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A Strawberry Disease Caused by Rhizoctonia

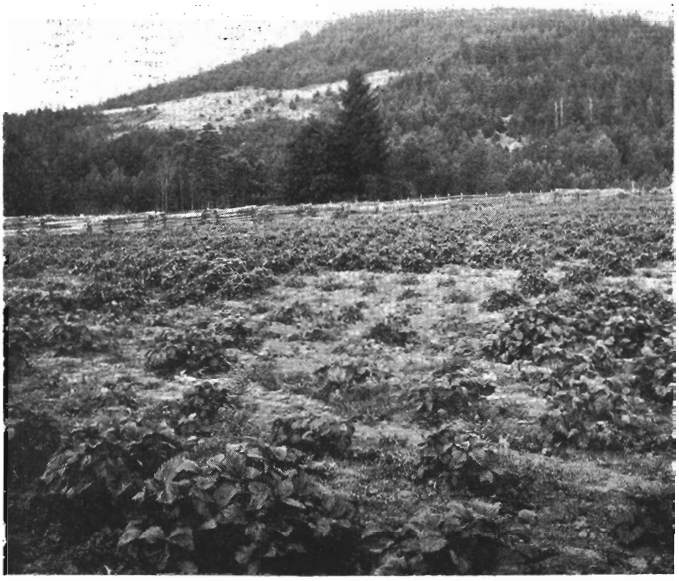

Figure 1. A Marshall strawberry planting showing areas infected with the Rhizoctonia disease. In the background is shown the type of wooded land usually cleared for strawberry culture.

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SUMMARY

1. A study has been made of the fungous flora of the crown and root tissues of strawberry plants showing a wilt disease in the Willamette and Hood River valleys of Oregon. Although several different fungi were isolated in small percentages from the crowns, none of these except Rhizoctonia were capable of reproducing the disease.

2. Rhizoctonia was the only fungus consistently obtained from black lesions on the roots and was the one fungus capable of reproducing the lesions when inoculated into sterile soil in pots containing strawberry plants.

3. The Rhizoctonia disease is described as it occurs in the field and greenhouse.

4. The several growth-forms of Rhizoctonia obtained from lesions on strawberry roots in the field come within the morphological limits of the variable fungus known as *Rhizoctonia solani* Kühn.

5. The disease has previously been reported from Michigan and Washington, and now from Oregon and Utah. It is very similar in symptoms to the Leptosphaeria and Pezizella diseases of strawberry recently reported from Michigan. All three diseases, unfortunately, have previously been designated as the "black root" disease.

6. Factors influencing the Rhizoctonia disease are discussed. It is usually found in Oregon where cultural conditions are most suitable for the Marshall and Clark's Seedling varieties of strawberries—i.e., in the near-virgin soils of the hill lands. These soils are residual clay loams.

7. The bracken fern, *Pteridium aquilinum pubescens*, a common native weed of these lands, harbors Rhizoctonia, which also seems to be native to these soils.

8. The most susceptible varieties of strawberry are, in descending order: Marshall, Clark's Seedling, certain unnamed hybrids, Corvallis, Gold Dollar, Nick Ohmer, Redheart, Improved Clark, and Magoon. The Ettersburg 121 and the wild coast strawberry (*Fragaria chiloensis*) are almost, if not entirely, immune. The field strawberry (*Fragaria cuneifolia*) and the wood strawberry (*F. californica*) have been found infected.

9. The best suggestion for control based on present knowledge of the disease is to plant vigorous stock of resistant varieties and rotate crops. Strawberries should not follow strawberries, potatoes, or other crops subject to infection by *Rhizoctonia solani*.

A Strawberry Disease Caused by Rhizoctonia

By

S. M. ZELLER*

AN INVESTIGATION of a strawberry disease of common occurrence in the Pacific Northwest has been under way at the Oregon Experiment Station since 1928. The evidence in hand points to Rhizoctonia as its cause. Losses from this disease have been realized for many years, but its nature had not previously been investigated. It seems to be present wherever the Marshall type of berry is grown, and it is also a serious factor in the growing of the variety known as Clark's Seedling. Experience with the disease has been limited mainly to Western Oregon.

DISTRIBUTION OF THE DISEASE

Occasional plants affected by this disease have been received from Eastern Oregon, Washington, Idaho, and Utah. In Oregon it has been observed or sent in from all the counties west of the Cascade Mountains and from Hood River, Umatilla, Wallowa, and Wasco counties, east of the range.

Heald[1] has apparently observed the same disease of strawberries in Western Washington and attributed the disease to Rhizoctonia. A trouble exhibiting similar symptoms has been briefly mentioned by Coons[2] in a short discussion of "black root" of strawberry occurring in Michigan. Undoubtedly, the various types of black root mentioned by him are caused by several factors, but he said that the only organism "associated constantly with diseased plants is the fungus Rhizoctonia." A later report[3] from Michigan, however, stated that various soil organisms were found associated with a similar disease there, but no mention of Rhizoctonia was made in connection with it. Still later, the same authors[4] attributed the disease in Michigan to two organisms, *Pezizella lythri* (Desm.) S. and D. and *Leptosphaeria coniothyrium* (Fuckel) Sacc. Undoubtedly, therefore, several troubles known as black root or root rot of strawberries deserve considerable separate study.

*The author expresses his appreciation to Professor H. P. Barss for helpful suggestions in the execution of this investigation and aid in the preparation of the manuscript.

[1]Heald, F. D. Division of Plant Pathology Report. Wash. Agr. Exp. Sta. Rept. 1919:36. 1920.

[2]Coons, G. H. Black root of strawberry. Mich. Agr. Exp. Sta. Quart. Bul. 7:25—26. August, 1924.

[3]Strong, F. C. and M. C. Black root of strawberry ruins plantations. Mich. Agr. Sta. Quart. Bul. 12:75—79. 1930.

[4]Strong, F. C. and M. C. Investigations on the black root of strawberries. Phytopath. 21:1041—1060. *illus.* 1931.

The only other mention of Rhizoctonia in connection with strawberry observed by the writer was made by Thomas,[5] who obtained this organism in culture in one instance out of 188 trials. From his description of the trouble in New York, however, it appears that the disease there is not similar to the one we are dealing with in Oregon. Other references to similar root troubles have been adequately discussed by Strong and Strong[4] and further mention here is perhaps needless.

It seems that the Rhizoctonia disease of strawberry may occur in Utah. The writer has examined and cultured Rhizoctonia from one sample of plants from that state, and Dr. H. L. Blood, Pathologist of the Utah Agricultural Experiment Station, has reported by correspondence that he was able to obtain a number of different organisms, including Rhizoctonia, from diseased tissues. He says: "The fact that we were able to obtain Rhizoctonia in about 32% of the isolations indicates that we may be dealing with the same trouble you are working with in Oregon."

It seems from the present knowledge of this type of root trouble of strawberry that the condition is widely spread but may be brought about by various organisms.

DAMAGE FROM THE DISEASE

The extent of loss from the Rhizoctonia disease as it is found in Oregon is variable. In some plantings few plants with definite symptoms may be found, while in others high percentages of plants in extreme condition of wilt may result.

In one extreme case in a 6-acre planting of 2-year-old Marshalls, 97 percent of the plants were wilted in June but the remaining 3 percent showed severe root infection. In another planting of 68 acres, about 10 percent of the plants were affected centering mostly around one totally infected area of about 5 acres. The disease is less severe the first year after planting. As a rule, it produces little wilting that year, but increases in severity year after year. In general it may be said to be one of the chief factors causing variability and unevenness in Marshall strawberry plantings in the Pacific Northwest (Figure 1). An estimation of the annual monetary loss would be difficult to make, since it involves not only loss in productivity but also loss of plants.

DESCRIPTION OF THE DISEASE

Leaf symptoms. A description of the leaf symptoms of the disease is not simple because there are often many associated symptoms which may or may not be directly attributed to the disease. It is not uncommon, for instance, to find plants affected with crinkle[6] which are also infected with Rhizoctonia, and the combined leaf symptoms are not easily described. Plants affected with this disease seem also to be more subject to scorch (*Diplocarpon earliana*) and powdery mildew.

[5]Thomas, H. E. Killing of strawberry roots. Phytopath. 18:245—246. 1928.

[6]Zeller, S. M., and E. K. Vaughan. The crinkle disease of strawberry. Phytopath. (In press.)

The outstanding leaf symptoms of the Rhizoctonia disease of strawberry during the summer are (1) a wilting under certain conditions and (2) purpling of the veins. Very slight infections may persist for 2 or 3 years with merely a dwarfing effect on the plants, but with unfavorable field conditions the plants wilt. As is the case in any root trouble, the wilted leaves curl much as when affected by mildew and then turn purplish,

Figure 2. Close-up view of individual plant wilted from effects of Rhizoctonia disease. Neighboring plants with apparently normal tops were seriously infected. Same planting shown in Figure 1 (cover).

especially along the underside of the veins, this color gradually spreading to the tissues on either side. In extreme cases the plants may wilt and die even under irrigation, but as a rule they will gradually recover and make some growth during the cool autumn and winter months. In contrast to the behavior described above, it is not unusual to see plants wilt down when no preliminary symptoms have appeared. In these cases, the leaves usually lie on the ground in the day time and revive some at night for several days, and then they may die.

As a rule in these cases, the Rhizoctonia lesions are high up on the adventive roots and cut off the entire root system below within a relatively short period. This has been the usual observation in the Clark's Seedling and in many new hybrids. The most severe wilting usually comes at about the stage of fruit maturity (Figure 2).

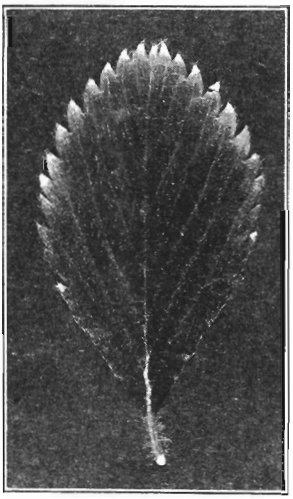

Figure 3. Leaflet from an infected Dunlap plant showing marginal yellowing, characteristic of Rhizoctonia-infected plants during fall months.

Strawberry growers in the Pacific Northwest as a rule cut off the leaves and burn them shortly after the crop is harvested, except in the case of first-year plantings. There is then a new crop of leaves produced in late summer and fall. These may or may not show symptoms, according to the extent of root injury. In late fall there is little if any wilting, but the leaves show lack of the normal green color similar to that in plants showing deficiency in such elements as manganese. That is, the leaves are chlorotic, particularly in the tissues between main veins and near the margins (Figure 3). In cases where the old leaves have remained, they are redder than in normal plants. The lack of vitality is quite prohibitory to runner-plant production.

Another condition sometimes observed, especially in the Clark's Seedling and some of the new hybrids, is very similar to the effect of Rhizoctonia on potato tops. When only a part of the adventive roots are affected, so as to cut off the translocation of food back to the roots, the leaves become erect, crisped, and gorged with starch. Such plants throw out vigorous adventive roots with the first fall rains and seem to have abundant vigor in late fall and early spring.

Root symptoms. The root symptoms are perhaps the most important phase of the disease. The one root symptom by which the disease may be characterized is the definite black lesions. These lesions are damaging on the main adventive roots and may also be found in great numbers on the secondary rootlets (Figure 4). The lesions seem to do *severe* damage, however, when many of the larger main roots are affected. This is due to the fact that they are main feeders to the crown and also that they are perhaps more easily infected than the secondary roots in which the endodermis has more greatly thickened walls, serving as more of a protection against invasion by fungi.[7] After the lesions have completely girdled a main root and the stele has become necrotic, the whole root and branches below die. The lesions due to Rhizoctonia are dark and become sunken, in contrast to the natural darkening of the roots which occurs each year. In this natural darkening of the adventive roots, the cortex becomes corky in texture and has a tendency to slough.

Stem symptoms. Rhizoctonia lesions have been found on runners in several plantings, and lesions on fruiting peduncles and petioles infrequently occur (Figures 5 and 6).

[7]White, P. R. Studies of the physiological anatomy of the strawberry. Jour. Agr. Res. 35:481—492. *illus.* 1927.

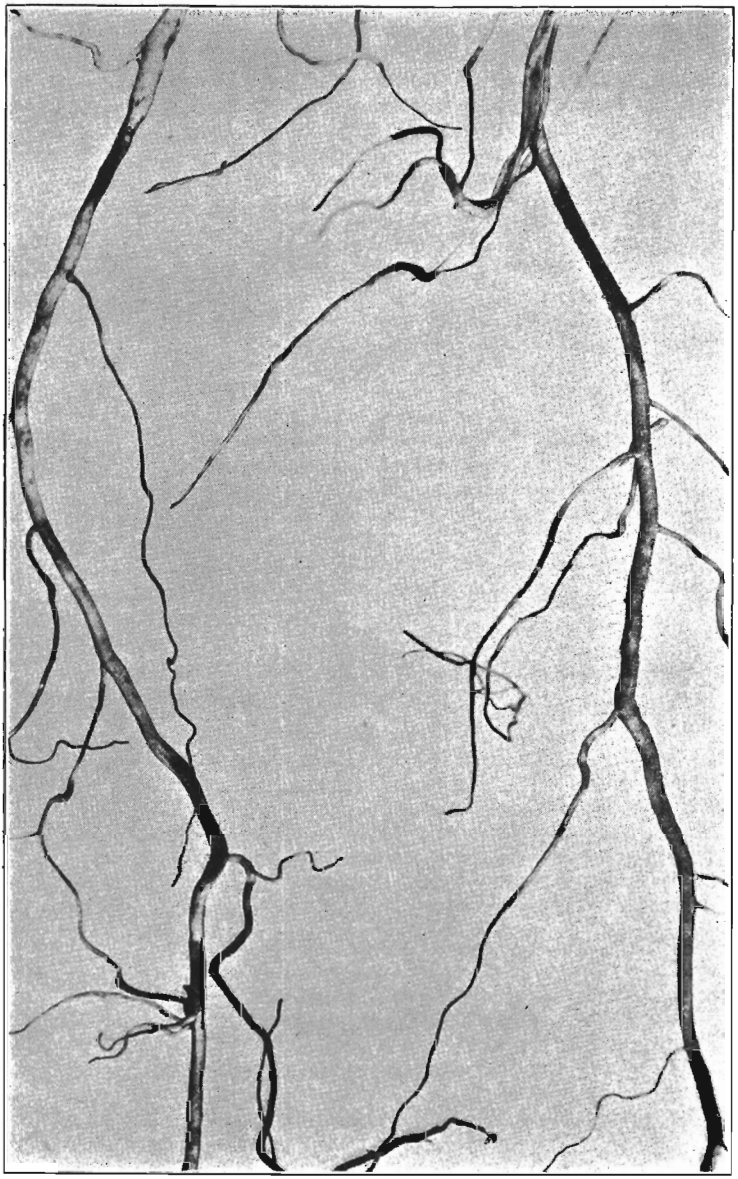

Figure 4. Rhizoctonia lesions on adventive and secondary roots of Marshall strawberry. 2 x.

Fruit symptoms. The hard, brown rot of strawberry fruit described by Dodge and Stevens[8] has been found in certain locations only occasionally affecting Ettersburg 121, Clark's Seedling, and Marshall fruit. The decay is hard, dry, and leathery, and Rhizoctonia has been isolated on two occasions about 10 days after warm rains. The affected fruits were in a half-ripened

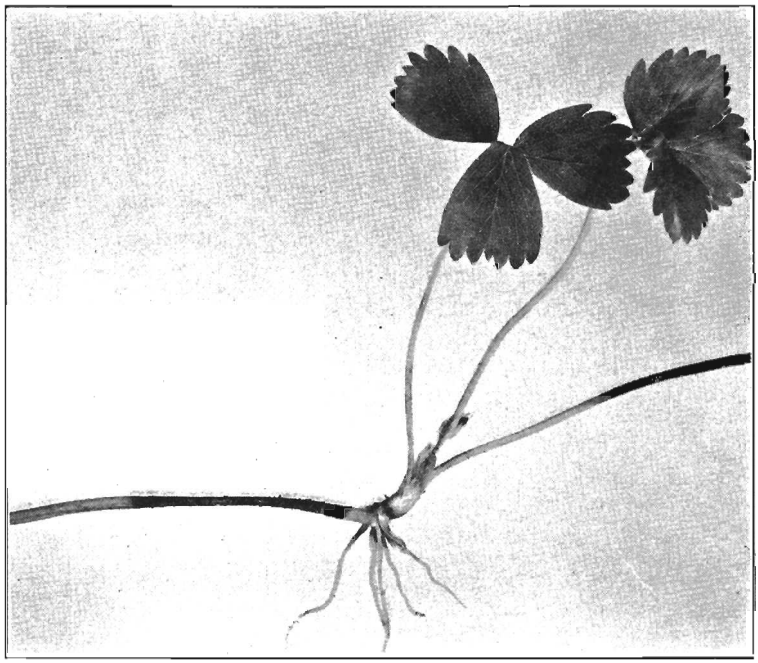

Figure 5. Rhizoctonia lesion on runner of *Fragaria cuneifolia* under cultivation.

stage and always in contact with the soil. Besides this fruit rot caused by direct infection there is the effect of wilting on the fruit. Although plants may not actually show wilt, the water supply to leaves and fruit may be so limited as to cause slow fruit development, the fruit becoming tough and leathery.

Crowns usually are not infected by Rhizoctonia. Where lesions on adventive roots start near the crown they may extend up and down for a very short distance on the crown.

FACTORS INFLUENCING DISEASE IN THE FIELD

Later in this bulletin the causal organism is discussed. Suffice it to say here that our study of its variable morphological and physiological characters in culture leads us to conclude it to be the same variable fungus found

[8]Dodge, B. O., and N. E. Stevens. The Rhizoctonia brown rot and other fruit rots of strawberries. Jour. Agr. Res. 28:643—652. *illus.* 1924.

on potato and other host plants which is at present included in the species *Rhizoctonia solani* Kühn, the sterile vegetative form of *Corticium vagum* B & C.

Soil temperature. One of the most evident factors making this fungus so effective a pathogene on strawberry roots in the Pacific Northwest is

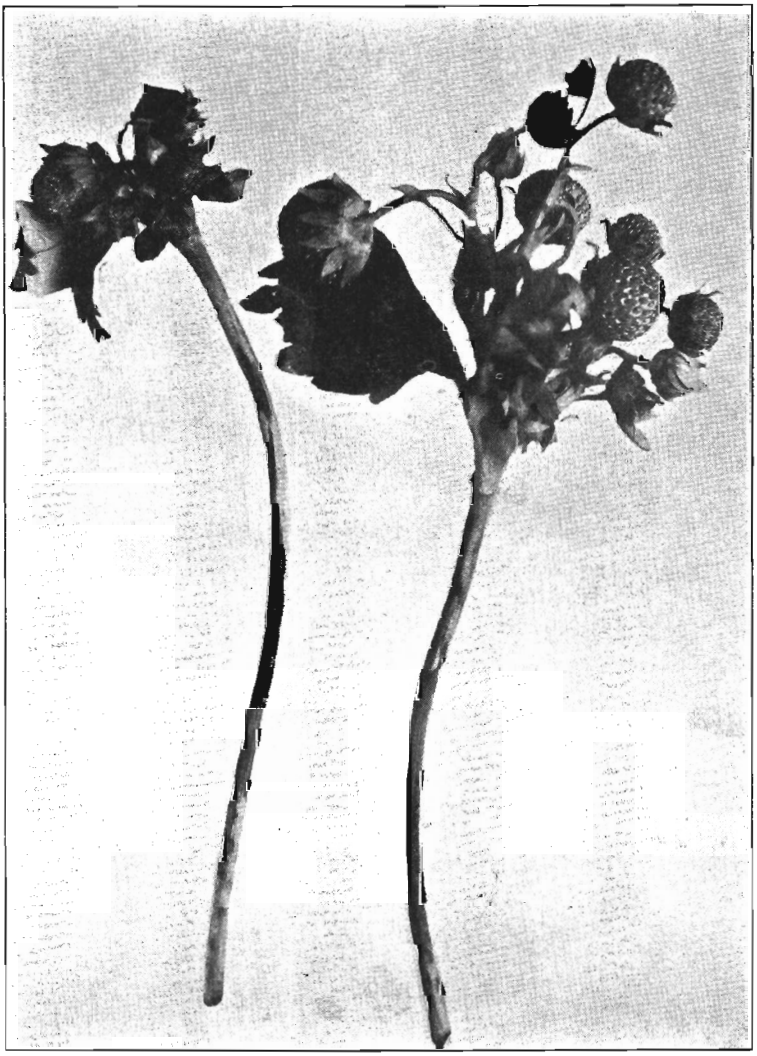

Figure 6. Fruit peduncles of Clark's Seedling strawberry with Rhizoctonia lesions.

cold, wet soil. Richards[9] has shown that in Utah serious destruction of potato tissues resulted from *Rhizoctonia solani* at 9° C., the greatest damage occurring at soil temperatures between 15° and 21°, above which the severity of fungous invasion decreased rapidly. Weber,[10] working with a strain of the organism causing bottom rot and related diseases of cabbage in Florida, found 25° C. to be the optimum and 5° C. a minimum for growth. Both in Utah and Florida the summers are perhaps warmer than in Western Oregon.

Character of soil. The disease seems most common in rather light soils having good body and rich in humus. It perhaps is most severe in some of the near-virgin soils of the foothills of the Cascade Mountains and the upper Hood River Valley. These can be classified in a general way as residual hill soils of a clay loam texture, red to brown in color.

Weed carriers. It may be that the disease is most severe in near-virgin soils because these soils harbor the causal fungus. One of the most common weeds of the logged-off lands used extensively for strawberry culture is the bracken fern (*Pteridium aquilinum pubescens*).[11] This fern has proved to be a persistent carrier of Rhizoctonia. From a very wide range of locations in Western Oregon, this fungus has been consistently isolated from the rhizomes and bases of frond stems. Growers who have religiously cleared their land of fern by repeated plowings and rakings have suffered relatively less from Rhizoctonia for the first few years than those who have not so thoroughly cleansed the soil of fern.

In newly cleared land where leveling has been done, the percentage of Rhizoctonia is far greater where top soil with fern-humus is accumulated than in the portions where top soil is relatively scarce.

"Burned" soils. In newly cleared land small areas free from Rhizoctonia and the bracken fern are often to be found. On these areas strawberries present a much more vigorous growth and have clear white roots free from the characteristic Rhizoctonia lesions. These areas have been found to be locations where great piles of stumps were burned during the clearing process, the soil having been sterilized for considerable depths by the intense heat. Of course, some mineral nutrients, especially potassium, may be liberated by the "burning" of the soil, but doubtless the killing of the Rhizoctonia had as beneficial results as the increased fertility.

Climatic factors. In Western Oregon the weather from early fall to late spring is usually wet and the temperatures relatively moderate. High temperatures are rare. Weather considerably below freezing, usually confined to a month or six weeks, is fluctuating if it occurs at all. Under these conditions the Rhizoctonia disease is active intermittently from early fall until well into the summer, perhaps hampered in its progress for a very short time in the winter. With this cool, wet weather persisting for such an extended period almost any type of soil is kept cool enough for the disease

[9]Richards, B. L. Pathogenicity of Corticium vagum on the potato as affected by soil temperature. Jour. Agr. Res. 21:459—482 *illus.* 1921.

[10]Weber, Geo. F. Bottom rot and related diseases of cabbage caused by Corticium vagum B. & C. Fla. Agr. Exp. Sta. Bul. 242:1—31. *illus.* 1931. (Review of other literature on this subject.)

[11]Ingram, D. C. Vegetative changes and grazing use on Douglas fir cut-over land. Jour. Agr. Res. 43:387—417. *illus.* 1931.

to do serious damage. In fact, the disease persists in any soil types where the Marshall variety of strawberry is productive.

In the upper Hood River Valley the Clark's Seedling strawberry is grown under irrigation. Here the winters are cold and the break from the cold weather to the warm, dry summer months is very much more abrupt than is the case west of the Cascade Range. Under these conditions, although the summers are very warm and dry, the Rhizoctonia disease of the strawberry is very severe. This is undoubtedly due to a great extent to the cool nights and to the very cold snow water used for irrigation purposes, both of which keep the soils cold enough for optimum Rhizoctonia damage.

CAUSAL FUNGUS

ISOLATION OF ORGANISM

Isolations from strawberry crowns and roots have been made over a period of four growing seasons.

Isolations from crowns. During the first season (1928) attention was given to abnormal conditions in the crown tissues, and attempts were made to isolate organisms from them. The crowns were thoroughly washed, the roots cut away, and while the crowns were still moist but with free water removed, they were split with a knife and portions of the inner tissues which had not been touched in any way were removed by a sterile needle and planted on Petri plates or tubed slants. Various kinds of agar were used at first but finally all were discontinued except potato-dextrose agar. Cultures were made in duplicate from 659 crowns. This is in addition to such crowns as were found to contain white masses of a felty, fungous mycelium which proved to be a crown rot produced by *Armillaria mellea* (Vahl.) Fries. This crown rot has been reported elsewhere.[12] Of the 1,318 cultures, 362 proved to be various strains of Rhizoctonia from 245 crowns. There were also 9 cultures representing several species of Fusarium from 6 crowns, 46 cultures of Phoma sp. from 30 crowns, 27 cultures of *Verticillium alboatrum*[13] from 15 crowns, 33 cultures of Sphaeronema sp. from 18 crowns, and 28 cultures of a basidiomycete from 22 crowns. These cultures seemed identical with those of *Hypholoma fasciculare* from sporophore tissues. This species is often found in strawberry patches on new soil. There were 207 crowns that gave no cultures whatever and 339 cultures, representing 116 crowns not accounted for elsewhere, that were contaminated with various species of bacteria, Penicillium and other common molds. There were 474 blanks.

Isolations from roots. Isolations from strawberry plants made during 1929, 1930, and 1931, were nearly all from the black lesions on the adventive and smaller roots. A different technique was used for these isolations. For the most part, lesions from 1 to 3 cm. long were selected after washing the soil from the roots. With a sharp scalpel or scissors the root was clipped off above and below the lesion so as to leave on both ends a portion of healthy root from 0.5 to 1 cm. long. These were dropped immediately into

[12]Zeller, S. M. Armillaria crown rot of strawberry. Phytopath. (In press.)

[13]This is the form of *V. alboatrum* which produces micro-sclerotia and which some workers have segregated under the name *V. Dahliae*.

a solution of mercuric bichloride, 1 to 1000, where they remained for 10 to 60 seconds, according to their general diameters. Lesions on larger roots could remain longer. An average period of safety was 20 seconds. After this the pieces were rinsed in sterile water two or three times and then the central portion of the lesion was removed and planted on agar plates. These

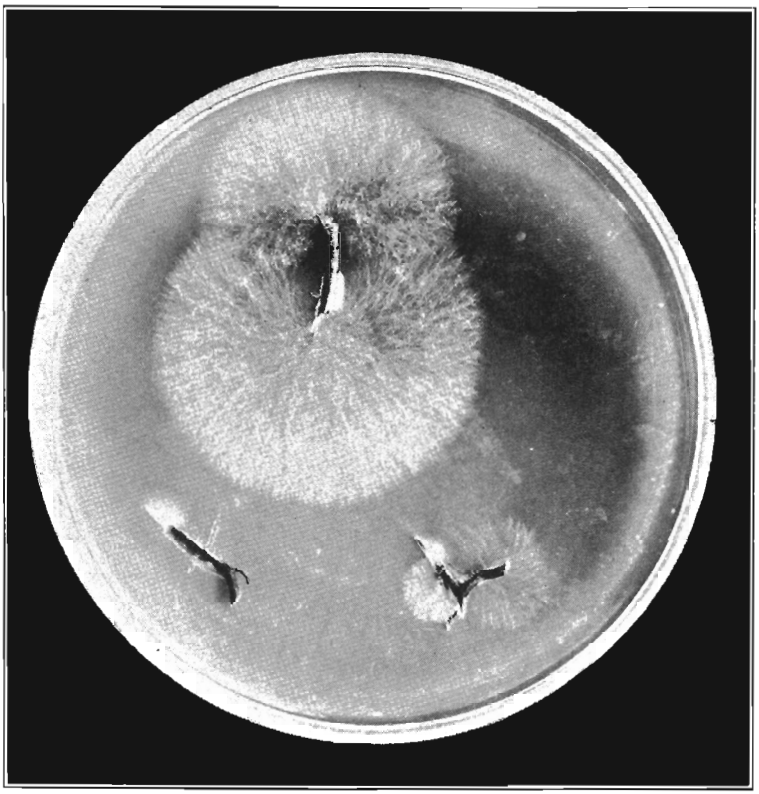

Figure 7. Showing Rhizoctonia growing out from both ends of portion of root lesion planted on plate of potato-dextrose agar.

central portions averaged 0.5 to 1 cm. long. The ends were cut away and discarded to eliminate the possibility of carrying over to the agar any quantities of mercuric bichloride which had entered the ends of healthy tissue. The newly cut ends of the central portions which were planted on agar allowed any fungi in the interior of the lesion to grow out without penetrating the outer layers which had been disinfected by the mercuric bichloride. This method proved very successful. There were, as a rule, no contaminating organisms which grew from the surface of lesions treated in this way but the organisms grew from the ends, as illustrated in Figure 7.

During the three seasons 5,715 lesions were treated in this way, and several different organisms were obtained. The most frequent of these

were various strains of Rhizoctonia from 4,479 (78.4%) of the lesions. From the remainder of the lesions there were 488 blank cultures (8.5%), 645 cultures (11.3%) of such contaminating organs as various species of bacteria, Penicillium, Aspergillus, and Mucors, 43 cultures (0.75%) of a Phoma sp., 42 cultures (0.74%) of Fusarium spp., 15 cultures (0.26%) of *Verticillium alboatrum,* and 3 cultures (0.05%) of Sphaeronema sp. Several of these organisms were used in greenhouse inoculation experiments reported below.

In addition to the isolations from roots and crowns, Rhizoctonia was isolated numerous times from lesions on runner stems (Figure 5) and a few times from lesions on petioles and peduncles (Figure 6). Among all these isolations were many strains or growth-forms of Rhizoctonia.

GROWTH-FORMS OF RHIZOCTONIA

It is not within the scope of this bulletin to discuss at length all of the growth-forms of Rhizoctonia obtained from Fragaria and Pteridium, and four strains from volunteer potatoes found in strawberry plantations. The term "growth-form" is used here to apply to variations in growth characteristics of different strains on artificial media, as illustrated in Figure 8. There were, for instance, many very distinct growth-forms isolated from Fragaria during one season (1929). These were picked out from the platings from time to time and stored on agar slants in test tubes. Then at one time transfers from these were planted singly on the centers of Petri plates of potato-dextrose agar. In these there appeared to be many duplicates of one growth-form but only a few of several others. In this way the form most frequently isolated from root lesions could be determined and 27 growth-forms were distinguishable on this one medium.

Next 6 different nutrient agars were plated at one time. These agars were (1) potato-dextrose, (2) lima bean, (3) green-bean pod, (4) prune, (5) corn-meal, and (6) oat-meal. After the 27 strains or growth-forms of Rhizoctonia had grown on each of these 6 nutrient agar plates for 7 days they were arranged in 27 columns, as strains, across, and 6 lines, as media, lengthwise, on a large table. This gave at a glance the growth reactions on these media and it was not difficult to reduce the whole to 14 growth-forms, where several gave the same reactions on several media. In this last elimination of 13 growth-forms produced on potato-dextrose agar, 9 were combined into one apparent growth-form which was within the group most frequently isolated from strawberry root lesions. Six growth-forms isolated from bracken fern (Pteridium) and 4 from potato were also similar to this group most frequently obtained from Fragaria. There were much greater differences between the extremes in growth characters exhibited by strains from strawberry than the differences between growth-forms from potato, bracken fern, and the most usual strain from strawberry. It would seem best, then, to consider that the growth-forms of Rhizoctonia isolated from black lesions on strawberry roots fall well within the limits of the variable fungus, which is at present classified as *Rhizoctonia solani* Kühn. Figure 8 illustrates 6 growth-forms frequently isolated from root lesions.

The perfect stage, *Corticium vagum* B. & C., has not been observed by the writer on strawberry plants.

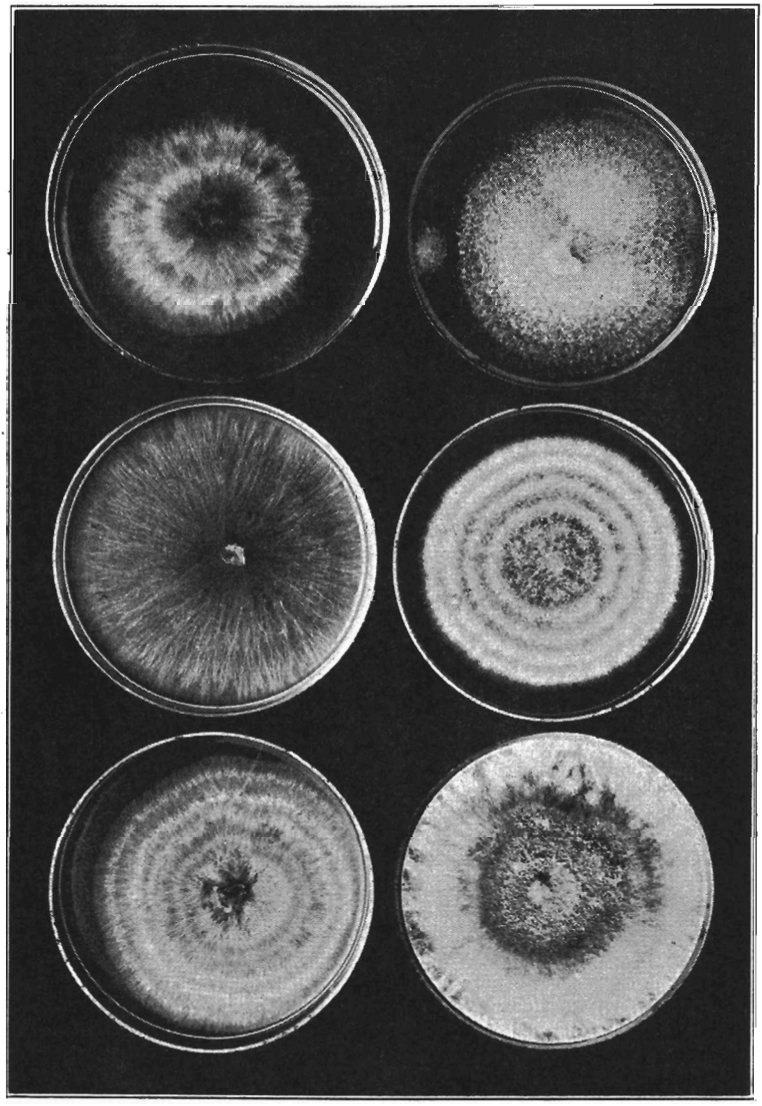

Figure 8. Six growth-forms of *Rhizoctonia solani* isolated from strawberry roots. Seven-day-old transfers.

GREENHOUSE INOCULATIONS

The greenhouse experiments are described in chronological order.

EXPERIMENT OF 1928-29

During the winter of 1928-29 potted strawberry plants were inoculated with the various organisms obtained from strawberry crowns during the summer of 1928. The organisms used were *Armillaria mellea,* two species of Fusarium, Phoma sp., Rhizoctonia sp., a short-rostrate Sphaeronema sp., and *Verticillium alboatrum.*

Forty Marshall strawberry plants were inoculated with each of the seven organisms and twenty uninoculated plants were reserved as checks. The plants were grown in 10-inch fern pots. The Armillaria, Fusarium spp., and Rhizoctonia were grown in pure culture on potato-dextrose agar, while the Phoma, Sphaeronema and Verticillium grew and sporulated best on sweet clover (*Melilotus alba*) stems.

Method of inoculation. Inoculation of potted plants was carried out in the following manner. The pots were irrigated a few hours before, so that the soil was damp. By means of a cork borer. a little larger than a culture tube, a plug of soil about 4 inches long was removed near the crown of the plant. Into the hole thus prepared was inserted the inoculum which consisted of the whole contents of a culture tube. In the case where agar was the culture medium the whole agar slant was removed from the tube and slipped into the hole in the soil. In order that the fungus might have organic matter for continued culture in the soil, sterilized sweet clover stems were also inserted, and the hole covered with soil. The inoculation hole was made near enough to the crown so that some of the adventive roots were cut off, and usually a chip of cortex removed from the side of the crown. This provided suitable wounds for weaker parasites, but the wounds were not sufficient to affect the vigor of the strawberry plants. In cases where cultures were grown on stems, several stems were inserted into the inoculation hole described above. Unless otherwise described, inoculations were made in this way in the other experiments reported below.

Results of experiment. In this first experiment the plants were allowed to grow for 10 weeks after inoculation. At the end of this period, no resulting damage or disease was noticeable, except in those plants inoculated with Rhizoctonia and many plants which had developed conspicuous symptoms of crinkle under greenhouse conditions. All 40 plants inoculated with Rhizoctonia showed the black root lesions, and Rhizoctonia was obtained from some of the lesions from each of the 40 plants. One of the check plants showed similar lesions, and Rhizoctonia was obtained from them. Crowns of the other 240 plants were cultured, but no fungi were recovered. These plants were destroyed before the Rhizoctonia lesions were discovered on the roots of the 40 plants inoculated with this organism, for this was the writer's first discovery of such lesions. No Rhizoctonia was obtained from the crowns of the plants inoculated with this organism.

The following spring and summer (1929), root lesions as described were found in nearly every planting of Marshalls, and Rhizoctonia was the only organism consistently isolated from them. The following winter (1929-30) potted plants in the greenhouse were inoculated with *Rhizoctonia solani* obtained from lesions in the field.

EXPERIMENT OF 1929-30

In this second greenhouse experiment, 155 Marshall plants which were well rooted were inoculated with Rhizoctonia obtained from root lesions in the field. In 8 weeks after inoculation, the root systems were examined and 57 showed numerous lesions on the roots, while most of the remaining 98 plants had a few lesions. Fifty uninoculated check plants had clear white root systems except 4 plants which were badly infected. The plotting soil had not been previously sterilized. In this experiment 11 plants were inoculated with each of the 14 different strains of Rhizoctonia discussed above and the 57 badly infected plants had been inoculated with 6 of the strains most frequently isolated from plants in the field (Figure 8). The results of this inoculation experiment further show 36.8 percent seriously infected plants and 72.9 percent total infection among inoculated plants, while 8 percent of the check plants were infected.

EXPERIMENTS OF 1931

Inoculation with Rhizoctonia on potato. In February, 1931, 190 Marshall plants were potted and grown in the greenhouse. On May 14, 148 were inoculated by placing next to each crown a potato tuber infected with sclerotia of *Rhizoctonia solani*. The eyes had been removed from these tubers to inhibit shoot growth. Root systems of these strawberry plants were examined July 8—16 and isolations made from the root lesions. Of the inoculated plants, 96.9% showed root lesions and 91.2% of them returned Rhizoctonia in culture, while 92.9% of the checks showed root lesions and returned 92% Rhizoctonia in culture. This showed that the type of potting soil available at the time was well infected with Rhizoctonia and an additional experiment was planned in which the soil and pots were sterilized.

Inoculation in sterile soil. For this fourth experiment the potting soil was sterilized in the pots at 20 pounds pressure for 2 to 3 hours. In order to introduce no contaminating soil, young greenhouse-grown runner plants which had never come in contact with soil were rooted in these pots, while yet connected by runner to the parent plant in another pot. Nine weeks later 50 plants were inoculated and 25 were left as checks.

These plants were examined 6 weeks after inoculation. All of the 50 plants inoculated with Rhizoctonia had numerous lesions on the roots, while one only of the check plants showed any lesions. This one plant was badly infected, however, while no lesions could be found on the remaining 24 check plants.

Description of healthy and infected roots. In the experiment involving inoculation in sterile soil, the contrast between the root systems of infected and check plants was striking. It was not difficult to distinguish the infected plants from healthy as soon as the mold of soil in which the root system was imbedded was slipped out of the pot. Check plants showed a heavy mat of very bright white roots, while infected plants showed a root system much darker brown. When the soil was sluiced out by gently rinsing in a water bath, striking differences were seen (see Figure 9). The check plants had heavy, bushy root systems of bright white roots with many tiny rootlets. The infected plants showed much less of the fine roots and most of the larger adventive roots and myriads of the small

rootlets were cankered. Visible lesions were counted in three average cases, and these showed 34, 114, and 79 lesions, respectively. There were many times these numbers on the finest rootlets. Some infected plants seemed to have few lesions, but the whole root system was smaller and darker in color with fewer fine roots than in the checks.

Figure 9. Two Marshall strawberry plants grown in sterile soil in greenhouse. Plant to left subsequently inoculated with Rhizoctonia isolated from strawberry roots. Note general dark color of root system, with myriads of black lesions; coarse appearance because finer secondary rootlets are missing. To right—uninoculated check; note bright clear roots, with finer secondary rootlets intact. ⅓ diam.

A study of infected root systems under binoculars shows myriads of very fine lateral rootlets blackened and withered, while rootlets of the same size in the checks are clear. Infected root systems seem also to be affected slightly in some toxic way. Besides the discolored condition where no definite lesions can be seen, the rootlets are not generally so vigorous as in the healthy root systems. Most of the very fine rootlets which had been blighted had apparently been infected very near to the parent root. Along the medium-sized secondary roots were to be seen tiny, short, black, spur-like ends of former fine rootlets that had been cankered next to the parent root. When infected root systems, washed out and the excess moisture allowed to dry off, were shaken over a paper, the tiny brittle rootlets fell out in quantities. In healthy plants treated in the same way this did not happen.

Five representative plants each from healthy and Rhizoctonia-infected groups were selected, washed out gently, and weights taken after the excess moisture was allowed to evaporate. Weights of these (1) whole plants, (2) root systems, and (3) tops were as follows:

	Weight in grams of:		
	Whole plant	Tops	Root System
Healthy plants			
1	113	59	54
2	111	64	47
3	119	52	67
4	118.5	52.5	66
5	152.5	70.5	82
Averages	122.8	59.6	63.2
Rhizoctonia-infected plants			
1	43.5	18	25.5
2	49.5	22.5	27
3	52	27	25
4	56	27	29
5	49	25	24
Averages	50.0	23.9	26.1
Average percent reduction	59.3	59.9	58.7

These weights would indicate approximately as much dwarfing effect in the tops as in the root system. This is not so evident under greenhouse conditions as the figures indicate because there was some loss of leaves from the tops when the plants were dumped out of the pots. The weights nevertheless are significant.

Another greenhouse experiment now under way should be mentioned here. *Pteridium aquilinum pubescens* for inoculation purposes has been grown in sterile soil from spores. The plants are in the frond stage but have not yet been inoculated with Rhizoctonia. This experiment is planned to learn the influence of Rhizoctonia on the bracken fern as an aid in field recognition of infected fern, if possible.

VARIETAL SUSCEPTIBILITY

The varieties of strawberries of commercial interest in Oregon and the Pacific Northwest are limited chiefly at present to the Marshall as a barreling berry, and the Clark's Seedling and Ettersburg 121 as canning berries. The new variety, Corvallis, being introduced rapidly as a canning berry, may replace the Ettersburg 121. Of these four varieties, the Marshall and Clark's Seedling are very susceptible to Rhizoctonia, perhaps in the order mentioned. The Corvallis is fairly susceptible but has not been seen in large-enough acreages to permit one to judge the damage which may be done in the field. On the other hand, the Ettersburg 121 is almost immune to the Rhizoctonia disease, at least under the heavy soil conditions where this variety is grown commercially.

Occasionally other varieties are to be found in Oregon, especially in nurseries where planting stock is produced. These odd varieties include chiefly the Improved Clark, Gold Dollar, Magoon, Nick Ohmer, Redheart,

and various unnamed hybrids. Of these, the Gold Dollar and some of the hybrids are somewhat susceptible, while the Nick Ohmer and Redheart seem to be scarcely affected. The Improved Clark and Magoon have been found infected but do not show any particular deleterious effects from the few root lesions. A few plants of Dunlap have been found to have chance infection in the greenhouse.

Among the local native species, the field strawberry (*Fragaria cuneifolia*) has been found rather severely infected by Rhizoctonia in nature and under cultivation. A few cases of the Rhizoctonia disease have been found on roots of the wood strawberry (*F. californica*) but never affecting the coast strawberry (*F. chiloensis*).

OTHER ROOT DISEASES OF STRAWBERRY

The recent stimulus to study root diseases of Fragaria has revealed that there evidently are several of these diseases which unfortunately have been designated under the one name "black root." In Michigan this name was first used (Coons) for the Rhizoctonia disease of strawberry and has more recently been applied (Strong and Strong) in the same state to two other similar diseases said to be caused by *Leptosphaeria coniothyrium* (Fuckel) Sacc. and *Pezizella lythri* (Desm.) S. & D., respectively. The term "black root" then should perhaps be abandoned for these diseases. Each might be designated preferably by reference to the causal organism—e.g., Rhizoctonia disease of strawberry, etc. So far as is known, the Leptosphaeria and Pezizella diseases of strawberry have been studied in Michigan only. These two organisms occur on other rosaceous hosts, especially on canes of Rubus, in the Pacific Northwest but the writer has never isolated either of them from the roots of Fragaria.

The Rhizoctonia disease, on the other hand, has been observed more widely. It was first briefly described from Michigan (Coons) and has been observed in Oregon by the writer, in Washington (Heald) and in Utah (Blood). Undoubtedly, the symptoms of the three diseases are very similar. It is not necessary to discuss here some other dissimilar root diseases, such as the Lanarkshire disease in Scotland caused by Phytophthora sp. (Alcock), the Verticillium crown disease in California (Thomas), a probable phycomycetous root rot in southern states (Plakidas), and a black root condition caused by high water tables, heavy wet soils, etc.

CONTROL

The nature of the Rhizoctonia disease of strawberries makes the problem of control difficult. As pointed out above, the fungus is a common soil inhabitant everywhere, attacking a wide variety of plants both cultivated and wild, including the common bracken fern which at once invades land cleared of forest in Western Oregon. It is believed to be able also to maintain its existence in the soil for some time on dead plant remains and pass readily on to the underground parts of susceptible crops. It can also be transferred to clean ground by planting therein sets from fields where the disease has previously existed. These facts suggest that the prevention or

reduction of Rhizoctonia damage to strawberries can be aided by the following practices:

1. The avoidance of planting stock that comes from strawberry fields where the disease is active or known to be present.
2. The selection for strawberry planting of ground that for several years, at least, has not supported a crop of strawberries or potatoes or a growth of bracken fern because of the danger of their propagating the disease. Land that has been in hay or grain for the preceding year or two is suggested since these crops tend to reduce the amount of Rhizoctonia present in a piece of land.
3. The choice of varieties of strawberries that are more or less resistant to damage by Rhizoctonia where such varieties can be profitably grown.

Rotation experiments are in progress on land where strawberries were severely infected with Rhizoctonia. It is too early, however, to obtain results.

While heat has been found effective in freeing soils from this fungus, this does not offer to the grower a practical means of dealing with the disease.