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POTATO FAILURES.

A PRELIMINARY REPORT.

—BY—

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POTATO FAILURES.

By F. M. ROLFS.

INTRODUCTION.

The following lines are written to call the attention of the potato growers in this state to a destructive disease of the potato, *Rhizoctonia solani* Kuhn. I am aware of the incompleteness of this report, but it is hoped that a publication at this time may stimulate an interest in the subject and thus call forth suggestions which will be helpful in working out a practical method of overcoming this disease. Undoubtedly this fungus has been common to the potato fields of America for years, and although of considerable economic importance it has been entirely overlooked by American investigators, and nothing of importance concerning its nature has been recorded. *Stewart and Duggar in 1900 published the first account of its occurrence in America.

European investigators have given it considerable attention and European literature contains a number of publications on a potato disease caused by *Rhizoctonia*. Its host plants cover a wide range and a number of species of the fungus have been described.

OCCURRENCE OF DISEASE.

The stem rot of the potato plant was first brought to my attention during the summer of 1900, while at the New York State Branch Experiment Station on Long Island. The potato growers in the various sections of the Island, complained of the early wilting or drying of the vines caused by a stem rot. On visiting these sections and making careful observations it was noticed that the disease in many instances resembled the stem rot of carnations, which is caused by the attack of a species of *Rhizoctonia*.

A microscopic examination of plants that had been recently killed invariably revealed an abundance of this fungus on the stems and roots. At least thirty plantations in various sections of the Island were visited and a number of dead plants from each field were carefully examined. Although other fungi were more or less plentiful on these stems, *Rhizoctonia* was constantly present both in the pith and on the outside of the roots and stems. These observations pointed toward the conclusion that this fungus had

*Bulletins 186 of the New York State Agricultural Experiment Station, and Cornell Experiment Station.

more or less influence on the death of the plants. The stems which had been dead for sometime were so completely overrun by other fungi that it was often difficult to identify the *Rhizoctonia* hyphae.

This Department has received many inquiries from potato growers in various sections of this State in regard to failures of the potato crop. Many of these inquiries gave a description of a diseased condition which is strikingly similar to the one that was so common on Long Island in 1900. After examining the tubers and stems from various parts of the state, it is quite evident that the fungus is common to nearly every section of this state, and especially abundant in many parts where failures occur. This information and the previous observations led us to believe that it is a parasite on the potato plant and that it probably had some influence on the failures recorded in these various sections. Accordingly the writer was detailed to take up this work and the results of the investigations and experiments are given in the following pages.

Our experiments prove that *Rhizoctonia* is an active parasite on the potato plant. Species of this fungus or possibly the same species occur on a great variety of plants among which may be mentioned the following: Beets, carrots, alfalfa, red clover, onions, turnips, peas, celery, lettuce, beans, cabbage, blackberries and raspberries. Usually it is a parasite but it is capable also of existing on dead organic matter in the soil and when favorable opportunities occur it invades and destroys the living tissues of plants.

The annual loss to the State from this disease is considerable. In many localities where potato growing was once a paying industry the soil has become so infected with the fungus that the crop is no longer profitable. Although it is more or less common to many fields, it apparently develops most rapidly in heavy soils which are poorly drained. The disease remains in the soil and grows worse with each succeeding crop, consequently failures are most apt to occur where a systematic rotation of crops is not followed.

Probably every state in the Union suffers more or less injury to its potato crop from this disease. It is known to be common to the fields of New York, Ohio, Iowa, Minnesota, Wisconsin, Florida, Oklahoma, Texas, Colorado, California and Washington.

EFFECTS OF THE DISEASE ON POTATO PLANTS.

In many sections of the State where potatoes are not successfully grown it is reported that large vines are pro-

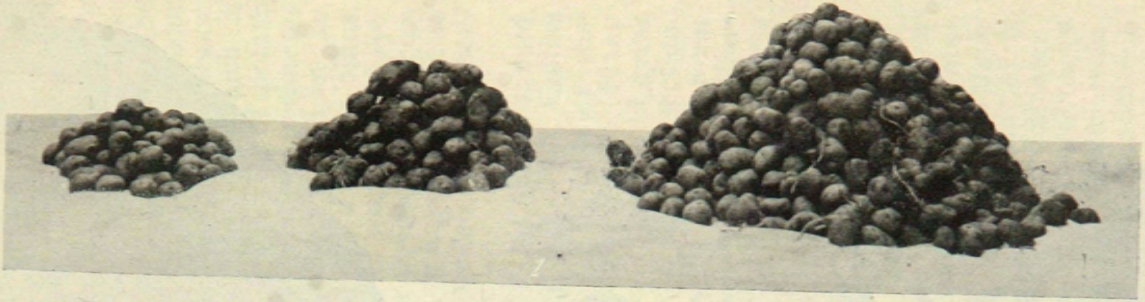

PLATE I.

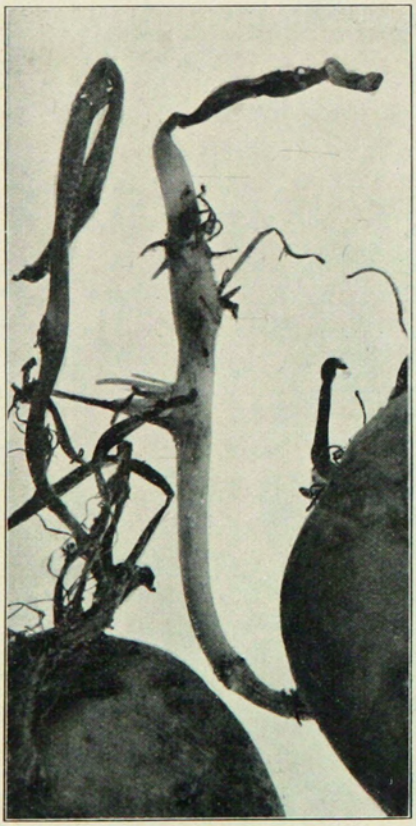

Figure 2.

PLATE II.

duced which give promise of an abundant yield, but when digging time comes it is found that so few tubers have set that it does not pay to dig them. Many of the thriftiest vines fail to produce a single tuber. (See Plate V.) It is a less frequent, but by no means uncommon occurrence, for the vines to set an abnormal number of small potatoes, or "Little Potatoes" as they are sometimes called. These often occur in compact clusters and are so small as to be worthless. (See Plate IX.) The above conditions occur most frequently on poorly drained land and especially on the heavier soils. A third condition and one which is common to the best potato districts is the dying of potato plants thus resulting in poor stands. Our experiments prove that any of these conditions may be produced by attacks of *Rhizoctonia*, and in the vicinity of Fort Collins, where most of our experiments and field work were done, this fungus is frequently responsible for the lack of success in the growing of this crop. So far as we have been able to learn, one or more of these conditions prevail in many sections where the potato crop is a failure.

The question naturally arises why this fungus should be so severe in its attacks on the potato at Fort Collins while the crop is so successfully grown in the Greeley district, twenty miles east and nearly the same altitude. Many farmers claim that if they had Greeley soil they could grow potatoes as successfully as those in the favored section. Our observations go to show that the difference between success and failure in potato growing is principally a difference in soils, not that the successful growers suffer no loss from the attacks of this fungus but that it finds less congenial surroundings in the lighter and better drained land.

NATURE OF THE FUNGUS AND ITS METHODS OF ATTACK.

The hyphae or root-like organs of the fungus are often found growing on the surface and in the scab ulcers of potatoes. These hyphae give rise to irregularly shaped dark masses know as sclerotia, which vary in size from that of a mere speck to areas one-half inch or more in diameter. (See Plate I. Fig 2.) The sclerotia resemble small bits of earth so closely that it is often difficult to distinguish them from particles of soil on the tubers, but by placing the potatoes in water these bodies become black and quite conspicuous. Many of them adhere very firmly. When such potatoes are used for seed the disease is planted with them and it is ready to begin its attack as soon as the new plants start to develop.

This disease like many other root fungi is greatly influenced in its growth by soil conditions. It may occur abundantly in the soil and on the seed potatoes and yet if the conditions are not favorable the plants may escape serious injury. On the other hand, a few diseased seed may cause considerable damage. The hyphae spread through the soil in various directions, hence a single diseased potato plant may be the means of infecting an area of considerable size, since the disease remains in the soil for a number of years.

Young plants are often severely injured by this fungus as shown in Plate III. Here two young shoots were killed before reaching the surface of the ground and the others were severely injured. Such wounds are usually characterized by a reddish-brown color and vary in size and shape.

Infected plants frequently show no marked signs of injury when first dug, but by leaving such plants in the collecting can over night the diseased parts take on a brown color and become quite conspicuous. Experience also shows that microscopical examination often fails to reveal the presence of the fungus if affected plants are not properly cared for after they are dug: therefore it is necessary to keep the plants in a fresh condition if they are to be successfully studied in the laboratory.

If the fungus produces wounds on the young plant that are small and confined to the outer tissues, the plant usually lives but it is apt to suffer more or less injury from the disease later in the season. The appearance of affected plants is familiar to many but the injury is usually attributed to such causes as altitude, dry weather, heat, over-watering, insect attack, blight and frost. Since conditions have a marked influence on the development of the disease there is some variation in the appearance of affected plants. Usually, however, there is no difficulty in its identification. Plants which are attacked while young, if not killed outright, are often dwarfed, take on an unhealthy appearance and frequently die long before the close of the season. On examining such plants one usually finds that the parts below ground are thoroughly infected with *Rhizoctonia* and often the pith of the stem is filled with this fungus. Such infections apparently start from diseased seed potatoes and the fungus grows up the stem, gradually killing the root system and finally starving the plant. (See plate VII.)

In some cases, the disease attacks the plant just below the surface of the ground, and if conditions are favorable for the development of the fungus, it produces a stem rot

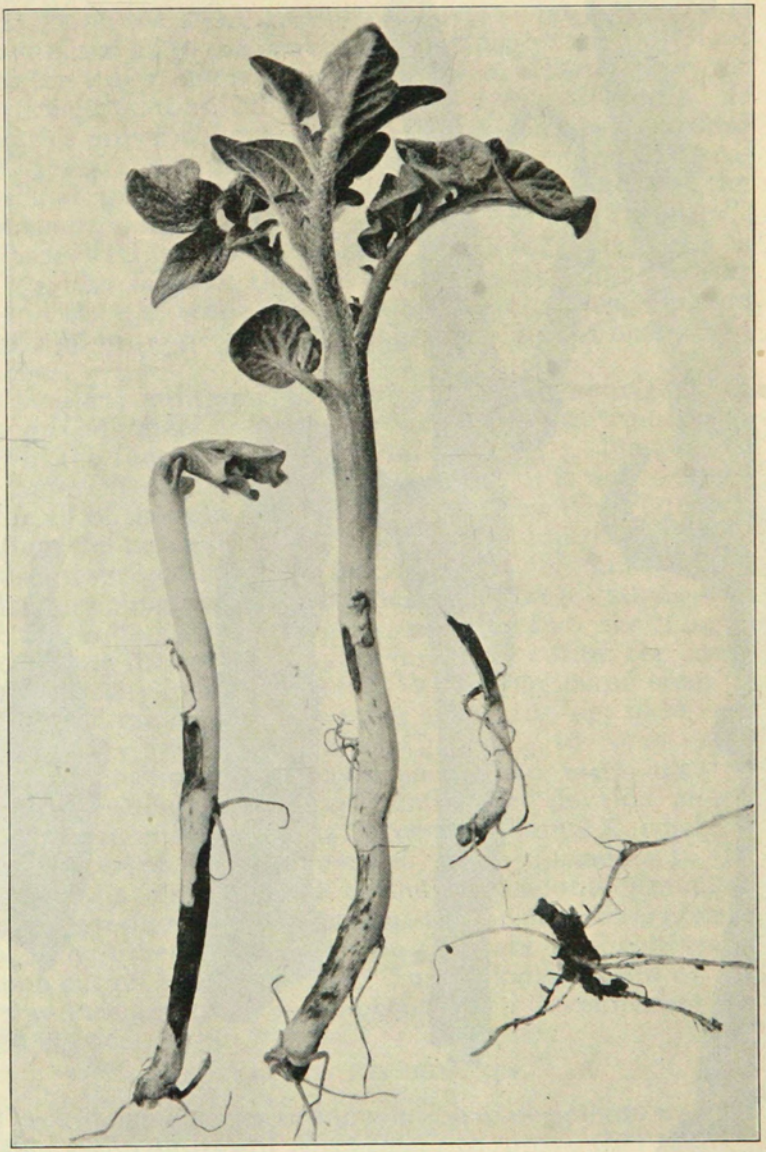

PLATE III.

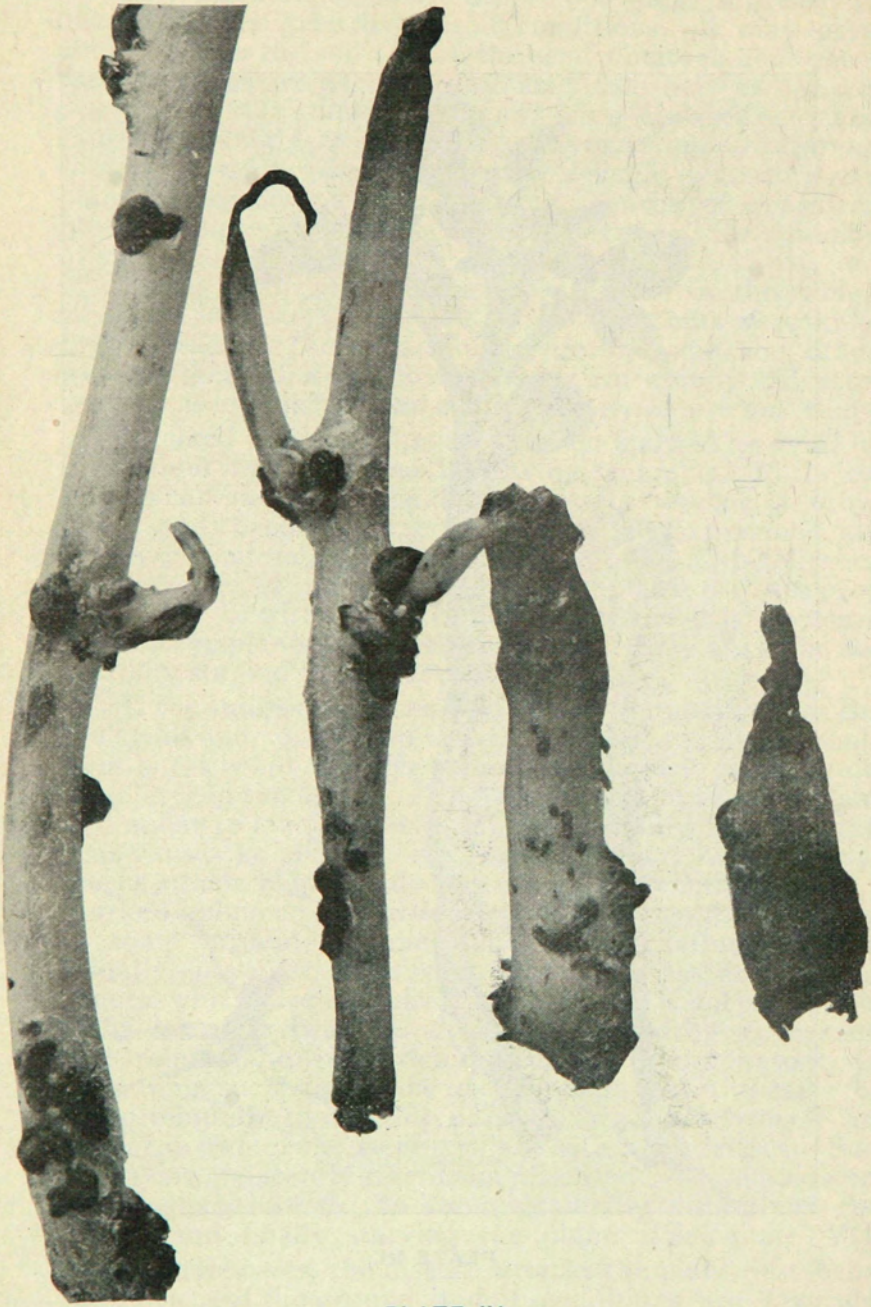

PLATE IV.

which is known in some sections as "Collar Rot" or "Black Ring" of the potato plant. Badly affected plants wilt suddenly and are soon dead and dry. Frequently, however, the attacks on the stem are not so severe but the wounds are so situated as to prevent the free transportation of plant food to the tuber stems, thus cutting off the food supply to the growing potatoes, which consequently remain small. If the injuries prevent the assimilated food from being stored in the subterranean parts of the plant, large tops are produced, and green tubers often form in the axils of the leaves, thus giving rise to the so-called "Aerial Potatoes". (See Plate VIII.) When the root system of such plants is more or less injured, the leaves usually take on a lighter color and have a tendency to fold. The stems become thicker, and grow prostrate, giving the plants a bushy appearance.

A similar condition is brought about by the attacks of the fungus on the tuber-stems. Young tubers are frequently cut off by the fungus as shownin Plate XI. Fig 2. The yield is often materially reduced in this way and it is not uncommon for all of the tubers to be cut off as shown in Plate VI.

When the tuber stems are less severely injured, but the wounds are severe enough to interfere with the flow of plant food to the young potatoes, the buds on these stems just above the wound often develop tubers. But the fungus may continue its work and again injure or cut off the stem above the newly formed tubers. When the main stem is infected with the disease, the tuber-stems are apt to be cut off before they have made much growth. In such cases blind or adventitious buds may push out and form on the main stem around the injured member and develop short-stemmed or stemless tubers as shown in Plate IX. where a typical cluster of "Little Potatoes" have formed. If the root system is also invaded by the disease, the vitality of the plant is reduced and it puts out few or no subterranean stems. The tuber-stems which do grow are probably weak and soon cut off by the fungus. Such plants set few or no tubers and usually take on the peculiar top development described above.

INOCULATION EXPERIMENTS.

The following series of inoculation experiments was undertaken with cultures of *Rhizoctonia* to prove that the disease is parasitic and that its attack on the potato plant may produce the conditions described above. Pure cultures were readily obtained from the sclerotia on tubers. Conditions have a marked influence in the growth of this fungus in the

laboratory as well as in the field; dryness and exposure to sunlight are especially liable to check its development. Test-tube cultures are very sensitive, hence results from inoculations are apt to be misleading, since the culture material may be weak or dead when the inoculations are made, or the conditions under which the plants are growing may be unfavorable for the best development of the fungus.

These experiments were conducted in the field with the exception of No. 2. *Check plants were used in the experiments and all of them remained in a healthy and vigorous condition.

No. 1. On August 24 placed pure cultures of this fungus on twenty tuber stems and carefully covered the inoculations with grafting wax. In this experiment long young stems were selected in order to be able to make the inoculations some distance from the main stem. On August 29 eight of these stems were examined. All of them had brown-colored areas on inoculated surfaces. September 10 examined the remaining twelve stems. Seven had deep scars under the wax and five of these seven developed new tubers above the wound. The remaining five inoculations gave no marked results.

No. 2. July 7 inoculated twenty green stems on plants growing in pots in the greenhouse. Small incisions were made and particles of the culture material inserted. Check wounds were made in the same manner but not inoculated and all wounds were covered with grafting wax. August 21 three of the inoculated stems were found to be cut in two, eleven were deeply scarred and six remained uninjured. Plate XII. shows four stems taken from this lot.

No. 3. Twenty inoculations made September 18 in the same manner as No. 1. Six of the inoculated tuber-stems were killed and the plants produced stemless tubers. Out of six root-inoculations four were killed and two remained healthy. Two of the eight inoculated branches were injured and six remained sound.

No. 4. August 31, inoculated seven stems just below the surface of the ground. The operation was performed as in No. 1. These inoculations were examined September 12. Three produced a distinct black ring around the stems and four gave no marked results.

No. 5. On the same day, August 31, fifteen tuber-stems and five roots were treated in the same way as in No. 1. These inoculations were made close to the main stem. September 12 five stems and the five roots were examined. All inoculations produced brown-colored areas on the inoculated surfaces. September 22 the remaining ten of these inoculations were carefully examined; seven of these had developed deep black wounds under the wax. The remaining three were completely cut off and small stemless tubers had developed on the main stem around the injured tuber stem. More or less of *Rhizoctonia* hyphae were found in all of the wounds.

No. 6. On August 15th twelve green stems were slightly injured with a sterilized knife, and pure culture of the fungus was placed in the wounds and the inoculations were covered with wax. A careful examination of these stems was made on September 6. Three of them were killed. (See Plate XI. Fig. 1.) Six developed marked wounds and three were healthy. Hyphae of the fungus were more or less plentiful in all of the wounds. The five check injuries healed and the stems remained vigorous.

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* In any inoculation experiment it is necessary that uninoculated plants be grown under the same conditions for the sake of comparison. In the following discussion such plants are designated as checks.

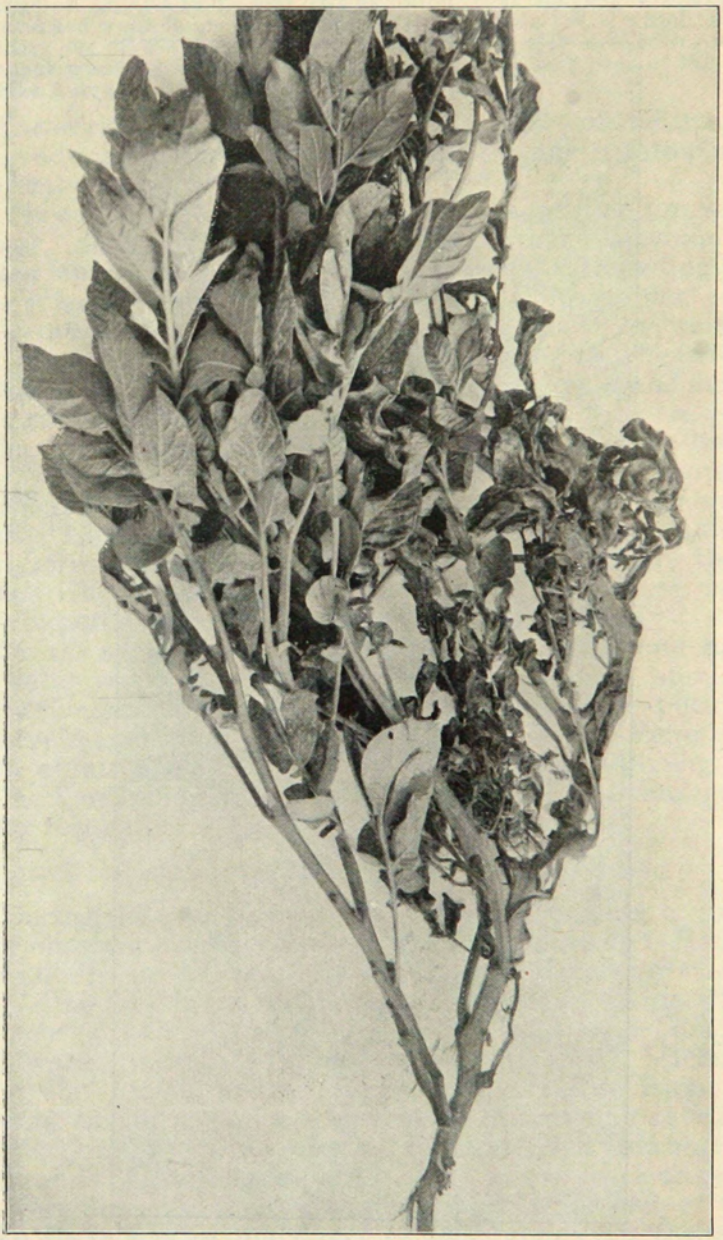

PLATE V.

PLATE VI.

7. On August 1st, pure culture of the fungus was placed on five tuber-stems and the cultures were covered with wax. These stems were examined on August 15th, and it was found that the fungus had produced marked wounds on all of them. Two of these stems which were practically cut off are shown in Plate XI. Fig 2. Two of the five stems used for a check were slightly colored under the wax but no traces of the disease were found.

These experiments show that the attacks of the fungus may produce the abnormal development of the potato plant, so common to many of our fields.

It is evident if fungus injuries are responsible for such peculiar development of the plant that mechanical injuries ought to produce similar results. Accordingly a series of experiments was planned to test these points.

Mechanical Injuries. On August 24th, all of the tubers were removed from forty plants. September 2d, the tubers which had formed during this time were removed and many of the roots were injured. All the plants soon took on the peculiar development described above and 29 of them developed "Aerial Potatoes." These plants were dug September 20 and it was found that many of them had produced typical "Little Potatoes." (See Plate X.) Examinations failed to reveal the presence of *Rhizoctonia* on any of these plants. Check plants growing by the side of those used in the experiment produced normal tops and tubers.

On the same day, a ring of outer tissue about one half-inch wide was removed from around the main stem of twenty-five plants. These plants also took on the peculiar top development and all produced aerial tubers. Plate IX. shows a fair specimen of this lot of plants. Twisting the stem and wrapping a wire firmly around the stem gave similar results.

THE SEED.

During the past spring, the Department made a number of observations on the percentage of infected *Rhizoctonia* tubers in different lots of potatoes offered for sale as seed. One lot examined contained 805 tubers. Ninety-one per cent of these were infected with the disease and were more or less covered with sclerotia. While the remaining nine per cent were free from the sclerotia, careful examination with the microscope revealed the fact that the eyes of most of these tubers harbored a few strands of the fungus. Five of the supposed clean potatoes were placed in a moist chamber and at the end of two weeks, there was an abundance of this fungus on three of them. The other two were completely overrun with *Fusarium* and no traces of *Rhizoctonia* could be found. The

amounts respectively of clean and diseased potatoes in this sack are shown graphically in Plate I. Fig 1.

From another lot of potatoes which had been in sacks for some time 549 pounds were carefully examined. Fifteen per cent were free from disease, so far as could be determined, and 85 per cent were infected. Many of the sprouts had been overrun with the hyphae, and sclerotia had been developed freely on both sprouts and tubers. (See Plate IV.) Some of the sprouts had been completely cut off; the tips frequently suffered most severely, and the ends of many of the sprouts were dead and dry. (See Plate II. Fig. 2.)

Fifteen of the diseased tubers were placed in moist chambers. Five of them developed sclerotia on tubers and sprouts. The fungus on the remaining ten was apparently dead, and no further development took place. These potatoes were carefully watched and examined from time to time. Apparently the development of the disease ceased soon after they had been removed from the sack. Exposure to the dry air and sunlight probably killed the fungus. Experiments and observations indicate that excessive drying and sunlight kills the hyphae and sclerotia which grow on the surface of potatoes, and that the hyphae which grow in the deeper wounds are probably not much influenced by such treatment.

Potatoes from these lots early in the season gave a much lower percentage of infection. In neither case did it exceed thirty per cent. In the lots examined during the winter before the tubers were placed in sacks, the proportion was usually low, and seldom exceeded twenty per cent.

It is evident that under favorable conditions infected potatoes develop hyphae and sclerotia freely after being stored. A few diseased potatoes in a bin or sack of clean ones, under suitable conditions will spread the disease, and in a short time may render the entire lot worthless for seed.

The cracked skin and rough surface on so many potatoes from diseased fields, led us to suspect that *Rhizoctonia* had more or less influence in bringing about this condition and the constant association of this fungus with these injuries also pointed strongly toward this conclusion.

Observations show that the hyphae frequently enter the lenticells of the tubers and produce corroded spots, or minute open pustules. In rapidly growing tubers such openings are often extended, producing numerous cracks which frequently become confluent. These cracks are repaired by a natural effort frequently producing a peculiar corky, or apparently a double skin on the potato as shown in Plate I. Fig 3.

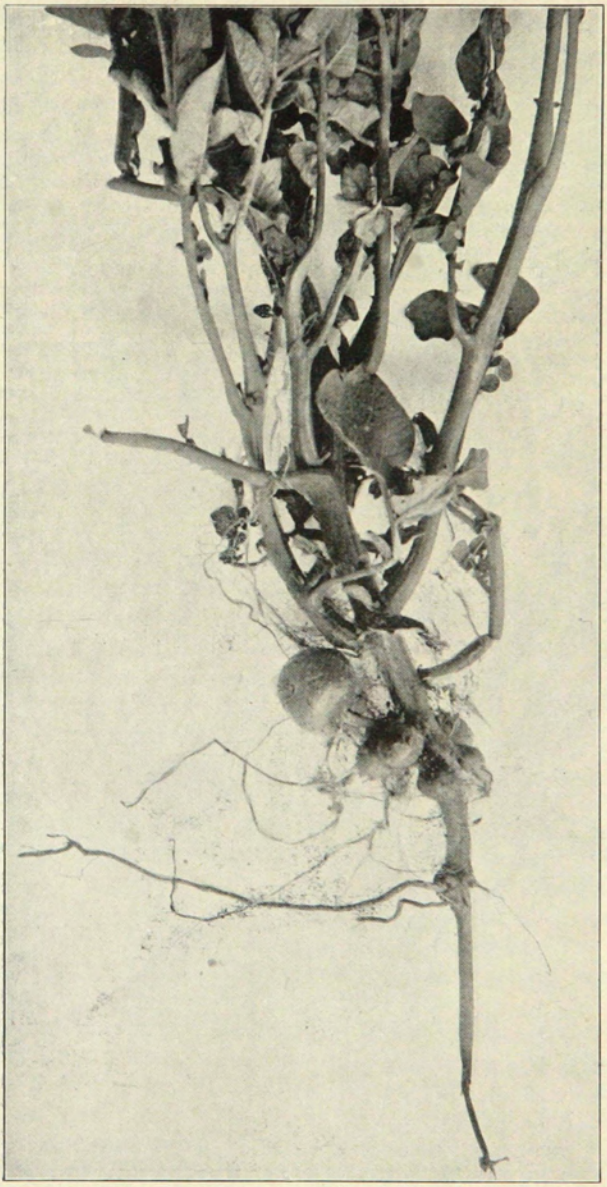

PLATE VII.

PLATE VIII.

And if the fungus continues its attacks, or if other fungi invade the injured parts, repeated efforts are made to repair the damage, and the surface of the potato may be brought into a rough or cracked condition, giving it an unsightly appearance. An extreme case of such injuries is shown in Plate II. Fig 1. That *Rhizoctonia* is the cause of this condition is proven by the following simple experiment.

On September 11, 1901, small amounts hyphae from pure cultures of the fungus were placed on the surface of eighteen small growing potatoes and covered with sterilized grafting wax. On September 25th, two of these potatoes were examined and a number of brown spots were observed on the inoculated surfaces. By a careful microscopic examination it was found that the hyphae had entered the lenticells and produced a small rupture in the skin. On September 26th, a third inoculated tuber was examined and a number of cracks each starting from a lenticell were observed. On October 10th, the remaining fifteen tubers were examined and it was found that ten of these had developed sclerotia abundantly, and the entire covered surface was a net-work of cracks. Two of the remaining five had each a deep crack extending across the tuber. All inoculations produced brown rough surfaces. An abundance of the fungus was found on each tuber, while the five checks which had been treated in the same way with the exception of adding *Rhizoctonia* culture, remained free from cracks.

METHODS OF TREATMENT.

It is difficult to treat this disease, since the external characters usually do not appear until the tissues of the plant are thoroughly invaded with the fungus. Applications of fungicides to affected plants would have little or no influence on the disease. Under favorable conditions the fungus spreads rapidly through the soil in various directions. There is no practical method of checking its spread after it is once introduced into the soil. The only way of dealing with it is by preventive means. From the nature of this fungus, it is evident that diseased seed potatoes are frequently the means of introducing the disease into clean fields; hence, too much care cannot be exercised in selecting clean seed. But even then, the potatoes are apt to harbor the fungus if they have been in contact with infected tubers. Danger from this source may be largely overcome by the treatment given on page 12.

The disease may be carried on beet roots, or dead potato stems or on the dead stems of many of the weeds which grow in the potato fields. Infected potato and weed stems often find their way into the barn-yard and compost heap, thus manure may become a source of general infection to clean fields. Great care should be taken to keep diseased plants and tubers out of the manure. The burning of all vines and weeds, as soon as the potatoes are harvested, is an excellent practice.

Some fields seem to be more favorable for the development of this fungus than others. A heavy poorly drained field seems to be of the favoring class. A thorough drainage of the land would probably do much good. Potatoes grown on heavy soils with good bottom drainage usually suffer less severely from the disease than those grown on poorly drained soils. It is not definitely known how long this disease will remain in a field when it once becomes thoroughly established, but it is quite evident that land on which diseased potatoes have been grown usually harbors the fungus a number of years, hence, it is important to follow a systematic rotation of crops, and it will probably be necessary to follow a five-year rotation in order to obtain good results.

"Prunet * believes that the fungus remains in the soil three years, and recommends that diseased fields should not be cropped with lucern or clover for several years. Evidences indicate that root crops should be avoided. Cereals which are probably not attacked by *Rhizoctonia* should be sown in the infected ground, and all weeds should be kept down. This is probably the only means by which the fungus can be destroyed."

Corrosive Sublimate Treatment. Corrosive sublimate or bichloride of mercury is sold in form of white crystals. It may be bought at any drug store for about fifteen cents an ounce. The cost of material for treating the seed for an acre will not exceed fifty cents. The solution is made by placing one ounce of this chemical in an earthen or wooden dish containing one gallon of hot water. As soon as it is all dissolved pour the contents of the dish into a wooden vessel containing seven gallons of water. Put the potatoes into this solution, and let them remain an hour and a half. The solution may be used a number of times. The disinfection may be done at any time. Experiments indicate, however, that treating the tubers about a week before planting, and spreading them on the floor or ground where they will be fully exposed to the sunlight, greatly facilitates their growth after planting. *Corrosive sublimate is a deadly poison to both man and animal when taken internally*, but the solution and treated potatoes may be handled freely without experiencing any ill results.

FORMULA.

Corrosive Sublimate	1 ounce
Water	8 gallons.
Soak Potatoes	1½ hours.

*(Prunet "Sur le *Rhizoctonia* de la Lucerne". Compt. rend. Paris 1893.

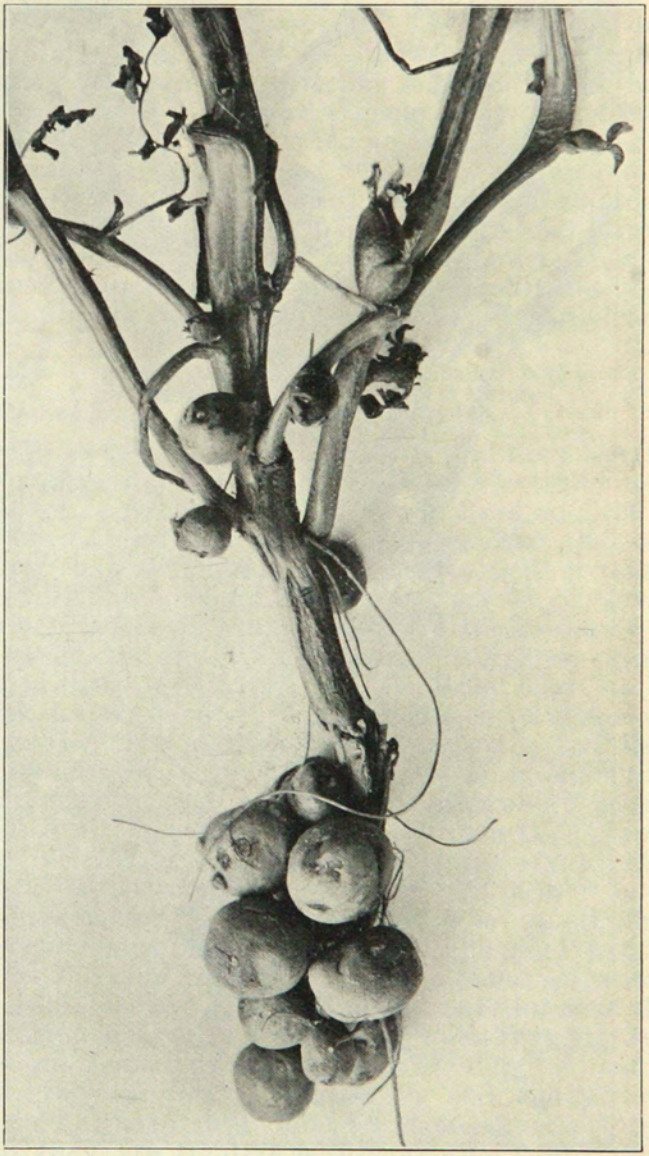

PLATE IX.

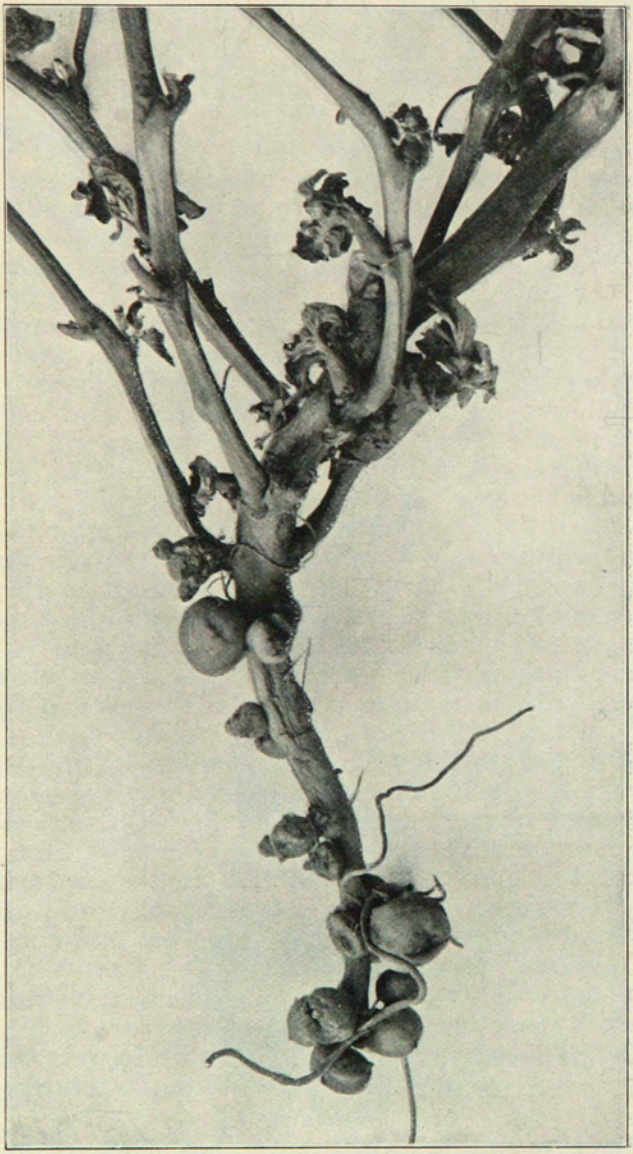

PLATE X.

Formalin Treatment. Formalin is sold in the form of a liquid at about fifty cents a pint. It is a little more expensive than corrosive sublimate but has the advantage of not being poisonous, comes in form of a liquid, and can be used in any kind of a vessel. The solution is made by adding one half-pint of formalin to fifteen gallons of water. The tubers are placed in this solution for two hours. This treatment does not retard the sprouting of the tubers, and it may be used at any convenient time before planting. If the tubers are treated during the winter, they should be dried and carefully stored avoiding all danger of reinfection from infected sacks and bins. The solution loses strength on standing, and must be kept in a closed receptacle if it is to be used a number of times. It is probably not best to use the solution for more than four successive treatments.

FORMULA.

Formalin	8 ounces (½ pint.)
Water	15 gallons.
Soak Potatoes	2 hours.

Keeping Seed Potatoes. It is evident that the success of the potato crop depends much upon the vigor and condition of the seed potatoes. Some growers have adopted the following practice with excellent results: When the potatoes are dug, those which are to be used for seed are stored in a dry, dark shed or barn until about the 10th of November. Just before freezing weather sets in, the potatoes are carefully sorted, and those which show the slightest signs of decay are rejected. A layer of straw from eight to ten inches thick is spread on the ground and the tubers placed upon this straw. The piles should not be made too large. The best resuits are usually obtained from mounds three feet wide at the base and piled up in ridges as high as convenient. A covering of straw is placed over the potatoes, and this is followed by a layer of soil from six to eight inches thick, but before severe weather sets in more soil is added, and when the severest weather is at hand, more straw, or strawy barn manure is added. The aim is to cover gradually as the cold increases. This method of storing potatoes seems to winter them much better for seed than when they are placed in root cellars, or when they are stored in mounds immediately after they are dug. About the last of April they are taken from the pit and again stored in a dark shed or barn until about ten days before planting-time when they are treated with corrosive sublimate, as given in formula on page 12. After this treatment they are placed where they will be freely exposed to the sun. Seed should not be cut until shortly before planting. If

planting is delayed, the cut pieces should be placed in a moist, cool place.

EXPERIMENTS IN TREATING SEED POTATOES.

Greenhouse Experiments. The following experiments were conducted in the greenhouse to get some hints on the value of treating infected tubers with corrosive sublimate:

Experiment I. The first experiment was with sixteen pots filled with sandy, clayey soil which was thoroughly infected with the disease. The soil in eight of these pots was sterilized two hours a day for three consecutive days, and planted with apparently healthy seed which had been placed in a solution of one ounce of corrosive sublimate to eight gallons of water for one and one-half hours. All tubers produced healthy and quite vigorous plants which lived until the experiment was closed. Careful examinations showed that all but one of these plants were free from disease. This infection was probably due to carelessness in watering the plants with a hose, since pots containing treated and untreated soils stood side by side. The soil in the other eight pots was not sterilized, and planted with clean tubers, treated in the same manner as those in the first lot. The potatoes all grew, but the plants did not do so well as those in the first lot, and three of them died shortly before the experiment was closed. On examination, it was found that all the plants were infected with the disease. A number of sclerotia were found on four of the tubers.

Experiment II. The second experiment contained twelve pots of heavy black loam which had been used in growing Alternanthera in the greenhouse during the preceding winter. The soil in the first four pots was not sterilized and was planted with tubers on which there were numerous sclerotia. These tubers were treated with one ounce of corrosive sublimate to eight gallons of water for one and one-half hours. The plants did quite well, but careful examination showed that all were more or less affected with the disease. The soil in the next four pots was sterilized two hours a day for three consecutive days, and planted with seed treated in the same way as those in the preceding lot. These plants made good growth and lived until the experiment closed. Critical examination failed to reveal any traces of the disease. The soil in the last four pots was treated as in the second lot, but was planted with infected tubers. One tuber failed to grow. Two produced weak plants which died prematurely and the fourth plant did poorly, but lived until the experiment closed. All plants were infected with *Rhizoctonia*.

Experiment III. In the third experiment, thirty diseased tubers were planted in a bench containing three inches of potting sand on the bottom and four inches of sandy clay loam on top. The first lot contained fifteen tubers which were treated with one ounce of corrosive sublimate to eight gallons of water for one and one-half hours, and planted twelve inches apart. These plants were slow in reaching the surface of the ground, but otherwise, they did nicely, and remained green until the close of the experiment. Thirteen of these hills, containing fifty-seven plants, were free from the disease, and only one plant in each of the other two hills, containing eight plants, was infected. It is possible that this was due to soil infection. In the second lot used in this experiment, the tubers were not treated, otherwise the conditions were much the same as in the preceding. Some of the plants soon reached the surface of the ground; others, however, were considerably delayed, and a number were killed before reaching the surface. Those which finally became established did quite well apparently, but twelve of the hills, sixty plants, died two weeks before the experiment was closed, and all were covered with an abundance of *Rhizoctonia* hyphae. The other three hills, fifteen plants, lived, but a careful examination showed that all of them were more or less affected with the disease.

These experiments show that diseased potatoes may be readily disinfected with the corrosive sublimate. But in or-

der to obtain good results the treated seed must be planted in soil which is free from the disease.

Field Experiments. Encouraged by the promising results in the greenhouse experiments, although somewhat late in the season, we concluded to try the treatment on a larger scale. Accordingly arrangements were made with Mr. J. G. Coy of Fort Collins, to carry on an experiment on his farm, in which he kindly consented to assist us. The soil of the field selected for the experiment was of heavy black loam on the river bottom. It was afterwards found that the level of the soil water was comparatively close to the surface. It had been flooded by late rains, and was too wet to get in shape for planting before June 6th. Most of the ground had been planted alternately with cabbage and onions during the past five years. It is quite probable that the soil contained more or less of the fungus since onions which remained in the field from last year's crop were badly infected. Potatoes grown on this place have suffered more or less from early blight for a number of years.

This field was divided into four plots. The rows were twelve rods long and planted in the usual way. All four plots were planted with Wisconsin seed of the Pearl variety. These tubers were infested with *Rhizoctonia*. Plots I., III. and IV. were sprayed with Bordeaux mixture, and Paris green on July 7th, 17th, 31st and August 15th. The seed of Plots III. and IV. was treated with corrosive sublimate as given on page 12. The seed of Plots I. and II. was not treated. The rains during the fore part of the season kept the ground sufficiently moist for the growth of the plants and the field received its first irrigation on August 13th. From this time on the ground was kept quite moist. The potatoes were dug October 10th.

Plot I. This plot occupied the lowest and most poorly drained part of the field. The seed of this lot was not treated, but the plants came up nicely, and most of them looked promising during the early part of the season. They were sprayed thoroughly four times, and remained green until killed by frost. Joining this plot was a garden patch of potatoes which was badly infected with the *Rhizoctonia*. The leaves of these diseased plants soon took on a lighter green color, had a tendency to fold, the stems became heavier, their internodes remained short, and in many of the plants, grew prostrate. These tops were soon invaded and completely ruined by early blight. During the later part of July, it was observed that a number of the plants in the rows joining the garden patch were taking on an abnormal top development. After the first watering, this peculiarity became prominent on many other plants, and at the close of the season, it is doubtful if there was a single plant in the entire plot which had a normally developed top. On August 10th, a careful examination was made of fifty plants taken from various parts of this plot, and it was found that the hyphae of *Rhizoctonia* occurred most abundantly on the plants in the first three

rows joining the infected patch. Apparently the disease gradually spread from the infected soil. Most of the plants in this plot developed small tubers and some of them grew no tubers at all. From eight rows one hundred and forty pounds of rough, corky potatoes were gathered. In some cases the plant apparently failed to put out tuber stems, while in others, the stems which were put out had been injured or completely cut off, producing Little Potatoes, and a number of the plants produced Aerial Potatoes. On October 10th, it was impossible to find a plant in the plot which was not more or less affected with the disease. The root system was also abnormally developed. It too showed the effects of the disease. The younger roots and root tips suffered most. Many of them were dead, and a careful examination of the living and recently killed parts showed the presence of an abundance of *Rhizoctonia* hyphae.

Plot II. was used for check. The seed of this plot was not treated, and the plants were not sprayed. They came up nicely, but some of these blighted early and many of them were killed fully two weeks before frost. It was found on examination, that many of these plants were more or less affected with *Rhizoctonia*. Nine rows yielded 1128 pounds of tubers, which averaged 94 pounds per sack.

Plot III. was planted with the roughest and poorest tubers of this lot of seed. They were treated with corrosive sublimate one day before planting but only about three-fourths of the tubers grew, and the plants were unusually slow in reaching the surface of the ground. This plot was sprayed four times. Diseased plants were less plentiful in this plot than in the preceeding. Seven rows produced 910 pounds of tubers, giving a gain of 4 per cent over check. These tubers averaged 102 pounds per sack.

Plot IV. The seed of this lot was treated with corrosive sublimate one day before planting. The plants were fully five days later in reaching the surface of the ground than those of Plot II, but four weeks later there was very little difference in the size of the plants between the two lots. These plants were sprayed four times which kept their foliage in an excellent condition, until injured by frost. Fifteen rows yielded 2,625 pounds of clean, smooth tubers, giving a gain of 40 per cent over check. It is quite evident that this gain would have been considerable more had the frost been a month later. The tubers averaged 106 pounds per sack.

For the sake of comparison, the methods of treatment and the yields of the different plots are given the following table.

TABLE I. RESULTS IN TREATING SEED POTATOES.

Plot.	No. of rows.	Treatment of seed.	No. times sprayed.	Yield per row in lbs.	Gain over plot No. 2.	Average lbs per sack.
No. 1	8	None.	4	17½	861 loss.	
No. 2	9	None.	None.	125⅓	———	94.
No. 3	7	Corrosive sublimate.	4	130	4	102.
No. 4	15	Corrosive sublimate.	4	175	40	106.

The results of these experiments may be briefly explained as follows: The poor yield in experiment No. 1, may be accounted for by the fact that the plot was situated by the side of a badly infected garden, where potatoes had been grown for several years. It is probable that the disease spread through the soil from the infested patch. (The result of this experiment cannot be considered for this reason.)

PLATE XI.

PLATE XII.

In Plot No. III. poor seed was selected which was treated with corrosive sublimate. That only three-fourths of a stand was secured was undoubtedly due to weak seed. The slight gain over the untreated seed indicated that in any method of treatment, it will pay to carefully select the seed potatoes.

The seed potatoes used in Plot No. IV. were of the same quality as those used in Nos. 1 and 2, and were treated with corrosive sublimate. The plants were sprayed four times. The results show a gain of 40 per cent over the untreated seed in Plot No. II.

The difference in the average weight of sacks of potatoes of the same size from different plots is interesting; the potatoes from Plot No. 4 averaging 12 pounds more to the sack than those grown in check Plot No. II. No explanation for this difference is offered at this time.

These experiments show that early blight can be held in check with Bordeaux mixture if the spraying is commenced early, and done thoroughly, but it is probably a waste of time and material to spray plants badly infected with *Rhizoctonia*.

FUTURE INVESTIGATIONS.

Different varieties of potatoes vary considerably in their susceptibility to disease when grown under the same conditions. It has been observed frequently that of plants of different varieties grown in the same hill, and probably equally exposed to infection, some will die early in the season, and produce no tubers at all, while the others will live to the end of the summer and produce a fair yield. Even plants of the same variety often show considerable difference in power of resisting the disease. The cause of such resistance will be studied, and it is hoped that in time a number of hardy or disease resistant varieties may be produced.

The best method of treating and wintering the seed is receiving careful attention, and it is believed that bin and sack infections can be largely prevented.

Some sections seem to have much trouble with the running out of potatoes. The indications are that this condition may be overcome, in some cases at least, but it will be necessary to repeat the experiments another year before making a report.

Field observations indicate that *Rhizoctonia* frequently produces a rot of potato tubers. However, only two tubers out of more than one-hundred inoculated in the laboratory gave marked results, but many were slightly decayed.

These negative results may have been due to unsuitable conditions. A thorough study of this phase of the disease will be made during the coming season.

From a number of observations during the year, it is quite evident that the *Alternaria* which infest the onions of this section may also invade the foliage and produce early blight of potatoes. Hence it was found necessary in the field experiments to spray the plants with Bordeaux mixture as a preventive of this disease. Further observations may show that early blight is an important factor in producing potato failures in some sections. Should this prove to be true it may be controlled with Bordeaux mixture. Onions also frequently harbor *Rhizoctonia*. This probably explains why potatoes so frequently do poorly when planted in onion ground.

Experiments during the past year indicate that sulphur has very little or no value in treating this disease. Lime may prove helpful. Both sulphur and lime will be given a thorough test during the coming season.

Preliminary experiments in rejecting all infected seed potatoes gave excellent results.

ACKNOWLEDGEMENTS.

In conclusion I wish to offer my sincere thanks to Prof. Paddock who has made many helpful suggestions in this work. The illustrations of this bulletin were all taken and arranged by him. I am also indebted to Mr. J. G. Coy of Fort Collins, for his co-operation in the field experiments.

SUMMARY.

Rhizoctonia solani (Kuhn) is the name given to a fungus which occurs on the underground parts of the potato plant. Our experiments show that this fungus is an active parasite on the potato and that it is one of the principal causes of potato failures in many parts of the state.

Many potato growers are familiar with one or more of the following conditions which have usually been thought to be due to the influence of altitude or climate; abnormally large vines which produce few or no potatoes, (See Plate V.) vines which though vigorous in appearance, bear a large number of small, worthless tubers, (See Plates IX. and X.) The failure of much of the seed to grow or the dying of plants during the fore part of the season resulting in a poor stand, (See Plate III.) This fungus, in the vicinity of Fort Collins at least, frequently produces all of these conditions.

The fungus lives over winter on the potatoes in the form of dark patches which resemble bits of soil (See Plate I. Fig 2.) When such potatoes are planted the fungus develops with the plant and begins its attacks at once.

When a field has become thoroughly infected with the disease it will remain in the soil a number of years.

The nature of the disease indicates that it may be combatted by preventive means which consist in planting clean seed in clean soil. Seed potatoes should be carefully sorted, disinfected and planted on land that is well underdrained. Then by practicing a long and systematic rotation of crops, the soil may be prevented from becoming badly infected with the disease.

The fungus may spread from a few diseased potatoes in a sack or bin and in a short time render the entire lot worthless for seed.

In our experiments diseased seed potatoes treated with corrosive sublimate and sprayed with Bordeaux mixture gave an increase in yield of forty per cent over untreated seed and unsprayed plants. The soil used in the experiments was heavy, poorly drained and infected with *Rhizoctonia*. A lighter, well drained soil free from the disease undoubtedly would have given still better results. The formalin treatment also gave encouraging results.

EXPLANATION OF PLATES.

PLATE I. FIG. 1. Sack of potatoes examined June 3. Large pile contains badly diseased potatoes, slightly diseased in the center, while the smallest pile contains the clean potatoes.

FIG. 2. Sclerotia of *Rhizoctonia* on potato. Very common on seed potatoes.

FIG. 3. Surface of potato covered by net work of fine cracks caused by attacks of *Rhizoctonia*. Figs. 2 and 3 natural size.

PLATE II. FIG. 1. Potato badly scarred by *Rhizoctonia*. Much of the so-called scab is undoubtedly due to this disease.

FIG. 2. Potato sprouts killed in the sack by the fungus. From the sack shown in Plate I. Both figures natural size.

PLATE III. Showing how *Rhizoctonia* attacks young plants in the field. Two on the right were killed before reaching the surface of the ground. The others badly injured. Natural size.

PLATE IV. Potato sprouts from sack. Some killed by and others showing sclerotia of *Rhizoctonia*. Enlarged.

PLATE V. Plant from which potatoes were all cut off by *Rhizoctonia*, producing an abnormally large top.

PLATE VI. Large vine from which all but a few small potatoes were cut off by the fungus.

PLATE VII. Potato plant infected from diseased seed; the root system badly injured.

PLATE VIII. Potato plant from which the tuber stems were all cut off by the fungus. As a result a large top was produced and tubers formed in the axils of the leaves.

PLATE IX. "Little Potatoes" and "Aerial Potatoes" produced by ringing the main stem. August 24.

PLATE X. "Little Potatoes" and "Aerial Potatoes" produced by removing all potatoes twice during the season. August 24 and September 2.

PLATE XI. FIG. 1. Three green potato stems inoculated with cultures of *Rhizoctonia*. One completely cut off, the others nearly girdled.

FIG. 2. Two tuber stems inoculated as above. Both cut off by the fungus at the discolored point. All natural size.

PLATE XII. Green stems inoculated with cultures of *Rhizoctonia*. One cut in two, the others badly injured. Natural size.

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