 1921	Oct. 26, 1921	0	Dec. 3, 1921	Jan. 18, 1922	0
Oct. 9, 1921	Oct. 14, 1921	7.2	Dec. 3, 1921	Feb. 15, 1922	0
Oct. 9, 1921	Oct. 28, 1921	1.6	Dec. 3, 1921	Mar. 15, 1922	0
Oct. 9, 1921	Nov. 20, 1921	0	Dec. 10, 1921	Dec. 14, 1921	2.4
Nov. 4, 1921	Nov. 8, 1921	11.2	Dec. 10, 1921	Dec. 22, 1921	1.6
Nov. 4, 1921	Nov. 19, 1921	0.8	Dec. 10, 1921	Jan. 18, 1922	0
Nov. 4, 1921	Nov. 30, 1921	0	Dec. 10, 1921	Mar. 15, 1922	0
Nov. 4, 1921	Dec. 14, 1921	0	Jan. 12, 1922	Jan. 18, 1922	7.2
Nov. 4, 1921	Jan. 18, 1922	0	Jan. 12, 1922	Feb. 15, 1922	0.5
Nov. 4, 1921	Feb. 15, 1922	0	Jan. 12, 1922	Mar. 15, 1922	0
Nov. 4, 1921	Mar. 15, 1922	0	Feb. 12, 1922	Feb. 15, 1922	1
Nov. 17, 1921	Nov. 21, 1921	5.6	Feb. 12, 1922	Mar. 15, 1922	1
Nov. 17, 1921*	Dec. 29, 1921	0	Feb. 12, 1922	Mar. 28, 1922	0
Nov. 17, 1921	Jan. 18, 1922	0	....	....	....
Nov. 17, 1921	Feb. 15, 1922	0	....	....	....

Table 26. Viability of Phymatotrichum as influenced by time exposure in the field of freshly infected cotton roots.

Date of pulling infected roots	No. of killing frosts during exposure	Date of killing frosts during exposure	Date of culturing material in laboratory	Per cent of tubes showing Phymatotrichum
Nov. 15, 1921	14	Nov. 19, 1921, Nov. 20, Nov. 21, Nov. 28, Dec. 5, Dec. 10, Dec. 11, Dec. 12, Dec. 18, Dec. 24, Dec. 25, Dec. 26, Jan. 5, 1922, Jan. 12, 1922................	Jan. 16, 1922	0
Nov. 15, 1921	0	....	Nov. 18, 1921	3
Dec. 27, 1921†	2	....	Jan. 16, 1922	0
Dec. 27, 1921	0	....	Jan. 2, 1922	4.5

*After being pulled, the plants were left in the field until November 28, 1921. The tops were then cut off and the roots placed in the weather cage at Substation No. 5, Temple, Texas.
†These plants before being pulled went through 12 killing frosts, killing the tops without affecting the roots. The dead tops were clipped off, and the living, infected roots were placed in the weather cage at Substation No. 5.

That *Phymatotrichum omnivorum* is unable to remain alive very long after its susceptible host has been pulled out from the ground and exposed to drying of indoor conditions, is shown in Table 25. From this table it is seen that every time a freshly-infected host was pulled out from the ground and isolation cultures made, a certain percentage of viable cultures of *Phymatotrichum omnivorum* was obtained; that on the other hand, and just as soon as the roots were pulled out, and exposed to drying under indoor conditions, the causal organism would die within ten to twenty days. This is true no matter what time of the year such freshly-infected roots are pulled out and exposed to drying. The same is also true when freshly-infected roots are pulled out and exposed to drying of outdoor conditions. This is shown in Table 26, which is self-explanatory. From these two tables, it is evident that the organism dies with the death of its host. However, *Phymatotrichum omnivorum* remains alive during the entire winter on cotton roots in a field if infection has taken place during a winter which does not result in the complete killing of the host, and if the roots are not pulled out from the soil as shown in Tables 24 and 27. From Table 27, it is seen that when live cotton roots remain undisturbed in the field during the winter months, they will show a higher percentage of infection the longer they remain in the field.

From the above studies, the following deductions are made. During the summer months the *Phymatotrichum omnivorum* fungus dies with the death of its host and to maintain its further existence, it must reach for the roots of neighboring healthy susceptible hosts. This actually occurs in the field from early in March until the first killing frost in the fall. During the winter months the causal organism is not as active as during the summer, but it nevertheless spreads slowly by contact from living root to root of cotton and perennial weeds, and maintains itself by invading only part of the root, killing only the parts attacked. Furthermore, during a wet fall, when fall plowing does not kill the cotton roots, or if plowing is delayed until the following spring, the disease will be given the best means to maintain itself during the winter months. This is seen in Table 27, which shows conclusively that the causal organism remains active during the entire winter, if given a live host, though it seems to work much more slowly in winter.

Table 27. Texas root rot in unplowed wintered-over cotton or weed (Ipomoea trichocarpa).

Place of study	Host	Row No.	December 29, 1921			Row No.	February 9, 1922		
			Per cent				Per cent		
			Roots alive uninfected	Roots alive infected	Roots dead	alive	Roots alive uninfected	Roots alive infected	Roots dead
Negro tenant farm near Belton, Texas.	Cotton................	1	17	83	0	5	8	92	0
	Cotton................	2	37	63	0	6	5	94	0
	Cotton................	3	....	....	....	7	0	100	0
	Cotton................	4	....	....	....	8	0	100	0
	Ipomoea trichocarpa.....	....	....	....	....	1	3.7	96.3	0
	Ipomoea trichocarpa.....	....	....	....	....	2	19	81	0
			April 4, 1922				April 27, 1922		
Substation No. 5, Temple, Texas.....	Cotton................	1	24	48	28	4	0	10.63	99.37
	Cotton................	....	....	....	....	5	0	28.84	71.16
	Cotton................	....	....	....	....	6	0	15.38	84.62
	Ipomoea trichocarpa.....	....	....	....	....	2	43.47	56.53	0

WINTER CARRIERS OF THE TEXAS ROOT ROT FUNGUS.

In the early part of this Bulletin, page 19, we have already referred to the large number of hosts which the Texas root rot disease is capable of attacking during the summer months. We have also shown that the causal organism continues its activity, although more slowly perhaps, during the winter months on roots of certain susceptible hosts. It should not be forgotten that of the large number of hosts which are susceptible to the Texas root rot disease during the summer months, many are fortunately annuals which cannot hibernate the causal organism because they die with the first fall killing frost. Such plants cannot, therefore, act as carriers of the *Phymatotrichum omnivorum* fungus, because as we have already shown, this organism is apparently incapable of maintaining itself on a dead host. It is, therefore, of extreme practical importance to determine which are the biennial or perennial hosts whose roots are capable of maintaining the causal fungus during the winter months, *because on this point depends the success in control methods.* If we are to succeed in controlling the Texas root rot disease, we must have definite methods of eliminating entirely from the soil all living roots of all susceptible hosts, whether cultivated or weeds, during the winter months. To allow the causal organism to maintain itself during the winter is merely to give it a chance for a new lease in life the following year. Our studies, so far, have definitely established the fact that the following hosts are winter carriers of the Texas root rot fungus: cotton, okra, pepper, sweet potato, carrots, beets (garden or stock), wild morning glory roots, *Ipomoea trichocarpa* (Fig. 5, d to g), and susceptible shrubs and trees, whether ornamental or fruit. In this case, the causal organism attacks the living but dormant root and it is capable of slow but steady spread. This is seen in Table 27, which shows that the disease is active on cotton and on *Ipomoea trichocarpa* during the winter, but it cannot be detected since all tops are killed by frost, and hence there is no wilting apparent. The following spring when the land is plowed up and devoted to a susceptible crop or even to a non-susceptible crop, but one in which susceptible weeds are permitted to thrive without molestation, the causal organism may continue its activity without interruption. It is especially peculiar with *Ipomoea trichocarpa* that cutting off the top of this plant with a hoe or cultivator during active growth does not necessarily kill the roots. These, on the other hand, will soon send out new sprouts and continue to thrive (Fig. 15, f).

WHAT IS THE BEST TIME FOR FALL PLOWING?

When it had been established that *Phymatotrichum omnivorum* passes the winter on roots of susceptible hosts, some preliminary tests were carried out with a view of determining which was the best time for fall plowing in order to destroy the roots of the cotton. We have already referred to the fact that Shear and Miles (21 and 22) have claimed that fall plowing controls root rot and we have also referred to our own work, Table 12, in which we have indicated that as long as the roots of the cotton are permitted to remain in the ground, fall plowing will have little effect on the control of Texas root rot. This does not mean that we were ready to condemn fall plowing, but it became more and more evident that we were in need of a cultural method which would permanently destroy the cotton roots and thus prevent them from becoming carriers of the causal organism during the winter months. We have repeatedly observed as we have studied fall plowing carried out by various farmers in Bell County, for a period of several years, that actual fall plowing does not necessarily kill the cotton roots as long as the soil is moist. On the other hand, fall plowing during a period of drouth during the fall actually kills a large per cent. of the cotton roots because in this case the disturbed roots remain in a dry mulch, and for lack of moisture, they fail to revive or to strike new rootlets. This means that we may sometimes control root rot through fall plowing if the plowing is carried out during a period of prolonged drouth and not during a rainy spell as is frequently done in the fall by the majority of farmers. In order to test this out, a field was selected which was practically free from the Texas root rot disease. Such a healthy field was necessary in order to determine the effect of the plowing on killing healthy non-infected cotton roots. The field chosen for this experiment was Plat C 1-10 at Substation No. 5, which only showed a trace of root rot. The results are indicated in Table 28. From this table it is seen that the first plowing carried out during November 21, 1921, resulted in the actual killing out of 96 per cent. of the cotton roots. In this connection it should be stated that this plowing was done during a dry spell and that the soil itself was very dry during the plowing and for some time after plowing. On the other hand, the second plowing, which was carried out on December 19, 1921, resulted in killing only 12 per cent. of the cotton roots; the plowing done on December 21, 1921, killed only 8 per cent. of the cotton. In both of these last two plowings there was considerable moisture in the soil from previous rains and this explains the small percentage of dead cotton roots in spite of the plowing at that time. These percentages were obtained on January 29, 1922. In further referring to Table 28, and to the percentage count taken during February, 1922, one will see that the greatest percentage of dead roots resulted from the early plowing on November 21, which was done during a dry spell. Table 28, although representing only preliminary plowing tests of one year, nevertheless points to a very promising method of control; namely, that cotton growers should watch weather conditions and plow up the cotton only during a dry spell in the fall and after the last cotton picking. If this is not possible, as is often the case during a wet fall, a different procedure is to be tried, which will be referred to under "Control" on page 90.

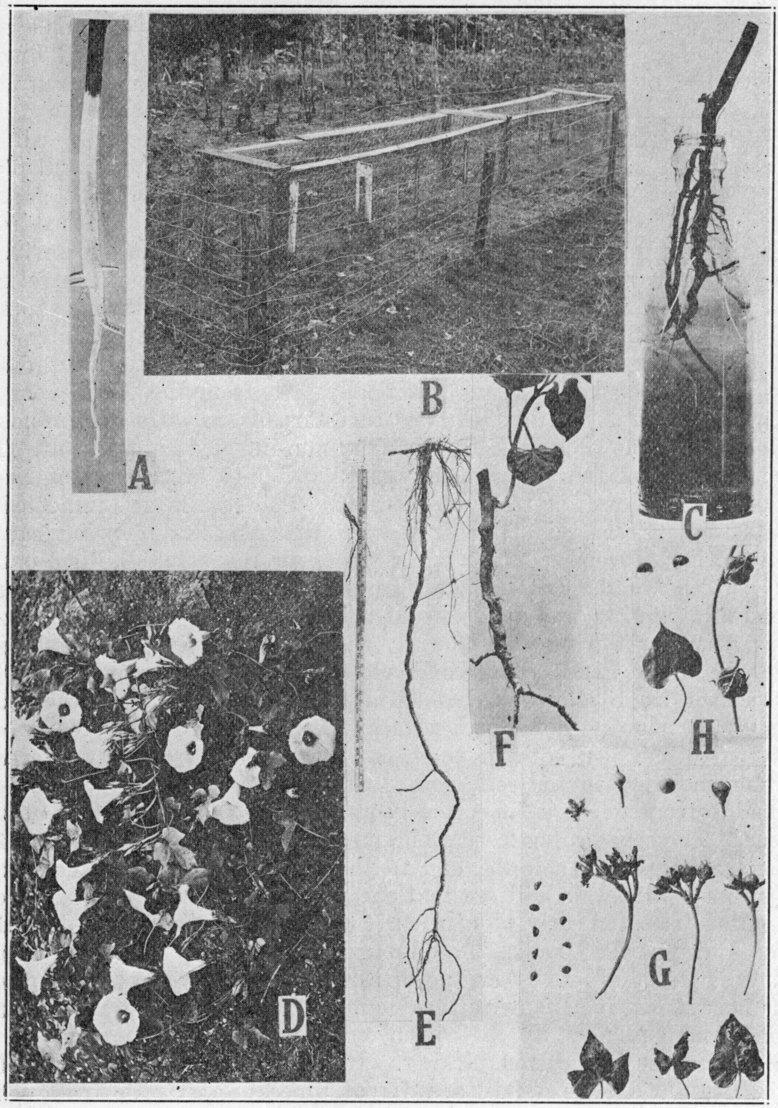

FIGURE 15.

a. Cotton root as it lives over in the soil during the winter. The blackened top shows part of the dead stem killed by frost. b. Soil thermometers for studying soil temperatures. c. Same root as *a*, placed in water in the laboratory to show that it is alive and capable of sending out new roots. d. Blossoms of *Ipomoea trichocarpa* to show the prolific nature of this weed. e. Fleshy trailing perennial root of *Ipomoea trichocarpa*. f. Root of *I. trichocarpa* with the top cut off by hoe, and the appearance of new sprouts. g. Leaves, seed pods, and seed of *I. trichocarpa*. h. Leaf, seed pods, and seed of *Ipomoea hederacea*, an annual weed.

Table 28. Field killing of cotton as affected by time of plowing during the fall months.*

Date of fall plowing	Per cent of live or dead roots as a result of fall plowing during			
	Jan. 29, 1922		Feb. 9, 1922	
	Per cent live roots	Per cent dead roots	Per cent live roots	Per cent dead roots
Nov. 21, 1921	4	96	8	92
Dec. 19, 1921	88	12	52	48
Dec. 31, 1921	92	8	68	32

*The cotton field of this experiment c-1-10 was practically free from Texas root rot. The dead plants referred to in Table are those killed as a result of disturbance or exposure from plowing and not from Texas root rot.

OF WHAT IMPORTANCE ARE THE CONIDIA SPORES IN THE LIFE CYCLE OF PHYMATOTRICHUM OMNIVORUM?

We have already referred to the work of Thornber (27) and that of Duggar (5) and our own in which we have shown that we have already obtained conidia of *Phymatotrichum omnivorum* from a pure culture grown on sterilized soil in the laboratory.

Under discussion of the physiology of Phymatotrichum, page 68, it has already been stated that attempts at germinating the conidia of this fungus failed. It is, therefore, difficult to tell just what role they play in the life cycle of the causal organism. Are they capaable of germinating only immediately after they are formed or are they able to retain the germination power a long time and thus pass the winter months in a dormant condition? How important are these spores in spreading broadcast the causal organism in the same field and from field to field and from state to state? These questions will be answered only when a satisfactory method of germination is developed. In the meantime, it is safe to assume that the conidia, at least in the summer, do help to spread about the causal organism, but to what extent is as yet unknown.

HOW DOES OUTDOOR AND SOIL TEMPERATURES DURING THE WINTER MONTHS AFFECT THE LIFE CYCLE OF PHYMATOTRICHUM OMNIVORUM?

References have already been made to the possible influence of outdoor and of soil temperatures during the growing months in the summer. We have also referred to the fact that while the first killing frost during the fall immediately kills all the top parts of the cotton plant and other susceptible weeds, the roots of these plants usually remain alive and pass over the winter months in great numbers. We have further shown that during the winter months the causal organism is active, although to a less extent than is the case during the summer months. We have also indicated that infection may take place at any time during the fall and winter months. It became necessary to study the soil temperatures, during the coldest days of both fall and winter with a view of gaining some idea as to why both the roots of the susceptible host and especially the causal organism itself are not killed in spite of low outdoor temperatures. The soil temperature studies were continued during the fall and winter months for a period of several years. We shall, however, refer only to studies during 1918 which are typical. From reference to Table 29, it is seen that during the coldest days in January, November, and December of 1918, no matter how cold the outdoor temperature was at any one day, the soil temperatures, especially those of 24 to 48 inches deep, never went below 59 degrees Fahrenheit. Because of this fact it becomes very evident that the relative moderate soil temperatures during the fall and winter months protect the cotton roots or the roots of other susceptible hosts from dying. This also explains why the causal organism itself is not inhibited, but instead is still capable of activity during the winter months irrespective of outdoor weather conditions.

Table 29. Soil temperature readings—freezing weather during 1918 at Substation No. 5, Temple, Texas.

Month	Outdoor		1 inch		3 inches		6 inches		12 inches		24 inches		36 inches		48 inches	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
January 6	60	29	80	70	76	72	74	73	72	72	72	71	70	69	68	68
January 7	57	16	64	59	68	64	70	65	70	67	71	68	70	69	68	67
January 9	65	26	68	60	68	64	68	66	68	67	71	69	69	69	68	68
January 11	38	6	68	67	68	66	69	68	69	69	68	68	68	68	68	68
January 12	30	1	80	63	75	65	75	66	69	67	68	68	69	68	68	68
January 13	41	14	80	62	75	64	73	66	69	67	68	69	68	69	68	68
January 14	46	32	81	68	78	70	77	72	70	70	70	69	69	69	68	68
January 15	56	21	83	68	80	69	78	70	72	70	70	69	69	69	68	68
January 16	53	22	82	68	82	70	79	72	76	71	71	70	78	69	68	68
January 17	50	24	82	68	81	71	79	74	76	76	72	71	69	69	68	68
January 18	60	18	83	69	81	72	79	74	76	76	72	71	70	69	68	68
January 20	37	22	74	61	75	66	71	69	71	71	72	72	70	69	69	68
January 21	35	23	81	62	81	67	77	70	75	71	72	72	70	70	69	69
January 22	52	12	81	63	81	67	78	71	75	71	72	72	71	70	69	69
January 23	70	25	75	69	77	71	74	73	76	76	73	72	71	71	69	69
January 24	69	22	74	69	76	71	75	73	76	76	72	72	71	70	69	69
January 25	86	32	54	40	52	44	49	46	49	49	52	52	56	56	59	59
November 28	57	30	49	37	49	39	49	46	51	51	59	58	65	65	58	68
November 29	50	32	51	38	49	42	49	47	51	51	58	58	64	64	68	67
December 1	59	25	42	35	53	41	50	46	52	52	58	58	63	63	67	67
December 2	60	31	46	38	53	42	51	47	52	51	59	57	63	63	66	66
December 3	68	27	44	36	54	42	51	47	52	52	58	57	63	62	66	66
December 4	71	30	44	39	57	44	53	48	52	52	58	57	63	62	66	66
December 15	64	32	57	40	58	45	55	51	61	59	63	61	64	63	65	65
December 24	48	25	38	35	43	42	48	47	54	54	59	59	61	61	63	63
December 25	40	24	41	35	41	40	45	45	53	53	58	58	61	61	63	63
December 26	50	19	43	33	46	34	46	35	50	31	57	30	61	30	63	35
December 27	53	25	44	36	45	40	45	44	50	49	56	55	60	60	63	63
December 28	57	21	48	31	47	40	46	42	48	46	55	50	60	37	62	42
December 29	59	31	50	41	49	43	48	45	50	48	54	54	59	59	62	62

IS PHYMATOTRICHUM OMNIVORUM CARRIED WITH THE COTTON SEED?

Considering the importance of the Texas root rot disease as it affects many economic crops, it is necessary to know whether or not this organism is carried about with cotton seed or the seed of any other susceptible host. There are but two possible ways in which it might be carried with the cotton seed, namely, with fungus hyphae and with conidia. In previous discussion, page 14, we have already shown that *Phymatotrichum omnivorum* attacks only the roots of its host, and as far as is known none of the parts of the plant above ground. Furthermore, the fungus dies as the result of drying. This, then, would remove entirely the possibilities of its being carried as adhering mycelial threads on the exterior of the seed coat or even in the interior of the seed itself. There remains, therefore, one possibility and that is that the conidia of *Phymatotrichum omnivorum* may be carried on the exterior of the seed coat of cotton seed as viable spores. Proof of this, however, is lacking and it is very doubtful whether this actually is the case. Pammel (15) actually sowed seed from infected plants which had died from the Texas root rot disease. He found that, from the seed germinated, in no case did the Texas root rot appear, although, as he states, many of the seedlings died from other rots. In our own work (Table 2), we have already referred to the fact that plantings made of cotton seeds from both healthy and affected plants germinated and in no case did the Texas root rot appear. Unless further research prove different, and we do intend to look into this matter more thoroughly, it is safe to make this statement, subject to change, that *Phymatotrichum omnivorum* is not probably carried over on the seed as viable conidia. If it were, the disease would certainly be introduced in many of the Southern States where Texas root rot is at yet unknown, since Texas is exporting a great deal of seed cotton to the many other Cotton States.

SUMMARY OF LIFE HISTORY.

From the above studies, it is safe to summarize the life cycles of the causal organism as follows: Very early in the spring (beginning, say, in March or April) *Phymatotrichum omnivorum* is found to be active underground and to infect the roots of the morning glory (*Ipomoea trichocarpa*) or other susceptible weeds. During the latter part of April and the first part of May, many of the cockleburs in the ground have germinated and some of the seedlings are fairly well advanced in growth. When these plants are pulled out, some of them will be found to be infected with the Texas root rot disease. The infection in this case may be traced to the dormant but infected roots of the morning glory (*Ipomoe trichocarpa*) in the soil which happened to be near enough to the roots of the young cocklebur plants. In this case, the infection of the cocklebur roots is more or less localized to the secondary rootlets or to the tip end of the main root without, apparently, killing outright the young weed itself. As the season advances and when cotton is planted, the young plants may become infected if they happen to be near enough to previously infected roots of Ipomoea or the cocklebur. This latter weed may be killed by cultivation, but the roots of *Ipomoea trichocarpa* remain alive, although its tops are cut off (Fig. 15, f) when the soil is worked. It is, therefore, the continual presence of the roots of this wild morning glory or of other susceptible weeds in the cotton patch that insures infection of the cotton plants during the summer months. Once the cotton becomes infected, the disease begins to spread, slowly at first and more rapidly later, depending on the season. In this way, the disease continues to spread during the summer months, attacking and killing not only cotton, but also other susceptible annual or perennial hosts. In this connection it is strange that although cotton, okra, black-eyed peas and many other hosts are killed outright when infected during the summer months, the morning glory (*Ipomoea trichocarpa*) exhibits a decided resistance in the sense that although infection does take place, the disease remains localized to certain parts of the roots and kills only a small percentage of the affected plants. In Bell County, this weed is one of the worst pests, carrying as it does the causal organism of root rot during the winter months, as well as during the summer. In this case, it acts as a bridge-over to carry the infection to the cotton or other susceptible hosts which it meets in its way. The rapidity of the spread of Texas root rot during the summer months depends on the amount of rainfall during July and August, and to a certain extent on the root system of the host itself. Fields of black-eyed peas, for instance, when sufficiently advanced, may be killed out to an extent of 80 to 100 per cent. The same is true of okra, castor bean, alfalfa, sweet clover, and other susceptible hosts which possess a well-developed system of lateral roots. With cotton, on the other hand, the spread of the disease will depend on the fertility and moisture conditions of the soil, both of which directly influence a scant or copious root system. For this reason, during a dry summer, there may be very little Texas root rot in cotton and a tremendous amount in sweet clover, for instance, all because of a difference in root system, the latter favoring root contact in the soil, and the former not.

In the fall, just as soon as the first frost kills the tops of the cotton plants as well as the tops of all other perennial, susceptible hosts, it becomes difficult if not impossible to tell outwardly whether or not the Texas root rot disease is active. However, although the tops of these plants are killed by frost, the roots in many cases remain alive and afford a means for the causal organism to live on. These roots act as carriers of *Phymatotrichum omnivorum,* and help it to live over the winter months. It is, therefore, seen how unsafe it is not to destroy the roots of cultivated susceptible hosts as well as those of the weeds. Methods of accomplishing this are indicated under "Control Methods" on page 90. It cannot be emphasized too strongly that control methods must depend on a thorough knowledge of the hosts which carry over the causal organism during the winter months. When this is definitely established, the next step is to develop practical methods in destroying these winter carriers. For instance, it is not an easy matter to destroy the perennial roots of the morning glory (*Ipomoea* *trichocarpa*), which constitutes such a menace in many counties in Texas. It may turn out to be a more difficult task to eradicate this weed than the Texas root rot. On the other hand, there are probably other perennial weed carriers in Texas whose destruction may not be as difficult. This will be determined by later studies.

As soon as the causal organism passes the winter months on the roots of living susceptible hosts, either cultivated plants or weeds, it starts anew its life cycle in the spring and summer months in a manner outlined in the beginning of this summary. It seems very doubtful whether the causal organism can maintain itself in the soil without the presence of a living host. Consequently, the eradication of the causal organism and the control of the disease becomes a possibility and in fact a reality as we shall soon see.

METHODS OF CONTROL.

What is uppermost in the minds of cotton growers in Texas is how to control the ravages from the Texas root rot disease. There have been various claims from time to time as to the best methods of controlling this disease. We have already referred to the work of Shear and Miles (21 and 22) and to the fact that deep plowing has generally failed to control the disease. We have also shown that deep plowing in the fall will not control root rot as long as the cotton roots remain in the soil during the winter months and if the land happens to be moist during the plowing time. There also have been various claims made especially by Shear and Miles (21 and 22) to the effect that crop rotation will control the Texas root rot disease. We have already indicated the fact that crop rotation did not in most cases give results hoped for.

No control methods for the Texas root rot are possible unless these methods are based on a thorough and fundamental knowledge of the life history of *Phymatotrichum omnivorum,* the cause of the Texas root rot disease. We have gone at length to present every bit of evidence obtained through systematic and careful research, evidences which are based altogether on the study of the life cycle of the Texas root rot fungus. Our recommendations for controlling the Texas root rot disease, therefore, are based entirely on the results of these studies, and it is believed that although future work may to a certain extent possibly modify some of our present recommendations, yet we feel that the main features of the life cycle of *Phymatotrichum omnivorum* as worked out justify the following recommendations:

In the light of our present knowledge, it seems evident that as long as the Texas root rot disease is perpetuated during the winter months on living dormant roots of the cotton, okra, and some of the roots of perennial weeds, it is certain that this disease will reappear during the following summer if a susceptible crop is grown on that land and weather conditions are favorable. Even though non-susceptible crops such as cereals or grain are grown on that land as a rotation, the root rot disease may reappear if we overlook the fact that through a lack of clean culture which would permit the development of susceptible weed hosts, Texas root rot will have a chance to thrive as though cotton had been grown there. It becomes, therefore, clear that the first attempt at controlling the Texas root rot disease should aim to kill out during the fall and winter months not only the roots of the cotton plants which remain alive in the winter months in the soil, but also the living roots of perennial weeds. This, it seems to us, is the key-note to practical methods of controlling the Texas root rot as it applies to the cotton and to the many other herbaceous susceptible crops.

In attempting to control the Texas root rot disease, we should consider two methods of procedure, determined by whether the fields are (a) badly infected, or (b) slightly infected, each case requiring a different treatment.

CONTROLLING TEXAS ROOT ROT DISEASE IN BADLY INFECTED LANDS.

Assuming that during 1921 a cotton field had died to an extent of 70 to 80 per cent., what are we to do? Immediately after the last picking of cotton is made during the fall of 1921, the cotton plants should be killed, by being pulled out and exposed to the air for drying. This may be done with a "middle buster" or the kind of plow that is used to dig out sweet or Irish potatoes. Such a plow will uproot the plants and expose them to air-drying. If all the cotton roots have not been exposed by this plowing, they should actually be pulled out, the farmer using the cheapest possible methods at his command to accomplish this. Sometimes hand pulling may be equally as cheap. The pulled-out cotton plants should remain in the field for about a month or six weeks and exposed to at least one or more severe freezes. The ground could then be plowed 5 inches deep and all trash, dead cotton stalks and roots worked under. In this case there will be no difficulty whatsoever in turning under the refuse of the dead cotton plants because dead cotton plants subjected to the effect of one or two freezes will break up very readily when gone over with a harrow. This second plowing should in preference be carried out during a dry spell, although it is not always necessary if weather conditions will not permit it. The land so plowed should remain untouched for a week or two, or longer, without being harrowed or disced until all growth, especially weeds, has been dried and killed. After this, the land should be disced and left alone for two or three weeks until evidence of weed growth begins to appear. Such a condition may be looked for in some of the southern parts of the State. Immediately, and as soon as new weed growth appears, the land should be disced and harrowed to a depth of about three or four inches so as to make a fine top mulch. The field will then need no further treatment until February, 1922. At that time, the land should be plowed again about 5 inches deep, exposed for a week or two for drying, and then disced, harrowed, and planted to oats. The oat crop will be ready to be harvested during May or June of 1922, depending on the locality, and immediately after harvesting (not later than one or two weeks) the stubble land should be plowed up to a depth of about five inches. All through the summer and fall months, the now-fallow land should be given frequent cultivations (three or four inches deep) so as to keep down every possible weed growth, especially to uproot and to expose the roots of the morning glory (*Ipomoea trichocarpa*). During the fall of that year (1922) that land may be plowed up and planted to wheat. The following spring of 1923 and after the wheat is harvested, the land is again plowed to work under the stubble and this is followed by frequent cultivations during the summer, fall, and winter months so as to keep down every possible growth of weeds. During the spring of the third year, that is, 1924, the land should be free from Texas root rot and ready for cotton again.

The above drastic control measure, it is seen, calls for a succession of plowings and shallow cultivations during the fall and winter months so as to kill out all possible weed carriers.

A more drastic method may be applied in dealing with a badly infected field and that is, to leave the land fallow the first year. Instead of devoting the infected land to some grain immediately after the cotton crop, the land is kept fallow for one year, in which the soil is persistently worked and cultivated to keep down all possible growth. The loss in crop during the fallow year will be more than compensated in the increase of cotton the next year.

This drastic measure may not always be necessary on lightly infected fields. For this reason each farmer should pick out his worst infected land and adopt this method of one year fallow together with persistent cultivations. His other fields which are less infected may be treated as hereinafter indicated.

There are regions in Texas where wheat and oats do not thrive. These regions include parts of the extreme southern and southwestern counties in Texas and counties in the Central Gulf Coast region. There the procedure under these drastic methods would consist in a one-year fallow accompanied by clean culture. After that the land may be devoted to corn, sugar cane, or resistant truck crops such as cabbage, lettuce, spinach, or onions. This is true especially for the Rio Grande Valley. When the land has thus been cleared of the Texas root rot, it may then be devoted to alfalfa, or even cotton.

In carrying out the drastic treatment and keeping in mind the clean culture idea, we should not overlook the fact that trees and certain perennial shrubbery around the edges of the field may act as persistent carriers of the Texas root rot disease. If these are permitted to remain unmolested, all our efforts at clean culture or at fallow clean culture may be practically defeated. It is, therefore, of extreme importance that all turn rows and all hedges on the roads should be persistently clean-farmed every year.

Once a field has been cleared of the causal organism of Texas root rot, any one system of crop rotation may be adopted that is best suited to the particular locality in which the Texas root rot disease is prevalent. Here, too, we must insist that in starting with a clean land and with a system of rotation, one should never neglect clean culture; if he does, the land will be reinfected. We shall soon suggest a few possible systems of rotation to be adopted after the land is cleared of the Texas root rot. Each farmer will modify these rotations to suit best crop conditions of his own locality.

As regards controlling Texas root rot in fields which are lightly infected, there is but one thing to do and that is to kill out both cotton plants and perennial roots of susceptible weeds during the winter months, carrying out the cultivation idea as outlined above and then devote that land to some system of rotation, the kind of which will depend on the locality and the inclination of the farmer, the clean culture idea always being kept in mind. Sometimes a one-year rotation of corn, or sorghum, or any other of the grain crops in which the land is plowed under and clean fallow practiced during the fall and winter months, will accomplish the desired results.

Beginning with a field which was cleared of root rot, the following system of rotations are suggested:

One-Year Rotation.

1921—*Cotton.*

1922—Either corn or grain sorghum; or wheat planted in the fall; or oats planted the previous fall or spring; after the grain crop has been harvested, the land is to be plowed up and all stubble worked under, and during the summer, fall, and winter months frequent cultivations given to destroy all weed vegetation.

1923—*Cotton.*

Two-Year Rotation.

1921—*Cotton,* followed by wheat or oats in the fall or oats in the spring of 1922.

1922—When the wheat or oats are harvested the land is devoted to clean fallow during the summer, fall and winter months.

1923—Corn, followed by clean culture during the summer, and clean fallow during the fall and winter months.

1924—*Cotton.*

Three-Year Rotation.

1921—*Cotton.*

1922—Corn, wide rows, clean cultivate until harvesting; harvest early, plow under stubble deep, keep clean fallow, plant wheat or oats in the fall.

1923—Wheat or oats harvested, stubble worked in deep, kept clean fallow in summer, fall, and winter months.

1924—*Cotton;* use 100 to 300 pounds of cotton seed meal per acre, plant in wide rows, clean cultivate until the last picking, then destroy the cotton plants; follow by clean fallow during fall and winter months.

Three-Year Rotation with Legumes.

1921—*Cotton.*

1922—Corn as above, followed by clean fallow and wheat or oats in the fall.

1923—Wheat or oats harvested, stubble worked in and if season is favorable, that is, if moisture is plentiful in the soil, the land should be planted to guar, a hardy, resistant legume. In the fall, this legume should be plowed under, followed by clean fallow in the winter.

1924—*Cotton.*

Four-Year Rotation with Legumes.

1921—*Cotton.*

1922—Corn, followed by clean fallow after harvesting and planted to wheat or oats in the fall.

1923—Wheat or oats harvested, stubble worked in and if season is favorable, followed by guar; in the fall the legume is worked under, followed by clean fallow during fall and winter months.

1924—Corn, wide rows, clean culture until harvesting, harvest early, plow under stubble, keep clean fallow during fall and winter months. In place of corn, grain sorghums may be used.

1925—*Cotton.*

Four-Year Rotation.

1921—*Cotton,* followed by wheat or oats in the fall.

1922—Wheat or oats harvested, stubble worked in, and if season is favorable, follow by guar, clean cultivate, in the fall plow under guar as cover crop, clean fallow during fall and winter months.

1923—Corn, wide rows, clean cultivate until harvesting, harvest early, plow under stubble, keep clean fallow, and harvest early, in the fall plant to wheat or oats.

1924—Wheat or oats harvested, stubble worked in and clean fallow maintained during summer, fall and winter months.

1925—*Cotton.*

Five-Year Rotation.

1921—*Cotton,* followed by wheat or oats in the fall.

1922—Wheat or oats harvested, stubble worked in deep and if season is favorable, follow by guar, the latter to be worked in as a cover crop, clean fallow during the fall and winter months.

1923—Corn, wide rows, clean culture until harvesting, harvest early, work under stubble, and in fall plant wheat or oats.

1924—Wheat or oats harvested, stubble worked in, if season is favorable follow by feterita or guar in the fall, keep clean fallow during fall and winter months.

1925—Corn, wide rows, clean cultivate until harvesting, harvest early, plow under stubble, keep clean fallow during fall and winter months.

1926—*Cotton.*

Five-Year Rotation.

1921—*Cotton,* clean fallow during fall and winter months.

1922—Corn, wide rows, clean cultivate until harvesting, harvest early, plow under stubble and in fall plant wheat or oats.

1923—Wheat or oats harvested, stubble worked in, followed by feterita or guar, clean fallow during fall and winter months.

1924—Corn, wide rows, clean cultivate until harvesting, harvest early, plow under stubble, and in fall plant wheat or oats.

1925—Wheat or oats harvested, stubble worked in and if season is favorable follow by feterita or guar, keep clean fallow during fall and winter months.

1926—*Cotton.*

Five-Year Rotation.

1921—*Cotton,* followed by wheat or oats in the fall.
1922—Wheat or oats harvested, if season is favorable follow by guar or feterita, stubble worked in and clean fallow during fall and winter months.
1923—Corn, wide rows, clean cultivate until harvested, harvest early, plow under stubble deep, keep clean fallow in fall and winter.
1924—Cowpeas, planted early in drills, cultivate clean, harvest seed, plow under vines and follow by wheat or oats in the fall.
1925—Wheat or oats harvested, if season is favorable follow by feterita, work in stubble in the fall, keep clean fallow during fall and winter months.
1926—*Cotton.*

It is thus seen from the above described tentative systems of rotation that there is no hard and fast rule that can be laid down as to the kinds to use. The thing to remember is that the first step in controlling the disease is to eradicate it from the land, if necessary, using a drastic system of cultivation and even a one-year fallow, and then to determine on the method of rotation best suited to the particular locality and systematically and persistently carry out the clean culture idea so as to eliminate all susceptible carriers, especially weeds, during the years when the non-susceptible crops are grown. In this way, the land is freed from disease for the cotton crop. It is further seen that we are greatly handicapped in the use of legumes as cover crops. Inasmuch as the cowpea is a very susceptible host, it cannot always be recommended except perhaps in the five-year rotation indicated on this page. However, it is fortunate that the guar, a legume introduced by the Division of Agronomy of the Texas Agricultural Experiment Station, has proved highly resistant to Texas root rot. Furthermore, because of its being an annual, it may be used to advantage as a cover crop and adapted to any one desirable system of rotation after the land has been freed from the disease.

In the extreme southern parts of Texas where irrigation is depended upon in making a crop, and where root rot is prevalent, it is somewhat more difficult to plan a rotation system. Here, then, the grower should aim first at freeing his land from the root rot fungus. This he could do by growing for two or three years resistant truck crops such as cabbage, onions, lettuce, cucurbits, following a rigid system of clean culture, and then by devoting the land to alfalfa for three or four years. Furthermore, all susceptible, perennial weeds, shrubs, and trees on roads or hedges should be kept down so as to prevent the possible reinfection of the lands so treated and freed from the pest.

FUTURE WORK REQUIRING A SOLUTION.

1. A careful survey of the exact distribution and hosts affected by Texas root rot in counties where it was reported to occur.

2. To determine if Texas root rot is definitely confined to the heavy lands only.

3. Why does Texas root rot apparently avoid all light sandy loam soils?

4. To determine the possible reasons why Texas root rot has not gained a foothold in Mississippi, Alabama, and other Southern States where soil and climatic conditions are similar to that of Texas.

5. To determine the rate of summer spread of a root rot spot under wet and dry seasons, and with various susceptible crops.

6. How is Texas root rot spread from field to field, and in new localities?

7. Further studies on the range of economic crops or weeds which are susceptible to the disease.

8. Field conditions best suited for infection.

9. How does the causal organism penetrate its host during infection?

10. Extended studies in life history of the Texas root rot as it affects susceptible perennials, shrubs, and trees.

11. Extensive studies on the pathological morphology and physiology of the affected host.

12. More extended studies on the morphology and physiology of *Phymatotrichum omnivorum* on the host and in pure culture.

13. What are the field and laboratory conditions which favor or inhibit the production of conidia.

14. Work out methods in germination of the conidia of *Phymatotrichum omnivorum.*

15. Determine the function of these conidia. Are they a factor in introducing the causal organism into new fields or localities? Are *they short-lived, or long-lived? Can they live over winter as dormant spores?*

16. Further extended studies on the probability of the conidia being carried about with the seed of susceptible hosts.

17. Intensive studies on the discovery of possible other spore stages (sexual or ascospores) of *Phymatotrichum omnivorum* either in the field or in pure culture.

18. Does *P. omnivorum* live over winter in the soil as a dormant spore form? If so, determine the length of time in which these spores will retain their viability.

19. Intensive studies in clean culture methods, and developing practical means of destroying perennial weed carriers.

20. Further studies on the possible use of fertilizers, sulphur, or chemical soil disinfectants in controlling Texas root rot in the orchards or with perennial ornamentals.

21. Can root rot be controlled by destroying all vegetation in an infected spot when it first appears?

22. Intensive studies of the root system of susceptible hosts as influenced by soil fertility, climate, rainfall, or irrigation.

REFERENCES.

(1) Atkinson, G. F. Methods of obtaining pure cultures of Pammel's fungus of Texas root rot of cotton. Bot. Gaz. 18:16-19, 1893.

(2) Chambers, C. O. Report of the Botany Department. 28th Annual Report, Okla. Agr. Expt. Sta. :34, 1919.

(3) Curtis, G. W. Alfalfa root rot. Texas Agricultural Experiment Station, Bulletin No. 22:211-215, 1892.

(4) Duggar, B. M. Fungous diseases of plants, :479-481, 1909.

(5) Duggar, B. M. The Texas root rot fungus and its conidial stage. Ann. Mo. Bot. Gard. 3:11-23, 1916.

(6) Elliot, J. A. Arkansas cotton diseases. Ark. Agr. Expt. Sta. Bul. 173:11, 1921.

(7) Galloway, B. T., and Woods, A. F. Root diseases. U. S. Dept. of Agr. Yearbook :248-249, 1896.

(8) Gilbert, W. W. Cotton diseases and their control. U. S. Dept. of Agr., Farmers' Bulletin 1187:3-32, 1921.

(9) Heald, F. D. Symptoms of diseases of plants. University of Texas Bul. 135:57-58, 1909.

(10) Heald, F. D. Texas root rot of cotton. Texas Department of Agriculture, Bulletin No. 22:303-308, 1911.

(11) Heald, F. D., and Wolf, F. A. A list of parasitic bacteria and fungi occurring in Texas. Texas Acad. Sci. Trans., Vol. 11:10-44, 1911.

(12) Heald, F. D., and Wolf, F. A. A plant disease survey in the vicinity of San Antonio, Texas. U. S. Dept. of Agr., Bur. Pl. Ind. Bul. 226:23, 38, 41, 48, 49, 55, 57, 59, 80, 1912.

(13) Orton, W. A. Plant diseases in the United States. U. S. Dept. of Agr. Yearbook: 718, 1902; 555, 1903; 603, 604, 610, 1905; 506, 1906; 586, 1907.

(14) Pammel, L. H. Root rot of cotton or "cotton blight." Texas Agr. Expt. Station Bulletin 4:3-18, 1888.

(15) Pammel, L. H. Cotton root rot. Texas Agr. Expt. Station Bulletin 7:5-30, 1889.

(16) Penzig, Sui rapporti genetici tra Ozonium et Coprinus Nuovo Giorn. Bot. Ital. Vol. 12:132-143.

(17) Saccardo, P. A. Saccardo Sylloge Fung. Vol. 6:345.

(18) Schroeter, Kryptogamen—Flora von Schlesien Breslau: 519, 1889.

(19) Scofield, C. S. Cotton root-rot spots. U. S. Dept. of Agr., Journal of Agricultural Research, Vol. 18:305-310, 1919.

(20) Shear, C. L. New species of fungi. Bul. Torr. Bot. Club, 34:305-306, 1907.

(21) Shear, C. L., and Miles, G. F. The control of Texas root rot of cotton. U. S. Dept. of Agr., Bur. Pl. Ind. Bul. 102, part 5:5-8, 1907.

(22) Shear, C. L., and Miles, G. F. Texas root rot of cotton. U. S. Dept. of Agr., Bur. Pl. Ind., Circular No. 9:3-7, 1918.

(23) Stevens, F. L. The fungi which cause plant diseases. :661-663, 1913, Macmillan Company, New York.

(24) Stewart, R. L. Cotton growing. New Mexico Agr. Expt. Sta. Bulletin, 120:10, 1919.

(25) Taubenhaus, J. J. Diseases of truck crops. :175, 269, 297, 1918, E. P. Dutton Company, New York.

(26) Thompson, G. E., and Wood, C. J. Growing cotton in Arizona. Ariz. Agr. Expt. Station Bul., 90:274, 1919.

(27) Thornber, J. J. Alfalfa root rot. Seventeenth Annual Report Ariz. Agr. Expt. Station, :160-162, 1906.

(28) Thornber, J. J. Root rot of fruit trees. Twenty-sixth Annual Report Ariz. Agr. Expt. Station, :431, 1917.

(29) Thornber, J. J. Plant disease inquiries. Twenty-eighth Annual Report Ariz. Agr. Expt. tation, :431, 1917.

(30) Toumey, J. W. Alfalfa root rot. Ninth Annual Report Ariz. Agr. Expt. Sta., :161-163, 1898.

(31) Tyler, A. A. Alfalfa root rot. Eleventh Annual Report Ariz. Agr. Expt. Sta., :168-169, 1920.

(32) Winter. Die Pilze, Vol. 1:405.

(33) Wulf, Holuby. Zur Kryptogamen Flora von m. s. Podhrad Oest. Bot. Zeitung, 1874.

(34) Youngblood, B. Suggested cropping systems for the black lands of Texas. U. S. Dept. of Agr., Bur. Pl. Ind., Circular No. 84:3-21, 1911.