LIBRARY
OF THE
UNIVERSITY
OF ILLINOIS
630.7
Il6b
no.458-469
cop. 2

AGRICULTURE

***NOTICE:* Return or renew all Library Materials! The *Minimum* Fee for each Lost Book is $50.00.**

The person charging this material is responsible for its return to the library from which it was withdrawn on or before the **Latest Date** stamped below.

Theft, mutilation, and underlining of books are reasons for disciplinary action and may result in dismissal from the University.
To renew call Telephone Center, 333-8400

UNIVERSITY OF ILLINOIS LIBRARY AT URBANA-CHAMPAIGN

~~MAR 0 1990~~
~~NOV 26 1990~~
MAY 08 1992

L161—O-1096

A Study of HORSERADISH DISEASES *and their* CONTROL

By
K. J. Kadow
and
H. W. Anderson

☆

Bulletin 469
UNIVERSITY OF ILLINOIS
AGRICULTURAL EXPERIMENT STATION

ACKNOWLEDGMENT

In an effort to incorporate in this monograph the latest information regarding horseradish diseases and their control, the authors have obtained the help of plant pathologists in various parts of the world. Valuable assistance from the following men is hereby acknowledged: Dr. E. Baudyš, Brně, Czechoslovakia; Drs. J. Peklo and C. Blattný, Praha, Czechoslovakia; Drs. H. W. Wollenweber and Braun, Berlin-Dahlem, Germany; Dr. V. Skoric, Zagreb, Yugoslavia; René L. Steyaert, Belgium Congo, Africa; Sutton and Sons, Ltd., Reading, England; Dr. E. Foex, Pont-de-la-Maye (Gironde), France; Dr. K. Togashi, Morioka, Japan; Mr. V. Ovchinnikoff, Moscow, U.S.S.R.; Drs. W. R. Beattie and Charles Thom, U. S. Department of Agriculture, Washington, D. C.; Dr. C. M. Tompkins, Berkeley, California. To Dr. Charles Chupp, Ithaca, New York, and Dr. C. M. Haenseler, New Brunswick, New Jersey, the authors are indebted for a critical reading of the completed manuscript.

C. R. Wutzke and W. H. Duis, graduate students of the University of Illinois, deserve mention for the studies they made of certain general problems of horseradish diseases. Many horseradish growers in the East St. Louis and Cook county regions generously permitted the use of their lands and their crop and were otherwise helpful during the field and storage studies. From Dr. J. P. McCollum, Assistant Chief in Olericulture, and L. H. Shropshire, Field Entomologist, Illinois State Natural History Survey, the authors obtained valuable advice and assistance thruout the course of these studies.

CONTENTS

PAGE

THE HORSERADISH PLANT........ 531

LEAF DISEASES..................... 536
- White Rust........................ 536
- Bacterial Leaf Spot.................. 542
- Cercospora Leaf Spot................ 545
- Ramularia Leaf Spot................ 546
- Minor Leaf Diseases................ 547
- General Control of Leaf Diseases.... 551

VIRUS DISEASES AND "DETERIORATION"............. 552
- Mosaic............................. 552
- Curly Top.......................... 554
- Deterioration....................... 557

ROOT ROTS.......................... 560
- Cause of Root Rots................... 560
- Relation to Cultural Practices........ 561
- Illinois Experiments.................. 561
- Bacterial Root Rot................... 564
- Verticillium Wilt..................... 566
- Rhizoctonia Root Rot................. 567
- Penicillium Root Rot................. 569
- Thielavia Root Rot.................. 570
- Root Knot.......................... 571
- Minor Root Rots.................... 573
- General Control of Root Rots........ 574

GEOGRAPHICAL DISTRIBUTION... 577

BIBLIOGRAPHY..................... 578

Urbana, Illinois September, 1940

Publications in the Bulletin series report the results of investigations made or sponsored by the Experiment Station

A Study of Horseradish Diseases and Their Control

K. J. KADOW and H. W. ANDERSON[a]

HORSERADISH studies were begun at the Illinois Agricultural Experiment Station in the fall of 1933 as an indirect result of increased interest in the production problems of the crop. Many requests were made of the Department of Horticulture of the University of Illinois by growers of horseradish for methods of controlling the outstanding diseases attacking the plant. Before 1933 the methods generally recommended were given to Illinois growers for trial, but in nearly all cases these methods failed to produce satisfactory results even tho applied under the supervision of representatives of the University. Some of the treatments caused even greater injury than would have resulted from the diseases. A careful study of the literature was started which soon led to the belief that few of the recommended treatments were based upon experimental evidence. This belief and the fact that Illinois is the leading state in commercial production of horseradish resulted in the establishment of a horseradish project at the University of Illinois.

Much valuable information and experience has accumulated from four years of study altho, unfortunately, few commercially satisfactory remedies for the important problems have been devised. This publication is intended to give other investigators and growers of horseradish the benefit of the experiments with horseradish at this Station as well as the results of research done in other parts of the world. A list of the important references from which definite contributions were obtained for this study is given on pages 578 to 583.

THE HORSERADISH PLANT

Horseradish was evidently first eaten by the Germans of the Middle Ages who found uses for both leaves and roots. At the present time the plants are grown for their pungent roots which are grated, mixed with salt and vinegar, and eaten as a condiment, being noted especially for imparting added delicacy to such foods as roast beef and oysters.

[a]K. J. KADOW, formerly Associate Pathologist, now acting head of the Department of Horticulture, University of Delaware, Newark; and H. W. ANDERSON, Chief in Pomological Pathology.

The pungency is claimed by Friese[44*] to be due to the presence of an allyl iso-thiocyanate (C_2H_5CNS) and a butyl thiocyanate (C_4H_9CNS), similar to the mustard oils, occurring in combination with the glucosid sinigrin.

DESCRIPTION OF THE PLANT

The roots are fleshy, corky tan externally, pure white within, conical at the top, and abruptly branched below. The leaves are usually

FIG. 1.—VARIATION OF HORSERADISH LEAVES UNDER ILLINOIS CONDITIONS

The shape of horseradish leaves varies greatly in the Middle West. Certain leaf types will predominate at different times during the year. The types of leaf produced are apparently influenced by climatic conditions. Some workers have regarded this variation in the leaves as a symptom of virus diseases.

large and docklike with wavy edges. Often, however, they are deeply incised, as shown in Fig. 1, especially those arising from the area of the base. Nearly all taxonomists have noticed and reported the extreme variation of leaf types in this plant. Recently some workers have regarded this characteristic as an indication of the presence of

*These numbers refer to literature citations on pages 578 to 583.

a virus (see *Mosaic,* page 552) which, if correct, would seem to indicate that the virus disease is about as widespread as the plant itself. This leaf variation is very common to horseradish thruout the middle west.

FAMILY AND NAMES

Horseradish is a member of the mustard family, Cruciferae, to which cabbage, turnip, radish, kale, Brussel sprouts, cauliflower, and broccoli belong. It is also closely related to such common weeds as peppergrass, shepherd's purse, false phlox, wild radish, wild mustards, winter cress, pennycress, and scurvy grass. Brzezinski[18*] regards horseradish as a hybrid. By girdling the roots just below the crowns, he obtained viable seed which gave rise to two distinct types of seedlings, indicating that his contention may be correct.

The plant is known by Spanish-speaking peoples as "Tarramago"; by French as "Raifort" or "Raifort sauvage"; by German as "Meerrettich" or "Meerrettig"; and by English as "Horseradish." There are many binomials used to scientifically designate the horseradish plant. A few of the most commonly used are: *Radicula armoracia* (L.) Robinson; *Armoracia rusticana* Gaertn.; *Nasturtium armoracia* Fries; *Armoracia armoracia* (L.) Britton.; *Roripa armoracia* Hitchcock; *Cochlearia armoracia* (L.). *Cochlearia macrocarpa* var. *hungarica* is considered by Engler as the primitive form of horseradish, but other workers agree that this is the same as the ordinary plant escaped from cultivation. Most workers seem to prefer the use of *Armoracia rusticana* Gaertn.

IMPORTATION INTO AMERICA

Horseradish is native from the Caspian Sea to Finland, but is grown at the present time in all temperate climates thruout the world. It grows best in cool, moist places but can be grown in rather hot climates. It tends to escape cultivation, which accounts for all wild horseradish in this country and which also accounts for the similarity between the wild and the commercially grown varieties. The plant which the Japanese call horseradish, *Eutrema wasabi,* is entirely different from the horseradish of this country.

According to Bailey[6*] horseradish was brought to America from England, where it had been naturalized from some more easterly European country. In recent years two distinct types have been imported from Bulgaria and Hungary, but as yet they have not met with general favor. Fairchild states that importations of the roots of the Maliner and Bayersdorf varieties were made from Bohemia and Austria about 1899 and distributed to experiment stations. These importations may account for the name "Bohemian horseradish," used by growers to describe the smooth-leafed type from southern Europe.

Illinois leads all states in the production of commercial horseradish at the present time with about 2,000 acres divided between the East St. Louis and the Chicago areas. Many states in America and several other countries produce small commercial acreages, but apparently none, with the exception of Germany and Missouri and Illinois in the United States, have more than 1,000 acres now in cultivation, altho several have many more acres if the plants growing wild are considered. In some countries nearly all horseradish sauce is made from wild plants.

CULTURAL PRACTICES

Planting. Horseradish does not produce viable seed, and propagation, therefore, is always asexual by various types of root cuttings, the most common cuttings being 5- to 14-inch laterals about 1/4 to 1/2 inch in diameter (Fig. 2). The cuttings, or "sets," as they are usually called, are obtained after the plants are dug in the fall from the laterals of the main roots. (Fig. 3 shows a mature root with laterals attached.) The longer cuttings are better whenever "lifting" or "stripping" is practiced, since growth of the main root is the objective, and the main root increases in diameter only. The sets are laid horizontally

FIG. 2.—HORSERADISH SETS READY FOR PLANTING

Sets are usually 5 to 14 inches long and about 1/4 to 1/2 inch in diameter. All sets should be carefully examined for rots before they are stored in the fall and again before they are planted in the spring. Healthy sets are the first requirement in production of good horseradish.

in furrows 2½ to 3 feet apart and spaced about 2 feet in the row. They are covered to a depth of 4 inches. In some parts of the world root cuttings are only 1 to 2 inches long and ½ to 1 inch thick. These are planted as are the longer roots, except that no effort is made to arrange them in the row as is the case with the longer sets.

Lifting. In order to meet the demands of grinders for large straight roots, most growers practice "lifting" or stripping, removing the side roots from the cuttings once or twice during the summer and leaving only those at the extreme end to gather nourishment for growth. This is done by removing the soil from the upper

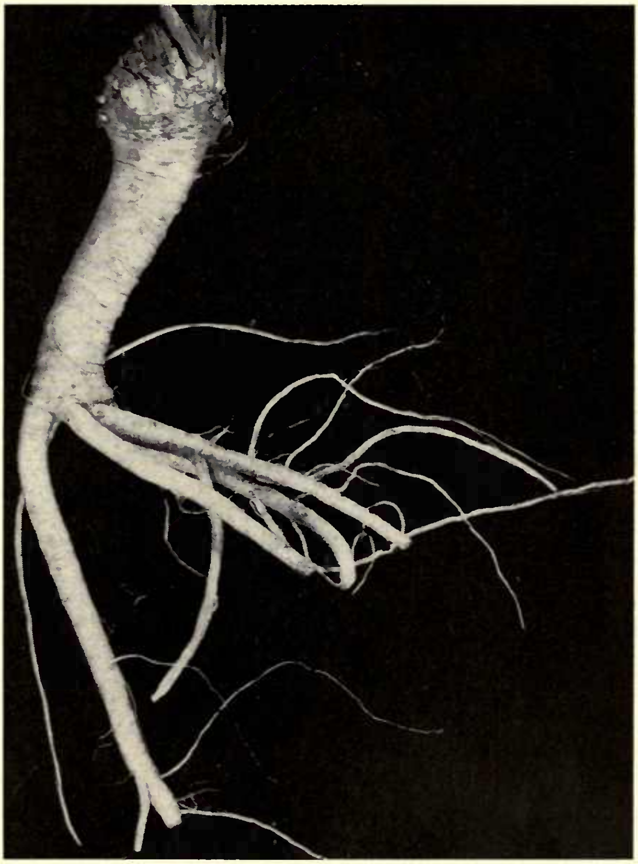

FIG. 3.—HORSERADISH ROOT WITH LATERAL ROOTS ATTACHED
The sets for the next season's plantings are obtained from these laterals.

end of the crown and rubbing off the secondary roots with a gloved hand. Some growers merely lift the crown end of their sets, depending on the mechanical action to break off the brittle secondaries.

Some authorities claim that a larger yield is obtained when the roots are stripped than when they are allowed to grow without being disturbed. It is doubtful if the practice increases yields any more than enough to offset the cost of lifting, but it does result in a larger percentage of straight roots of good size which bring a premium on certain markets.

Storing. After the roots are dug in the fall and the laterals are broken off, the marketable roots are either sold immediately or stored in pits or cellars. The cuttings saved for planting the following spring are stored in a similar manner.

LEAF DISEASES

WHITE RUST

White rust is undoubtedly the most destructive of all leaf diseases with which the horseradish grower has to contend. It has been reported on horseradish from all countries where this crop is grown, and is known to cause damage in all the important horseradish areas in the United States and Europe. When the disease appears in epidemic form, the leaves may become so thoroly infected as to dry up and die; repeated infections of new leaves will so reduce the vitality of the plant as to result in very poor root growth. Such weakened roots are often attacked by rot-producing organisms. The roots tend to be tough and woody with numerous lateral fibrous roots.

Symptoms. White rust is easily recognized in its early stages by the pearl white appearance of the sori (spore masses). The first visible symptom is the appearance of light yellow areas on the upper surface of the leaf. Very soon after these appear, the under surface shows the presence of hemispherical white creamy blisters. One or several of these blisters, or sori, may appear on an individual spot. In rare cases the sori develop on the upper surface of the leaf as well as the lower. The number of spots on a leaf determines the type of symptoms. If only a few spots occur, the infected area may be a half inch or more in diameter with numerous pustules arranged in a more or less concentric manner. When the infections are more numerous, or when there is a systemic invasion, the entire leaf may become curled and distorted, and the pustules may appear over the entire surface (Fig. 4).

The sori are at first creamy in consistency and glossy white, but as the spores dry they become powdery in texture and turn to a dirty gray color. The leaf tissue on which the sori are borne remains alive for some days, but after this period a definite dead light brown area develops on the upper surface of the leaf above the clustered sori. When the infection is more general, the entire leaf blade withers.

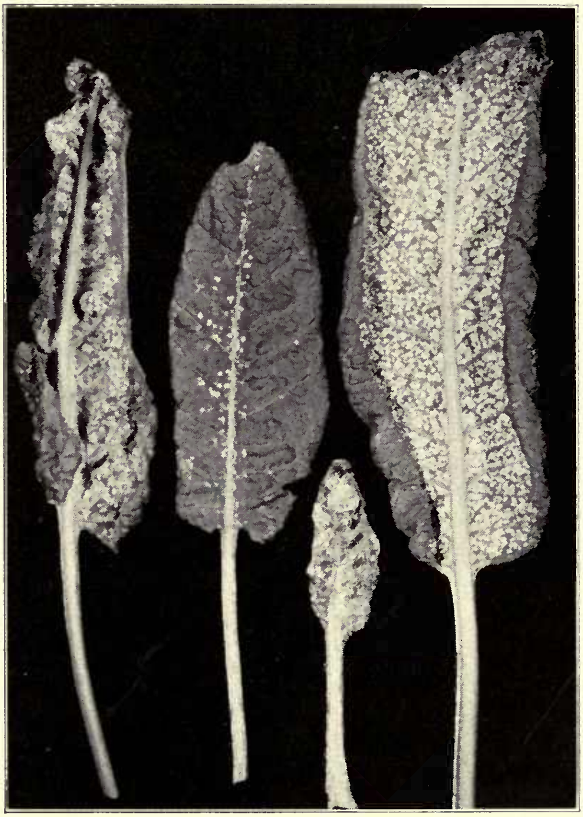

FIG. 4.—SEVERE INFECTION OF WHITE RUST ON HORSERADISH

The lesions on the underside of the leaves, along with the "cupping" of diseased leaves, are quite typical of white rust. Lesions on the stem and a few on the top side of the leaf are visible in this picture. The brownish-red discoloration that occurs on the top side of infected leaves in areas corresponding to points of infection on the underside does not show here.

While the leaf tissue remains alive, the disease can be easily distinguished from other leaf spots. After the dispersion of the spores, the spots take on the appearance of other leaf spots such as those caused by Cercospora or Macrosporium.

Cause and host plants. White rust is caused by a fungus, *Albugo candida* (Pers.) O. Kuntze. Altho called a "rust," the fungus does not belong to the true rust fungi but is more closely related to the downy mildews. The fungus develops only in living tissues and accordingly is often referred to as an obligate parasite. This fungus occurs on a large number of plants of the mustard family. It is most commonly observed on wild mustard and shepherd's purse while horseradish, the common radish, and mustard are the most common cultivated host plants altho occasionally white rust attacks cabbage and its relatives.

The white rusts commonly observed in the field on pig weed (Amaranthus) and purslane are different species from the one occurring on crucifers.

Life history. The pustules seen on the lower surface of the leaf infected with white rust contain thousands of microscopic spores (the seeds of the fungus). When dried the spores are powdery in nature, and when the leaves are disturbed, dustlike spore clouds may be observed. The spores may be carried in great numbers by the slightest breeze to neighboring healthy leaves and to plants at a distance. It is common to observe entire fields becoming quickly and uniformly infected from a few early-infected plants. When water is present, each of the spores mentioned above breaks up into 4 to 8 swarm spores which after swimming about for a few minutes settle on the leaf surface, germinate, and infect the leaf.

Infections take place thru the numerous breathing pores (stomata) of the leaf. Since most of the stomata are on the under surface of the horseradish leaf, infection is most likely to take place there. After the fungus enters the stomata, it grows between the cells, forming a number of branches as it penetrates deeper into the tissues of the leaf.

Thru the development of special structures, the fungus secures the bulk of its food from the living substance (protoplasm) within the cells of the host tissue. The cells remain alive for some time after being invaded by the fungus. In some cases the presence of the fungus stimulates the cells so that increased growth and cell multiplications take place. This may be seen in the enlarged stems and seed pods of radish and shepherd's purse but is not so common in the case of horseradish. The fruiting pustules seen on the surfaces of infected plants arise from fungus mycelium within the leaves. The spores thus developed are the asexual spores known as conidia.

In addition to asexual spores, white rust produces a sexual spore (oospore) which is much more resistant to drying and may live over winter in dead leaves and stems of infected plants. Many attempts were made by the authors to find oospores in old plant material of horseradish but without success. So far as is known, oospores are not formed on this host and if formed are probably so rare as to be of little importance as a source of spring infections.

Cool, rainy weather is necessary for infection by white rust. Since horseradish is planted fairly late in the spring and does not appear above ground until the coming of warm dry days, on commercial plantings it is rarely attacked by white rust until the fall months. However, if periods of cool, rainy weather or heavy dews prevail during the early summer, the disease may become serious early in the growing season. Altho infection occurs late in most seasons, the damage may be extensive, because horseradish makes its most extensive growth in the late summer and fall months.

Overwintering of the fungus. One of the most perplexing problems connected with the life history of this fungus is its method of overwintering. It has been established that the conidia do not survive for more than a few weeks at most, and few, if any, oospores are formed on horseradish. Other possible methods of overwintering have been investigated.

The fungus might overwinter as mycelium either in perennial plants of other crucifers or as oospores in hosts where these are common. Unpublished data secured by William Duis working in the authors' laboratory proved that the form found on horseradish infects only a few of the other crucifers. It was also proved that the conidia taken from common weed hosts will not infect the horseradish. It has been proved by a number of investigators, especially Melhus,[78*] Napper,[80*] Hiura,[53*] and Togashi and Shibaski,[110*] that there are a number of biologic forms of *Albugo candida,* so that a form fruiting on shepherd's purse, for example, will not infect horseradish altho it is evidently the same species that occurs on this host. This would also exclude the possibility in most cases of oospores from plants other than horseradish being responsible for spring infections. Only a limited number of forms on wild crucifers were investigated by Mr. Duis in the authors' laboratory; it is possible that other cruciferous weeds common in the commercial horseradish areas might carry the biologic form which goes to horseradish and thus account for the transfer of the disease to this plant.

Since the fungus is known to be systemic in some hosts, it was thought that it might invade the roots of horseradish and thus be carried as mycelium in the sets which are used to renew the planting. It would then invade the sprout and appear on the leaves. Mr. Duis and the authors proved, however, that this is not possible. The fungus was found to invade the crown and to penetrate a short distance into the root tissues, but never to the point where the lateral roots used for sets are produced. In addition, plants produced from sets obtained from heavily-infected plants always failed to show the disease when protected from outside infection.

The above experiments proved that the fungus may persist in the crown of the plant. Often whole roots with the attached crown are left in the field, or crowns with a stub of the main root are discarded at harvest. In the spring these plants send up new shoots and may appear in the field as "volunteer" plants. It is not uncommon to see several hundred of these in a field that was planted to horseradish the previous year. Such plants are usually the first to show white rust and since they are likely to appear above ground before those in planted fields, the disease may become established in the leaves and produce an abundant crop of spores, which in turn may be carried to the cultivated fields of horseradish. Crowns from which all the infected leaves were carefully removed were planted in sterilized soil in the greenhouse during the winter when no outside source of inoculum was present, and the new leaves developing from the dormant buds on the crowns were thoroly diseased when they appeared.

Histological studies have revealed the presence of mycelium in the main root tissues but never more than an inch below the crown. Similar studies with sets taken from diseased plants have not shown a single instance of infection on the developing shoots. In this connection it should be remembered that the sets are lateral roots produced at the opposite end of the main root from the crown. The crown and the sets are seldom produced less than 6 inches apart and more often 8 to 12. In some parts of the world lifting is not followed as a commercial practice. In such instances sets may be produced directly from the crown or very near it, in which case it is possible that mycelium of the white rust fungus overwinters directly in the sets. The extensive experiments by Duis and the authors seem to show that direct overwintering of the mycelium of the white rust fungus in sets from lifted plantings is rare. In the Middle West practically all commercially grown horseradish is lifted and wild horseradish is not found in the commercial areas.[a]

Control. Satisfactory practical methods for the control of white rust on horseradish have not been developed. In a number of experiments over a four-year period in the two large commercial horseradish areas of Illinois, copper and sulfur sprays and dusts failed to give satisfactory control and in many cases caused serious injury. Some workers have suggested the use of bordeaux sprays; these should never be applied either just before or just after lifting, since they are almost certain to cause serious wilting and subsequent injuries. For the same reason they should not be applied in hot weather. Unless spraying is started early enough to prevent primary infection, there is little chance of securing satisfactory control, and if it is continued often and late enough in the season to cover and protect the new growth, the expense becomes too great and the danger of spray injury in the form of copper burn is increased. The systemic nature of the fungus probably accounts in part for the failure of sprays or dusts as control measures.

Altho it is reasonable to suppose that the elimination of all escaped and volunteer plants in an area where horseradish is grown on a commercial scale would give effective control of white rust, no experimental work has been done on this subject. However, diseased horseradish crowns should not be left in the field and allowed to come up as volunteers in the spring, and if they do appear, should be dug up as soon as seen.

Keeping the fields free of weeds and proper spacing of the plants reduce infection by permitting rapid drying of the leaves following rains and heavy dews.

The greatest hope of successfully controlling white rust is to de-

[a]Field observations during the 1940 season indicate that a small number of sets may carry the fungus over winter. In one field where horseradish had never been grown and where no volunteer plants could be found, about one plant in a thousand showed pustules as soon as the leaves appeared above the ground. The pustule development was characteristic of a systemic infection. Another 30-acre field showed about one plant in five thousand infected in the same manner. While these rare cases might be accounted for by chance inoculum from other sources or possibly by the presence of oospores in the soil or debris, it seems more likely that they were caused by a rare systemic infection of set roots during the previous season. Experiments are now in progress to secure further information as to the source of the sets showing systemic infection. That sets having systemic infection are rare is indicated by the fact that often sets are taken from fields having 100-percent infection and do not show any evidence of white rust the following season until secondary infection is general.

velop resistant varieties such as the Bohemian type. A successful breeding program would be necessary, and since horseradish does not produce viable seed under ordinary cultivation, the girdling method described by Brzezinski could probably be used. This method is now being investigated.

BACTERIAL LEAF SPOT

Bacterial leaf spot of horseradish in some seasons rivals white rust in destructiveness, altho it is not well known and has only recently been described. It is probable that this disease has been confused in the past with fungus leaf spots, especially by growers. In 1929 McCulloch[75*] described the bacterial leaf spot of horseradish and reported its occurrence in widely separated states (Virginia, Connecticut, Missouri, and Iowa). It is evident from her statements that at that time it was probably of common occurrence wherever horseradish was grown in eastern and midwestern states. It was reported from South Dakota in 1930, but there are no reports of bacterial spot in the far western states. It was found in Illinois by the authors in 1934 and, according to Anderson and Thornberry,[4*] was especially destructive in the wet season of 1938.

Since bacterial spot causes the leaves to "fire" during the period when the plant is making its most vigorous growth, it is evident that serious reduction of root enlargement must occur altho there is no experimental evidence on this point. A large field in the East St. Louis area was so severely injured in 1938 that the grower stated he expected a 50-percent reduction in yield. The loss is not ordinarily so great. So far as is known, the bacteria do not invade the root or vascular system of the plant, and consequently there is no general rotting as is the case with the closely related crucifer black rot bacterium.

Symptoms. The first evidence of infection is the appearance of small dark-green translucent spots which later enlarge and turn black. The spots are usually scattered over the entire leaf blade between the veins, but may be localized at places where water has been retained longer than usual. They are especially conspicuous on the under surface of the leaf. The spots rarely exceed ¼ inch in diameter, and vary in outline from definitely circular to angular (Fig. 5). The lesions may remain quite small during periods of dry weather and then enlarge considerably after rains. The killed tissues fade with age so that later the central area may appear light brown in color, tho ordinarily the spots are much darker than those produced by other organisms.

When the leaf spotting is general, the toxic effect of the invasion is very evident because the entire leaf quickly curls and dries up (Fig. 6). When the spots are localized, rather large areas of the leaf-blade fire, especially when the hot sun strikes the leaf. Diseased plants may be seen at a distance because of the conspicuous firing.

Cause. Bacterial spot of horseradish is caused by *Phytomonas campestre armoraciae* (McCulloch) Bergey *et al.* It is a motile bacterium with a single polar flagellum. It is closely related to two other pathogenic bacteria which develop yellow colonies; namely, *Phytomonas phaseoli,* the bean-blight organism, and *Phytomonas campestre,* the cause of black rot of cabbage and other crucifers. In fact *P. phaseoli* causes a leaf spot on horseradish, but the lesions are small and do not resemble those produced by the horseradish organism. *P. campestre armoraciae* differs from the true cabbage black rot organism in that it does not invade the vascular system as does *P. campestre.* These three organisms also show certain differential cultural characters and are described in detail by McCulloch.

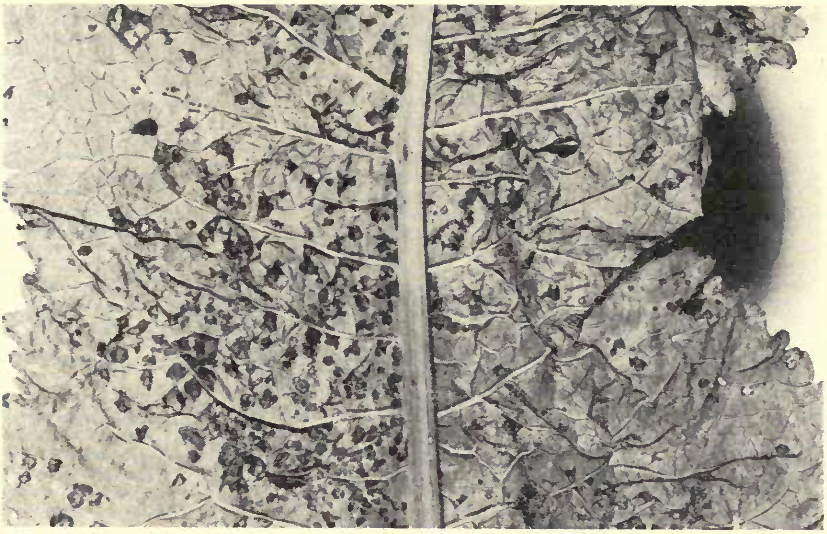

FIG. 5.—BACTERIAL LEAF SPOT OF HORSERADISH
The typical size and shape of the individual lesions are shown. When infections are very numerous, the leaf curls and finally dries up (*see also Fig. 6*).

Life history. Bacterial leaf spot is prevalent only during excessively wet seasons. Once started it spreads very rapidly thruout the field. Well-advanced infection of fields was noticed in Illinois in July, showing that the disease may continue its destructive action thru most of the growing season. Little is known of the life history of the causal organism, but because of the location of the lesions, it is probable that it usually invades the stomata. There is no evidence of the disease being primarily disseminated by insects, tho it is probable that insects carry the bacteria when feeding on the plants. McCulloch[75*] found that the organism can be made to produce lesions

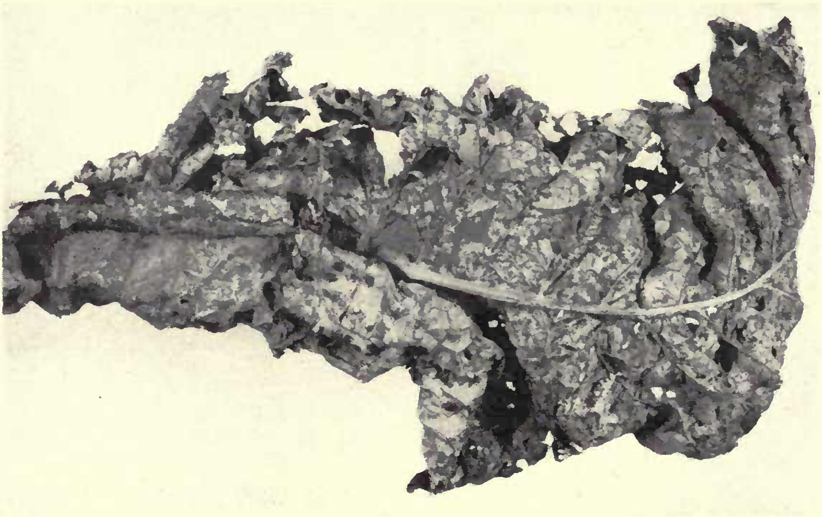

FIG. 6.—SEVERE INFECTION OF BACTERIAL LEAF SPOT

The curling of the leaf is very evident. Large spots have fallen out of the leaf, and altho the infection is only a few days old, the leaf is already beginning to dry up. Bacterial leaf spot is very serious during some seasons.

on cabbage and cauliflower only with difficulty, and it has not been found on other cruciferous hosts. It is probable, therefore, that in nature the disease is confined to horseradish, and that it overwinters on this host, probably in the old leaves and discarded crowns. No information is available as to how long the organism can survive in the soil.

Control. No experiments on the control of this disease have been reported. It appears from our meager knowledge of the habits of the organism that sanitation yields the best results. This consists of as thoro elimination of old leaves and crowns as possible.

CERCOSPORA LEAF SPOT

Cercospora is one of the most common leaf spots in Illinois, and has been reported as occurring in most countries where horseradish is grown. In North America it has been reported from Nebraska eastward in the United States and from eastern Canada. At times the disease causes serious injury to the leaves, but there are no data of experiments on the reduction of the crop as a result of the attack.

The fungus causing this leaf spot is *Cercospora armoraciae* Sacc. The spores are produced on dark brown, rather long (30 to 40 μ)[a] conidiophores which arise in groups of 3 to 10 from both surfaces of the leaf. The spores which are borne singly on the end of the unbranched conidiophores are needle-shaped, hyaline, and 100 to 180 μ in length with 3 to 7 septa. As the spot ages, the number of sporophores increases.

Symptoms and life history. This leaf spot appears first as a small light-colored circular area. This enlarges until it may be from ½ to ¾ inch in diameter (Fig. 7). The dead central area is a uniform light-

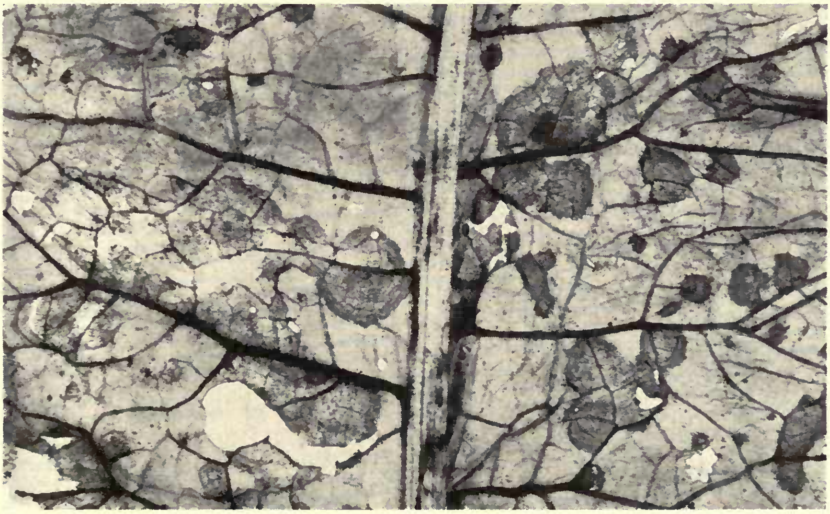

FIG. 7.—CERCOSPORA LEAF SPOT OF HORSERADISH

The young spots are bright colored, but as the lesions progress, they turn dark because of the presence of fruiting bodies of the causal fungus, *Cercospora armoraciae* Sacc. The spores themselves are hyaline, but the conidiophores are brownish black. Note the concentric ringing of the older spots.

[a] μ = 1/25,000 inch.

gray color. Later the spots may appear almost black, due to the presence of the numerous conidiophores of the fungus. Sometimes these appear in definite concentric rings, but this is not generally the case. The spots often coalesce, forming large dead areas covering the greater portion of the leaf. Leaves having a number of lesions are easily scorched by the hot sun and the dead areas may extend beyond the limit of the infection or the whole leaf may wither.

Little is known concerning the time and method of infection, but judging from our knowledge of similar diseases, it is probable that the mycelium of the fungus overwinters in old leaves and gives rise to spores the following spring. Alternate host plants may also be responsible for spring inoculum.

Control. No method for the control of this leaf spot based on data from experiments has been reported. It has not been considered serious enough to warrant special control methods.

RAMULARIA LEAF SPOT

Ramularia leaf spot has been reported on horseradish from practically all countries where this crop is produced. It seems to have a wider distribution than Cercospora spot. Reports from Poland and Russia, together with those from all sections of the United States and Canada, indicate that this leaf spot is cosmopolitan. It appears to be the predominating leaf spot of the western United States.

Appearance. Ramularia leaf spot (Fig. 8) is quite similar in appearance to the Cercospora leaf spot with which it is often confused. Lesions are found on the leaf blade, usually between the larger veins, appearing first as yellowish-green circular areas. Later the spot becomes more definite, and there is often a separation of the thin, papery, diseased area from the healthy tissue. This area may drop out, giving a shot-hole effect. The lesions are frequently irregular in outline due to an uneven advance of the fungus from the central area. Later in the season dark bodies resembling pycnidia may be observed over the surface of the lesion. Withering and drying of the entire leaf results when the infection is heavy.

Cause. Ramularia leaf spot is caused by *Ramularia armoraciae* Fuckl. It produces conidiophores in groups similar to those of Cercospora, but they are colorless. The conidia are rod-shaped, usually nonseptate, hyaline, and 15 to 20 μ long by 4 to 5 μ in width. They are borne both on the upper and lower surfaces of the leaf. The sclerotial bodies mentioned above are produced late in the season and serve to

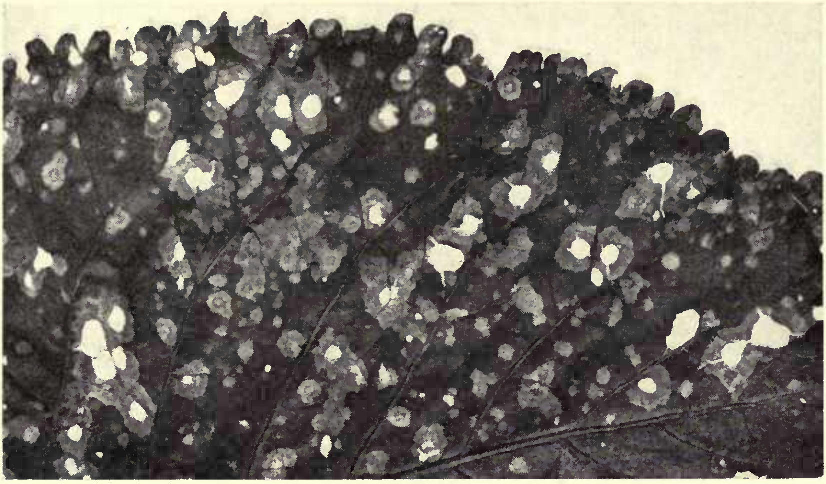

FIG. 8.—RAMULARIA LEAF SPOT

Ramularia leaf spot resembles Cercospora and the two are often confused. Usually the lesions are smaller and lighter in color than those shown here. *(Photo by Charles Chupp, Cornell University.)*

carry the fungus thru the winter months. Infection seems to take place thruout all of the summer months.

There have been no reports of the disease becoming serious enough to warrant special control measures; accordingly, no information is available regarding control methods.

MINOR LEAF DISEASES

A number of fungi have been mentioned by pathologists as causing leaf spots of horseradish. Because these minor leaf spots rarely appear in any abundance in the horseradish-growing areas of Illinois, they have been given little attention and accordingly are not discussed at any length in this bulletin.

Alternaria and Macrosporium leaf spots. A common leaf spot of cabbage and other crucifers is caused by *Alternaria brassicae* (Berk) Sacc. This has been listed as occurring on horseradish from most of the regions of the world that produce horseradish. It is rarely found in Illinois altho the fungus is common on cabbage and other crucifers in this state. The leaf spots produced are of all sizes up to 2 inches in diameter. They usually appear on older weakened leaves or about insect punctures. Olivacious masses of spores, often produced in concentric rings on the spots, are characteristic of this disease (Fig. 9). *Macrosporium herculeum* E. & M. is described from horseradish as well as from other crucifers. It has been listed from Ceylon, Russia, southern Europe, and from a number of eastern states in this country. The leaf spot caused by this fungus is much smaller than

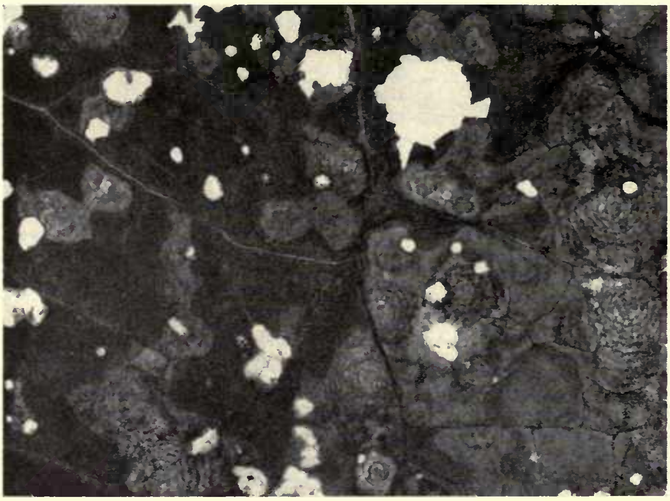

FIG. 9.—ALTERNARIA LEAF SPOT OF HORSERADISH ON OLD LEAF

Altho Alternaria leaf spot is very general, it is seldom important. Its symptoms are identical with those of Macrosporium, both being characterized by large spots which form concentric rings when mature. Spots often fall out, giving the leaf a ragged and torn appearance.

that due to *Alternaria brassicae*. These two leaf spots are undoubtedly confused by many workers.

Ascochyta armoraciae Fuckl. *Ascochyta armoraciae* Fuckl., also known as *Septoria armoraciae* Sacc., is described as being widespread and common in Europe. It causes a leaf spot very similar to the one caused by *Ramularia armoraciae*. This fungus has not been reported from America.

Phyllosticta leaf spots. *Phyllosticta armoraciae* (Cooke) Sacc., *P. decidua*, and *P. orbicula* E. & E. (Fig. 10) have been described as occurring on horseradish. None of these are known to cause serious leaf spotting. *P. orbicula* causes a small definite white spot with few scattered pycnidia. It has been reported from Ontario and New York.

P. decidua is probably not parasitic but is often found associated with other leaf spots. *P. armoraciae* has been found in Europe only and is not known to occur in America.

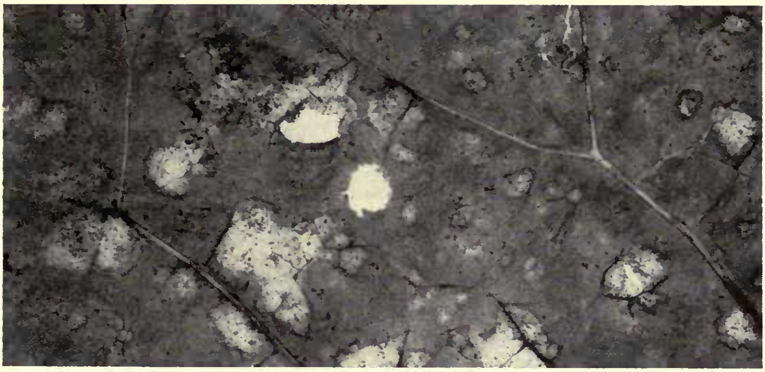

FIG. 10.—PHYLLOSTICTA LEAF SPOT OF HORSERADISH

Phyllosticta leaf spot is a minor disease which may be confused with other more important leaf spots.

Surface mildew. Surface mildew caused by *Erysiphe polygoni* has been reported from Europe but is not prevalent on horseradish in America.

Downy mildew. Downy mildew caused by *Peronospora parasitica* has been reported from New Jersey, South Dakota, Alabama, and Wisconsin. It is not commonly found on horseradish in Illinois.

Chlorosis. Chlorosis of horseradish (Fig. 11) has been observed in Illinois and reported by Dr. Baudýs[a] from Czechoslovakia and by Schleyer[99*] from Germany. It is evidently genetic in origin and is never of commercial importance.

Black streaking. Black streaking of leaf petioles, a diseased condition of unknown origin, is found during the summer and fall months. The disease first appears as numerous small black spots about ⅛ to ¼ inch in length and $1/16$ inch in width. The spots are scattered but are usually most numerous along the midrib on the underside of the leaf in the general area where the leaf blade originates. They may appear also on the upper surface of the midrib, and small streaks sometimes appear on the larger veins. As the season advances, these spots

[a]Correspondence of July 25, 1935.

elongate so that black streaks from 1 to 2 inches long may result (see Fig. 12). These streaks often fuse, resulting in a general blackening which may extend over the half length of the petiole and midrib. The spots are somewhat sunken, especially as they become older. There is no general collapse of tissue beneath the spots and the vascular system is not affected.

FIG. 11.—CHLOROSIS OF HORSERADISH

Altho chlorosis appears to be quite common, it is never of commercial importance. It is considered to be a genetic disturbance. (*Photo by courtesy of Dr. Baudýs of Czechoslovakia.*)

A cross section of the midrib or petiole indicates that the blacking originates below the epidermal layer and extends into the cortex to a depth of five or six cells. These cells show a dark brown gum-like deposit. There is no evidence of a rupture of the epidermal cells over this area, and no fungi or bacteria have been found associated with the condition. In older streaks the same tissue is involved, but a larger number of cells show the brown deposit. The damage to the leaf does not seem to be serious, since normal green leaves may show extensive black streaks.

In discussing a mosaic disease of horseradish, Dana and McWhorter[33]* stated that "Old leaves developed black elongated lesions in the epidermis and outer cortex of the petioles." Since the black-streak condition has been observed in a large number of plantings in Illinois and elsewhere, and since it is found generally distributed over entire fields, it is evident that either all plants are infected with the mosaic or else the diseased condition is not always associated with the unidentified mosaic of Dana and McWhorter (see *Mosaic,* page 552).

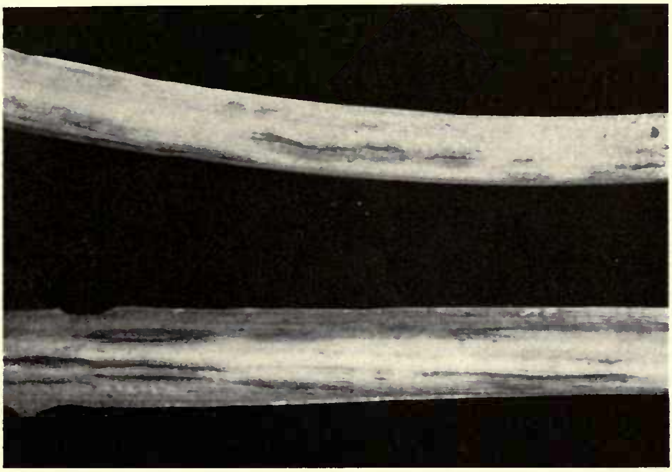

FIG. 12.—BLACK STREAKING ON HORSERADISH STEMS
Black streaking is very common on horseradish thruout the Middle West. It originates with the epidermal cells and often extends into the cortex to a depth of 5 or 6 cells. Some investigators regard black streaking as a symptom of virus infection.

Black streaking had previously been reported from various localities in Washington.

GENERAL CONTROL OF LEAF DISEASES

Bordeaux mixture has been recommended by several workers as a satisfactory spray for the control of white rust and some of the other leaf spot diseases. But four years' studies with copper and sulfur sprays on Illinois fields have not yielded results good enough to justify the recommendation of any spray for the control of horseradish leaf diseases. The results with white rust, the most important leaf disease, were especially unsatisfactory. Some of the copper sprays caused considerable injury to the foliage. Sulfur sprays did not cause injury, but neither did they control white rust. Similarly Böning[15*] in 1936 found that lime sulfur was of no value for white rust control and that bordeaux mixture caused too much injury to be considered safe to use as a horseradish spray.

All escaped and volunteer horseradish near commercial plantings should be destroyed because some of the leaf diseases, including white rust and virus troubles, are known to overwinter on such plants. The value of the above practice has not yet been fully proved.

Horseradish should not be worked when the tops are damp. The plants should not be lifted or disturbed at any time any more than is necessary. Plants should not be set less than 2 feet apart, and an effort should be made to keep down weeds in all plantings in order to facilitate drying of the tops after rains and dews.

VIRUS DISEASES AND "DETERIORATION"

MOSAIC

Smith[105*] classifies five virus diseases from crucifers and briefly mentions four others. Of these, three have been reported as occurring on horseradish: (1) curly top (see page 554); (2) "Brassica Virus 2" described by Hogan and Johnson[54*]; and (3) an undifferentiated virus reported by Dana and McWhorter.[33*] The other virus diseases, mostly of the mosaic types, evidently were not transferred to horseradish by the workers who described them. Therefore, it is not known whether these crucifer viruses will go to horseradish or not.

In 1932 Dana and McWhorter[33*] briefly described a mosaic disease of horseradish from Washington. They described the symptoms in the field as dwarfing and yellowing of foliage and small roots with rough scaly surfaces. The roots were pithy and showed frequent dark streaks. When root cuttings were planted, the foliage which was developed was somewhat stunted, and "leaf blades were strikingly segmented in a fernlike manner." A mosaic pattern developed on the young leaves, but vein clearing was not noticeable. Old leaves developed black streaks on the petioles and midribs (page 549). Cross inoculations were made on turnip and mustard by the needle prick method and 100 percent positive results were secured; the inoculated plants developed mosaic symptoms similar to those on horseradish. Many died within a short time. No mention is made of control horseradish plants in this account.

It is well known that under certain conditions of growth, fernlike leaves (see Fig. 1, page 532) are predominantly produced in supposedly normal plants, and as indicated on page 551, black streaking of the leaf petiole is almost universal in cultivated horseradish. If these are regarded as symptoms of a virus disease, it is probable that most commercial horseradish is virus-infected.

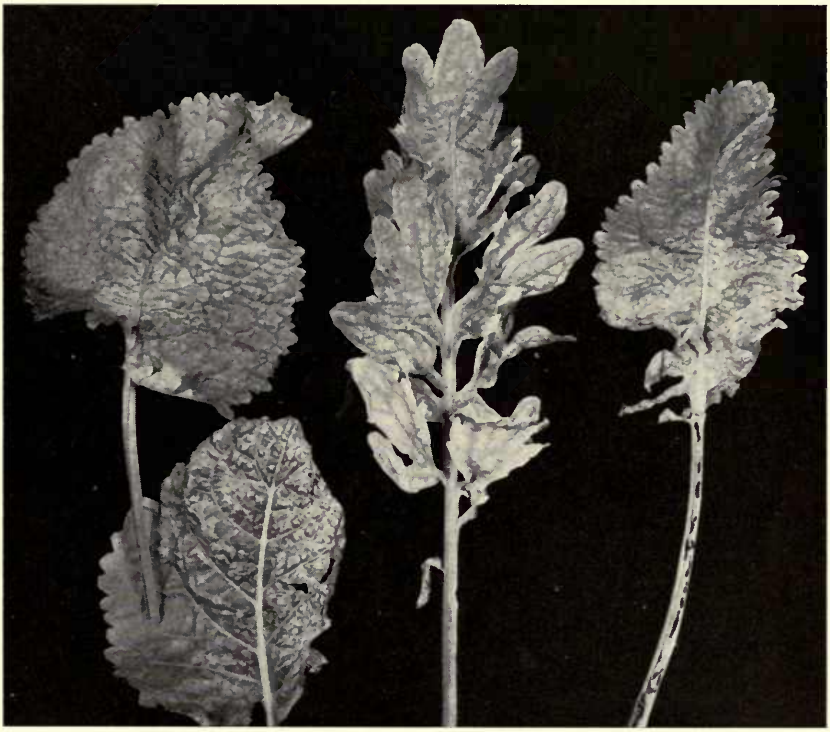

FIG. 13.—MOSAIC SYMPTOMS ON YOUNG HORSERADISH LEAVES

These leaves show mottling and chlorotic spotting. They also show indistinct black streaks on the petioles. The petiole on the right has been touched with ink to make the black streaks more evident.

In 1935 Hogan and Johnson[54*] described a virus of the mosaic type which they obtained from turnip. This was compared with a virus obtained from leaves and root cuttings of horseradish obtained from Cook county plantings (Fig. 13). According to Hogan and Johnson, "Plants obtained from the root-cuttings showed distinct vein clearing and mottling of chlorotic spotting of the foliage." The viruses obtained from these plants, as well as from the turnip, produced conspicuous brown necrotic lesions on tobacco (*Necotiana tabacum* var. *Connecticut Havana No. 38*).

CURLY TOP

Another specific disease which some workers may be calling "Schwarzwerden" is caused by the curly top virus. In America the common names of this disease, "brittle root" or "wilt," are taken from the outstanding symptoms. The first definite report of curly top on horseradish was made to the U. S. Plant Disease Survey in 1926 by McKay and Dykstra; however, it was not until 1929 that Severin[102*] definitely proved the relation of the curly top virus to the horseradish disease. He transmitted curly top from beets to horseradish and back again with the beet leafhopper, *Eutettix tenellus* Baker. It is a common and serious disease of horseradish and many other crops in the United States west of the Rocky Mountains. What appears to be the same disease was reported on horseradish from the East St. Louis district in 1936 by the authors.[61*] The beet leafhopper was reported from this same area in 1937. A disease of horseradish which appears to have been curly top was reported from Tunis, Africa, in 1932.[10*]

Symptoms. The first external symptoms of curly top on horseradish occur above ground as an inward curl of the leaves. The outside leaves are the first to show this condition which soon appears on

FIG. 14.—BRITTLE ROOT OF HORSERADISH IN THE FIELD

The typical wilting and dying of the plants can be seen. Brittle root is evidently caused by the curly top virus. In some seasons it is very serious in the East St. Louis area.

all leaves. About the time the inside leaves begin to curl, the entire leaf system begins to wilt (Fig. 14). Wilting plants may recover some during the night, but in the heat of the day collapse again. Infected plants usually die within a few weeks after the first appearance of the leaf symptoms altho some have been reported to live the entire season. Severin[102*] observed the presence of exudate from the petioles of infected leaves similar to that caused by curly top of beets. This condition has not yet been seen in Illinois.

History of the disease. Whenever symptoms of curly top are visible above ground, root symptoms are always clearly defined. Infected roots are usually much smaller than normal roots and are always brittle. They show a very pronounced discoloration just outside the cambium (Fig. 15), and in some cases xylem strands inside the cambium are also discolored. In the early stages of the disease before leaf symptoms appear, the discoloration may be visible as a yellowish-tan tissue in the vicinity of the phloem. As the disease progresses, the discoloration darkens thru brown until in most cases it is black by the time the plant is dead. It is interesting to note that the deposition responsible for discoloration in the phloem region appears between the cells rather than in them (Fig. 16). However, when

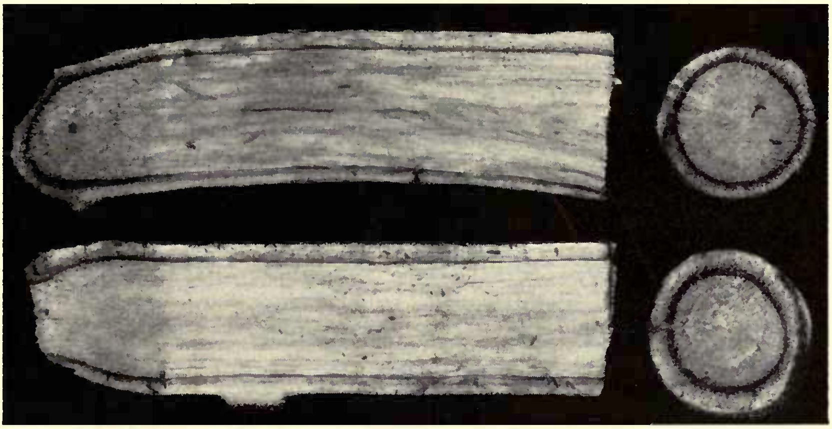

FIG. 15.—BRITTLE ROOT OF HORSERADISH

A typical discoloration of phloem tissue is shown. Roots with this symptom are always extremely brittle and will snap instead of bending as most horseradish roots do.

xylem strands are infected, the deposition is usually found within the tracheae.

Roots which are visibly diseased usually fail to sprout; in some cases spindling shoots may develop, but these die either before pushing thru the ground or soon afterward. Plants infected late in the season often show no disease symptoms until sets from them are planted

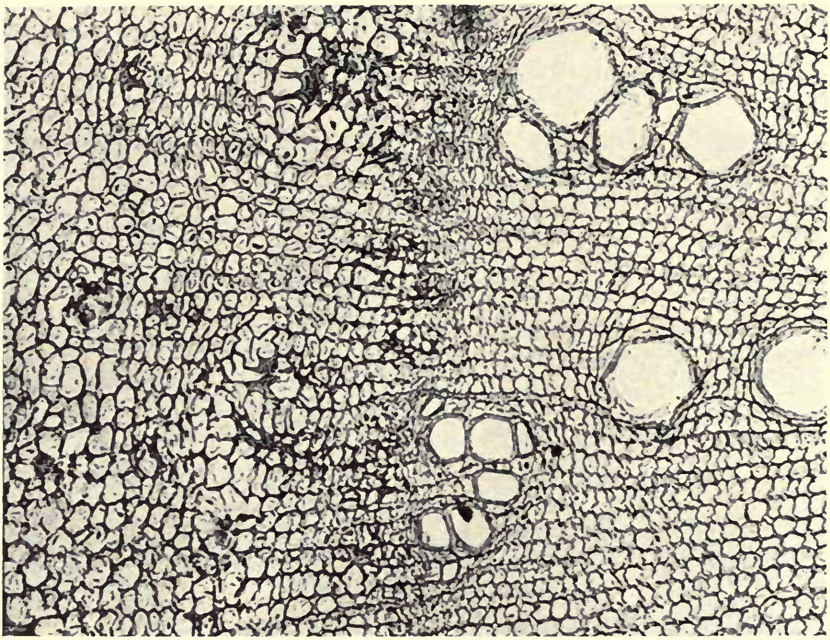

FIG. 16.—SECTION OF HORSERADISH ROOT

The xylem and phloem tissues are shown separated by the cambium. Discoloration begins at the cambium and continues thruout the phloem. Note that the deposit is between the cells rather than in them.

the following spring. Such cases usually account for the relatively small number of scattered infected plants seen in early June. The losses from the disease increase as the summer advances, usually becoming greatest in late August and September. In advanced stages of the disease soil organisms may contaminate and rot the roots, but until this point is reached, the interior tissues of the roots are free from organisms. Unlike Verticillium wilt (page 566) curly top does not usually occur from year to year on the same ground.

So far as is known, curly top is transmitted from one plant to another only by the beet leafhopper, *Eutettix tenellus* Baker.

Control. No satisfactory control for curly top on horseradish is known. As a general precaution sets from infected fields should not be used at all whenever this is practicable since they may facilitate the spread of the virus the following spring.

Nor has any satisfactory control of the leafhoppers been discovered yet. They migrate great distances and overwinter wherever suitable food plants grow; there are many weed and cultivated plants that serve as hosts for these insects. They thrive in a hot dry climate. They seem to be less destructive in seasons following severe winters and in areas of high rainfall.

DETERIORATION

During the general study of horseradish diseases by the authors, growers often complained that they could no longer produce superior roots as they had done when the industry was young in their particular area. These complaints were substantiated by observations in both the Cook county and the East St. Louis areas. It appeared that there had been a gradual deterioration of the quality of the roots.

Illinois experiments. In order to obtain definite data on the question of deterioration, experiments were carried out in which yields from sets obtained from fields in Cook county were compared with yields from sets grown in one locality for a number of years. The sets from Cook county were from a strain which had recently been introduced from wild plants at a distance from commercial vegetable-growing areas. The other sets in the comparisons were from plantings that had been grown for many years in the same locality and in most cases had been introduced from abroad. So far as could be learned the types of horseradish were the same, having the same type of leaf and root growth.

The experiments were carried on at the farm of P. Fournie and Son, Collinsville, Illinois. In 1937 two lots were used, one from Cook county and one from Mr. Fournie's own stock; each was planted to $\frac{1}{10}$ acre. In 1937 the yield from the Cook county sets was almost three times the yield from Mr. Fournie's sets.

In 1938 another lot of Cook county sets was added and the experiment was repeated. Again very significant results were obtained. Mr. Fournie's stock totalled 197 pounds when harvested; the second year crop from Cook county weighed 531 pounds, an increase of 170 percent; and the new addition to the experiment yielded 477 pounds, an increase of 142 percent. These increases were equivalent to 3,340 pounds and 2,800 pounds respectively per acre.

Sets from these same plantings were also grown at the Branch Experiment Station in Cook county. Again there was a significant difference between the two varieties. The Cook county plants made a much more vigorous growth and at the end of the season the harvested roots showed an average weight per plant of more than twice that of the East St. Louis variety. There was an increase equivalent to 3,679 pounds per acre.

The results obtained in 1939 substantiated the results of the previous years. Of particular interest was the study of the length of time necessary for deterioration to begin, as expressed by the decreased yield from northern-grown sets grown over a period of years in the Collinsville area. The first sets on which the figures are based were grown in Cook county in 1935 and planted on the Fournie farm

RESULTS OF HORSERADISH TESTS AT FOURNIE FARM, COLLINSVILLE, ILLINOIS, 1939

Source	First year planted[a]	1939 yield[b]	Acre yield[c]	Increase over old line	
		lb.	*lb.*	*lb.*	*perct.*
Collinsville (old line)	....	288.5	2 563	.....	.....
Cook county	1939	632.5	5 622	3 059	115.4
	1938	638.5	5 675	3 112	121.4
	1937	576	5 120	2 557	99.7
	1936	445	3 955	1 392	54.3
Wisconsin	1939	570.5	5 071	2 508	97.8
Wisconsin (Bohemian)	1939	624	5 547	3 004	117.2
Bulgarian[d]	1939	465	4 133	1 570	61.2

[a]First year grown in East St. Louis area. Sets were grown the year previous to this date in area indicated under source.
[b]Based on 900 plants. Total weight of sets and roots (Nos. 1 and 2).
[c]Based on 8,000 plants per acre.
[d]Sets were from Bulgaria in 1937. They were grown at Urbana in 1938.

in 1936. It is evident from the above table that the yields from northern-grown sets in 1938 and 1939 were more than 115 percent over those of the homegrown ("old-line") sets.

There is no evidence of deterioration during the first two years as shown by decreased yields from the plants originally from the north. In the third year there is a significant decrease which becomes even more marked in the fourth year. However, even after four years of growth in the East St. Louis area, the imported sets still gave an increase of 54 percent over the "old line" sets; this increase over the old-line sets is less than half the increase of the newer sets over the old-line sets.

Cause of deterioration. The cause of the deterioration of horseradish stock is not clear. It was considered possible that viruses might be responsible. Since horseradish is always asexually propagated, it seemed evident that a virus once introduced into a field would continue to increase from year to year as long as sets were taken from infected plants. Extensive observations by the authors resulted in the conclusion that most of the symptoms described for crucifer mosaics on horseradish are to be found in any field. Mosaic patterns are very common and "fern leaf" occurs under a variety of conditions in all plantings. In fact, some of the early taxonomists describe it as a normal variation of horseradish leaves. Therefore, one must conclude either that most horseradish plantings carry viruses or that the symptoms described for the virus diseases are not diagnostic.

If "deterioration," or "running-out," is a symptom of a virus or a virus complex, then the results obtained in the above experiment can be explained. One could assume that plants which have grown wild for a long time, or at least away from the larger vegetable-growing areas, are in less danger of becoming virus-infected. Horseradish grown in a truck crop region is not only exposed to insect vectors from other horseradish but also from a great variety of plants, including crucifers, which may carry the viruses.

Final conclusions as to the extent of virus-infected horseradish must await a more extensive study of cross-inoculation experiments on indicator plants. One difficulty in the way of this study is that horseradish does not produce viable seed from which virus-free plants could be obtained.

Control. Even tho the cause of horseradish deterioration is not known, it seems evident that one solution to the problem is to secure sets from sources where there is no evidence of general stunting. If the disease is of virus origin, it is possible that it can be controlled by obtaining sets from plants grown in an isolated area. Experiments are in progress which may solve the problem of seed production; and if these are successful, the propagation of virus-free plants may be expected to follow quickly, since the viruses are rarely transmitted thru seeds.

ROOT ROTS

In 1895 and 1899 there were reports of horseradish root diseases in Germany causing yield reductions as great as 50 percent of the crop. None of the diseases were identified except for brief accounts of the most conspicuous symptoms. Sorauer[106*] stated that some of the troubles had been known for more than fifty years prior to his report and that horseradish sent to him from Russia was similarly diseased. Reports of root rots since 1895 are too numerous to cite except as they may bear on specific troubles discussed below.

CAUSE OF ROOT ROTS

Altho there are many references to horseradish root rots, few offer proof of the actual parasitic relation between the organisms listed and the condition observed. Most of the reports do no more than identify organisms associated with rotting roots.

A disease referred to as "Rotbrüchigkeit" was briefly mentioned in 1895, as also was "Schwarzwerden." Both diseases were discussed a little more fully in 1899 by Sorauer,[106*] who had no explanation for their cause. "Kernfäule" was mentioned for the first time by Sorauer as referring to "core rot." Roots that were smooth but with a gray yellow color and a very bad odor were referred to as "Wasserschlündige." Sorauer also spoke of "Kropfigwerden" roots which may refer to our present nematode or clubroot diseases. A rotting of the crowns (Kopfbrandigkeit) was mentioned as being especially bad in wet years.

Schwarzwerden. The word "Schwarzwerden," which may be translated to mean a black discoloration, appeared in reports on horseradish as early as 1895 to indicate a blackened condition of roots thought to be a fungus disease. Since it was first reported much has been written concerning its possible cause. It is obvious from the various and contradictory reports that at least two or three distinct troubles may have been considered under this extremely general term. Some European workers believe the disease is caused by some unusual soil condition, but this contention does not seem to be well established. It seems fitting to point out that there is a disease of horseradish from which "no organism has been isolated," as is contended by some of the above workers, that seems to have many symptoms similar to those reported by them. It is caused by the curly top virus and has been reported from Africa and several places in the United States.

RELATION TO CULTURAL PRACTICES

Formerly very little horseradish was grown under cultivation as now practiced by commercial growers. Most of the horseradish used was obtained from plants growing in the wild, altho many gardeners had small plantings which were not disturbed until wanted for household use. At the present time there is still considerable horseradish grown in this same manner, especially in small plantings for home use.

Horseradish which arises from small roots left in the ground the previous fall and is not disturbed once it has rooted in the spring seldom has a serious root rot problem. However, if large crowns and large roots are not removed from such plantings each year or two, the roots are apt to become hollow and tough. Such roots (see hollowroot, page 574) may produce growth cracks after becoming hollow and tough, and become overrun with decay organisms. This observation was first recorded in 1888 by Henderson.[52*] The condition is common in undisturbed horseradish growing wild.

The most important difference between present and old horseradish cultural methods is that now most commercial plantings are cultivated and lifted or stripped, a process which has been described on page 535. Lifting is usually done when the soil is moist. Growers have learned by experience that lifting in dry weather stunts the plants severely and often causes a high mortality. Practically all lifted roots become infected where side roots have been broken off, especially in a wet season. Usually these infections cause only small lesions which never extend beyond the cortex of the main root; however, at other times they progress until the entire root is destroyed. Fig. 17 shows a typically infected root about two weeks after lifting and a more advanced stage of the same condition.

ILLINOIS EXPERIMENTS

Because of the generally excellent condition of roots from small home gardens an experiment was conducted to discover the relation of root rots to our present-day commercial practices. The experiment was conducted in 1935 and 1936 at Urbana on the University of Illinois farm.

In 1935, 4,500 apparently healthy sets were selected for the study and in 1936, 4,000 were used. The 1935 plants were grown beneath an overhead irrigation system so that soil moisture could be regulated nearly as desired. In 1936 the plants were grown under regular field conditions.

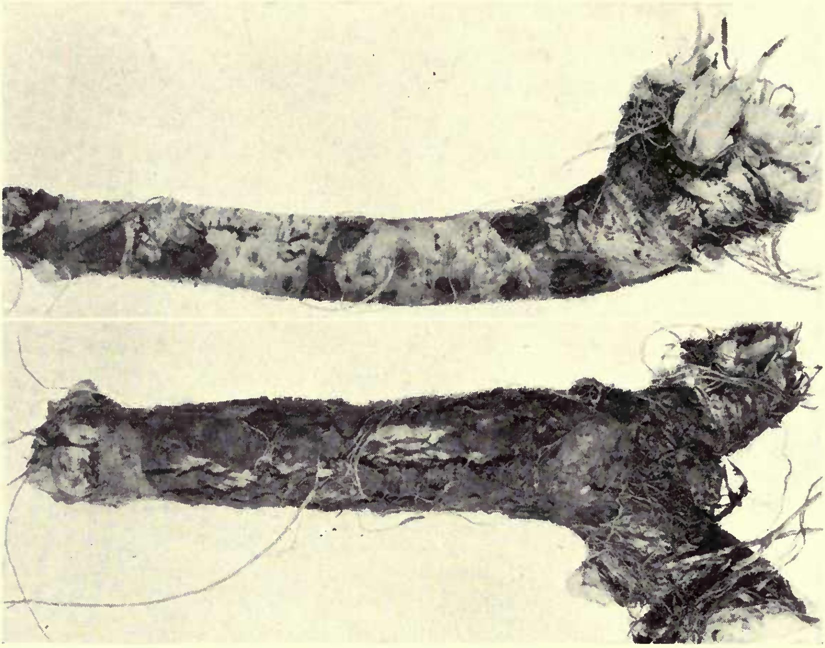

FIG. 17.—HORSERADISH ROOT ROT RESULTING FROM LIFTING

The upper root shows the condition of a root two weeks after lifting, and the lower root shows an advanced stage of rot caused by lifting about 6 weeks before. The season was rainy and favored the development of the condition shown. The organisms responsible for root rot often enter the root and rot out the inside, leaving the outside as an empty shell. Horseradish root rots are often very serious in storage pits also.

Thruout this study roots were considered infected when a lesion ½ inch or more in diameter was present. Except as a general observation, multiple lesions per root were not recorded unless the root had become unmarketable. In 1935 the plantings were watered in such a manner as to keep the soil moisture high thruout the season. The growing conditions of 1936 were normal, with much less soil moisture than in the 1935 experiment. The various tests and the results of them were as follows:

Test 1. One thousand sets were lifted when the tops were 6 to 8 inches tall and the soil was quite dry. The plants were soaked with heavy rains 6 days after lifting in 1935 and 9 days after in 1936. All roots in this treatment were covered with soil immediately.

The results in 1935 were as follows: 11 percent of the roots were unmarketable, and 67 percent of the plants were root-infected. In 1936, 5 percent of the roots were unmarketable and a total of 43 percent diseased. The difference in results is attributed largely to the difference in soil moisture. The soil was much wetter during the 1935 season due to the supplemental irrigation.

Test 2. One thousand sets were lifted as in Test 1. In 1935, however, they were lifted 7 days after those of Test 1, and in 1936 10 days later; in each year there were good rains the day before lifting.

The 1935 results gave 14 percent unmarketable roots and 72 percent diseased. In 1936 there were 9 percent unmarketable with 51 percent diseased.

Test 3. The same number of plants was used and the same procedure was followed in these plots as in Test 2 except that the roots were lifted twice instead of once, the second lifting coming one month after the first. This plot was used only in 1935. Twenty-one percent of the roots were unmarketable and 87 percent were diseased.

Test 4. In 1936, 1,000 sets were planted and lifted as in Test 2 for 1936. After lifting the plants were not put back into the ground until 5 days later. This was done to see if the wounded tissue would form a wound periderm or harden off in such a manner as to prevent infections when the plants were returned to the ground. No true periderm was formed. The wounded surface hardened as a result of drying out, but this did not seem to prevent infection. Apparently the wounded tissues softened soon after the plants were replaced in the moist soil. The total number of diseased plants on these plots was 57 percent, with 6 percent of the roots unmarketable. These results are very similar to those of Test 2 for 1936 in which the plants were returned to the ground immediately after lifting.

Test 5. In this test 1,000 sets were planted in 1935 and 1,000 more in 1936. They were never lifted but were hoed and cultivated four times during the season as were all other plots thus far discussed. In 1935 there were 3 percent unmarketable roots and 28 percent diseased, while in 1936 there were 5 percent unmarketable and 21 percent diseased.

Test 6. Only 500 sets were used on this plot, and the test was not repeated in 1936 because of lack of space and sets. The sets were not lifted, hoed, or cultivated at any time during the season. When the weeds became troublesome, they were pulled by hand from the middle of the row and cut off with a hedge shears in and near the rows. This was done so that the horseradish roots would not be disturbed. Only 2 percent of the roots were unmarketable. Only 11 percent of the roots were diseased.

From the results given above, and from extensive observations by the authors, it seems quite clear that wounds inflicted to horseradish roots as a result of commercial practices now followed play an important role in the origin of horseradish root rots. Also excessive soil moisture may be an important factor in the increase in root rots. Lifting causes the greatest increase in rots while careless cultivation and hoeing also play a part.

BACTERIAL ROOT ROT

In 1909 a very serious outbreak of horseradish root rot occurred in England. According to Middleton[79*] the rot was caused by *Bacterium campestre.* This was the first report of a definite bacterial root rot on horseradish, altho the "Kernfäule" or core-rot disease described in 1899 by Sorauer[106*] was apparently bacterial in nature. Middleton recognized two phases of the disease; one caused the inside of the roots to rot out while the other caused the outside to rot away but did not affect the inside. The same disease was reported by Massee from England in 1914. In an extensive series of New Jersey reports, beginning about 1920 and reported principally by Poole[90*] or Martin,[73*] a bacterial root rot is described and in some instances attributed to *Bacillus caratovorus* L. R. Jones. The New Jersey workers also report two types of bacterial root rot symptoms: a core rot which decays all but ¼ to ½ inch of the outer root tissues, and a second type which begins on the outside and continues until the entire root is decayed. They report that the rot is soft and more or less granulated and that the fibrous strands are not attacked.

Unidentified root rots similar to the known bacterial root rots have been reported from nearly all horseradish-growing areas in the world. They have caused serious losses both in the field and in storage.

Report on research. Because of the importance of the root rot problem in Illinois, a graduate student of the University of Illinois, Mr. Clyde Wutzke, was assigned the general problem of bacterial root rots of horseradish. Wutzke's report (unpublished) is very instructive. Over 60 distinct species of bacteria were isolated from horseradish roots, many of which could cause rot as individual species, while others not capable of rotting roots alone did so in various combinations. Of all the bacteria found parasitic, *Phytomonas phaseoli*

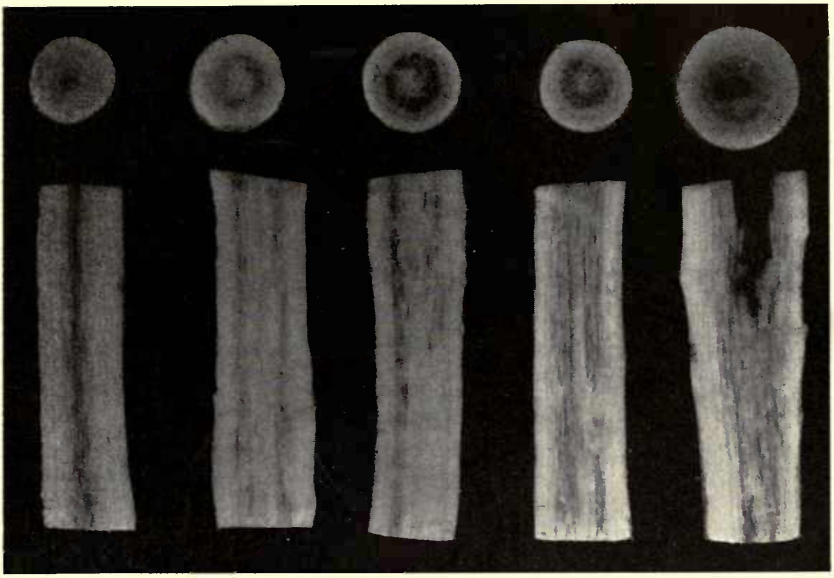

FIG. 18.—INTERNAL ROTTING OF HORSERADISH ROOTS

Once organisms gain entrance thru openings of any sort the conductive bundles soon become avenues for the rapid advance of rots. This picture shows a progression in degree of severity of rotting. The rot pictured is being caused by bacterial organisms.

(EFS) Bergey *et al* was the only one previously described as a vegetable disease. It is the cause of one of the bacterial blights of bean and many other plants. By making cross-inoculations, Wutzke was able to produce typical lesions on bean leaves and core rot of horseradish. All of the other parasitic bacteria were studied on differential media, but were not named. All degrees and stages of root rots were observed and produced in his studies. Wutzke concludes:

"Many species of bacteria can thrive upon the horseradish root, causing discoloration and so materially alter the product as to render it unfit for sale. There are many species able to cause soft rotting and also many causing dry rots. The author feels that his collection of over sixty species from roots is but a mere start, as contrasted to the possible numbers of potential importance.

"Observation has shown that whenever entrance from the outside to the stele is gained, whether it be by nematodes, insects, or some mechanical injury, bacteria are always on hand to start decay and from thence on cause the destruction of the root. The usual symptoms will be a stringy mass of fibres in the core if infections be on the inside (Fig. 18). Some species have the power of destroying epidermal and cortical cells; these usually are, however, in the minority."

Some vascular infections have been observed to cause a discoloration of vessels but never actually to rot them. Similarly, infections at epidermal wounds have been observed to start decay but not to continue it. Both of these conditions were commonly observed in connection with stored roots and sets (Fig. 19).

These incomplete studies will give a fair idea of the complex nature of the horseradish root rot problem. The complexity of the problem may also account for some of the contradictions in the reports on horseradish.

For a discussion of control methods of root rot see page 574.

VERTICILLIUM WILT

In 1923 Potschke[92*] described "Schwarzwerden" as being caused by a species of Verticillium differing only in minor respects from *V.*

FIG. 19.—EARLY STAGES OF HORSERADISH ROOT ROT

These sets were taken from the pit after three months of storage and before winter freezes had set in. The rotting of roots while in storage often causes serious losses.

albo-atrum. Sorauer[106*] observed in 1899 that a fungus was associated with the "Schwarzwerden" disease. On the other hand, several European workers have shown that no organisms are associated with a disease that is quite similar in appearance and known by the same name. It seems quite certain now that both groups of workers are correct and that the symptoms of several root rot diseases are very nearly identical. They are so identical that cultural and pathogenicity tests are required for accurate diagnosis.

Since Potschke's first report several other workers have confirmed his findings. Additional reports from Europe have been made by Gram,[47*] Blattný,[13*] who identified the causal fungus as *Verticillium dahliae*, Korff and Böning,[68*] and Böning.[15*] Klebahn[66*] found Verticillium and other fungi associated with "Schwarzwerden" but did not consider them parasitic. He claims that the cause of the disease is not yet known. In the United States *Verticillium albo-atrum* was reported to the Plant Disease Reporter as the cause of a horseradish root rot in Michigan in 1931 and by Heald et al[51*] from Washington in 1938.

The Verticillium fungus and the discoloration which it causes may be found in either or both xylem and phloem bundles. They may be found in isolated vessels or in large or small groups. Infected plants are usually badly stunted and show wilt symptoms most conspicuously during dry spells, but they usually live. In severe cases, however, the leaves wilt and the infected plants, after many attempted recoveries, die. Potschke[92*] reports that the vessels of diseased plants have been observed to be obstructed with gum or tyloses.

The general importance of Verticillium wilt is not known, but it is undoubtedly of considerable concern in some regions. Suggested control measures are to select the sets from disease-free plants and to grow the crop on ground which is not known to harbor the causal organism. There are many plants, other than horseradish, subject to infection by the Verticillium wilt organism.

RHIZOCTONIA ROOT ROT

Rhizoctonia was first reported on horseradish from New York by Burkholder in 1903,[86*] who isolated the fungus from diseased roots and identified it as *R. solani* Kühn. Since then the disease has been reported to the U. S. Plant Disease Survey from Washington, New Jersey, Illinois, and Michigan. Dr. Baudyš,[a] at Brně, Czechoslovakia,

[a]Correspondence of July 15, 1935, and December 4, 1935.

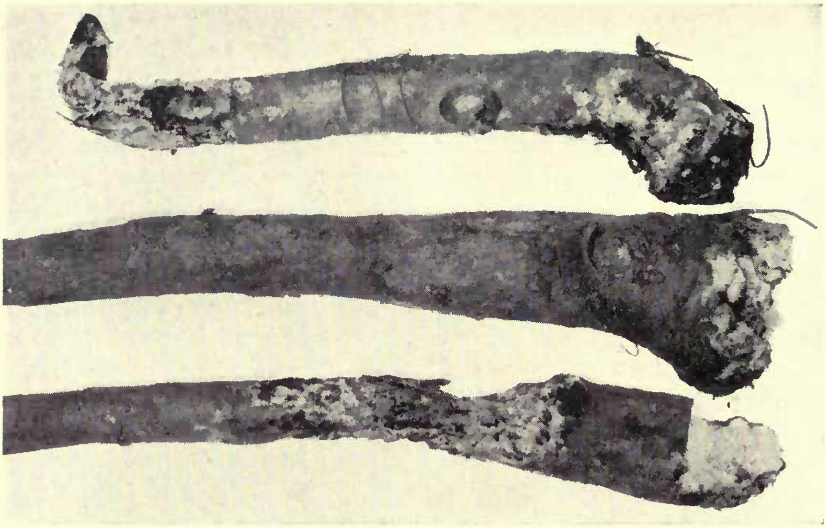

FIG. 20.—RHIZOCTONIA ROOT ROT ON HORSERADISH

Rhizoctonia is principally a storage rot of horseradish altho it may be seen occasionally in fields. Sulfur dust is effective in its control.

has isolated and identified *Rhizoctonia violacea* from horseradish root. He has also proved its pathogenicity and demonstrated that finely ground sulfur and a special preparation known as "Germisan" were effective as control measures.

The sulfur treatment was tried in 1920 and 1921 for the general root rot complex of stored roots and sets by Poole,[90*] and both good and bad results reported. Since a disease complex rather than an individual disease was under consideration by Poole, it is not surprising that the results of the sulfur treatment were erratic. Experiments conducted by the authors on stored roots and sets at the Sass farm in Cook county demonstrated clearly that ordinary 325-mesh sulfur dusted on the roots when they are being stored is very effective for the control of Rhizoctonia and Penicillium rots (page 569), but is of little or no value for the control of other root rot troubles.

A species of Rhizoctonia, culturally and morphologically similar to *R. solani,* has been isolated from horseradish in Illinois and has been proved to be pathogenic to Illinois horseradish. It has been observed only in connection with pitted roots and sets and was found to be the cause of serious losses in 1934 and 1935.

Infections from Rhizoctonia usually occur at the crown or in wounded areas of the roots (Fig. 20). From limited observations it appears that roots which are pitted so that sunshine falls directly on the pits for extended periods of time may sprout prematurely, and if a hard freeze follows, the young sprouts are killed back. Under such conditions Rhizoctonia is usually but not always the most important cause of the rot which follows.

Tissue infected with Rhizoctonia rot is a light yellow to a light dirty gray and is rather dry unless overrun by bacteria. Infected tissue is friable and separates readily from the advancing edge of the rot. As the infection ages, black sclerotial bodies produced by the fungus may be seen scattered among the white mycelial growths. There is no odor associated with Rhizoctonia decay.

Control. Roots should be pitted in a shaded location. Dusting roots and sets lightly with finely-ground sulfur practically eliminates Rhizoctonia and Penicillium but has little effect on most other fungus and bacterial root rots. However, since sulfur dust is cheap and the treatment easily applied, it is thought worth while to dust all sets as a preventative practice. Both Rhizoctonia and Penicillium rots are very serious diseases, some seasons causing losses of 50 percent of the crop.

PENICILLIUM ROOT ROT

Penicillium root rot is a very common disease of pitted horseradish in Illinois. It has been found in nearly every pit examined. A storage root rot, attributed to *Penicillium,* was reported from Germany by Böning[15*] in 1936 and from New Jersey by Poole[90*] in 1920. The rot

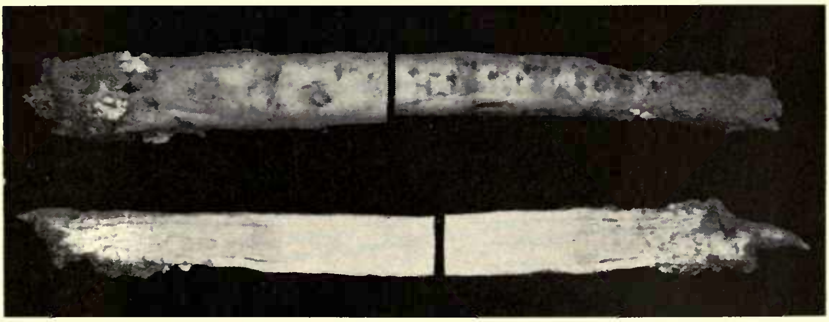

FIG. 21.—PENICILLIUM ROOT ROT ON HORSERADISH

Penicillium root rot, caused by *Penicillium hirsutum* Dierckx, often causes considerable losses of stored roots and sets. It does not rot roots when plants are growing. Dusting roots with sulfur is an effective control.

caused by this disease is very similar to that caused by Rhizoctonia, except that the Penicillium fungus always sporulates abundantly, coating the surface of the diseased tissue with its greenish-blue spore masses (Fig. 21). Losses of stored sets have been as high as 40 percent altho as a rule they range from 2 to 10 percent.

During the course of this study all organisms found associated with rotting roots were isolated and pathogenicity tests conducted. Many healthy roots were inoculated with our Penicillium cultures in various stages of their development. Inoculations were always positive when the roots were kept in storage. Inoculation of roots actively growing in the field was always negative, indicating that the fungus is only a weak parasite.

After the pathogenicity of the fungus was proved, cultures were sent to Dr. Charles Thom of the U. S. Department of Agriculture for identification. Dr. Thom[a] considered the fungus to be *Penicillium hirsutum* Dierckx. Undoubtedly other workers have seen this fungus on horseradish but probably considered it a saprophyte.

Little is known of the control of Penicillium rot except what was learned while it was present in the storage pits at the Sass farm in Cook county when the authors' experiments for the control of storage rots were in progress. Sulfur-dusted roots were completely free from Penicillium and Rhizoctonia rots, while the undusted checks were badly overrun by both fungi. Growers who have tried the sulfur treatment have controlled Rhizoctonia and Penicillium, but storage losses are often still large due to root rots from other causes.

THIELAVIA ROOT ROT

Chlamydospores of Thielavia were found by Sorokin on rotten horseradish roots at Kazan, Russia, in 1876; he described it as a new species, but it was considered by Gilbert[46*] to be *Thielavia basicola* (B.&Br) Sopf. The actual pathogenicity of *Thielavia basicola* to horseradish does not appear to have been demonstrated as yet, altho it occurs quite commonly on horseradish and has often been reported as causing appreciable damage in New Jersey. It was identified there in 1917 by Schwarze[100*] from diseased roots, and there have been numerous other New Jersey reports of the same disease. In 1922 White reported it from Kansas. Specific control measures are not known.

[a]Correspondence of May 15, 1935.

ROOT KNOT

In 1899 Sorauer[106*] and in 1907 Schleyer[99*] reported a disease of horseradish roots which is probably similar to root knot in America. Root knot is caused by a microscopic eelworm or nematode and is characterized by enlargements of the host tissues at the point of infestation (Fig. 22). The first report of a definite organism associated with the disease on horseradish appears to have been made by Bessey[9*] in 1911 who found *Heterodera radicicola* causing moderate injury. *Caconema radicicola* was reported in 1928 from material sent to the U. S. Department of Agriculture Herbarium from Mississippi. *Tylenchus filiformis, T. pratensis, Aphelenchus prietinus,* and an unidentified

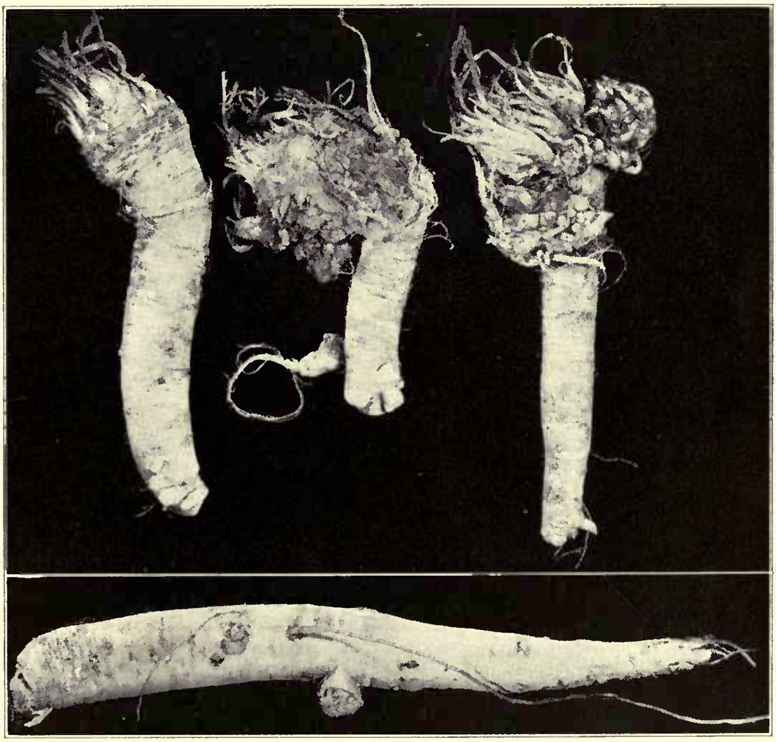

FIG. 22.—ROOT KNOT DISEASE ON HORSERADISH

Two mature roots affected with root knot are shown at the right in the upper picture; at the left is a healthy root. On the set in the lower picture (much enlarged in proportion to the mature roots) are small root knots. Horseradish roots affected by clubroot are very similar in appearance to the large roots shown above.

species of Aphelenchus were found associated with roots intercepted from Germany in 1931. Park[85*] reports *Heterodera marioni* from Ceylon in 1933. The disease was pictured and described by Shropshire and Kadow[104*] from Illinois in 1936.

Root knot is not a serious disease of horseradish, altho it is probably much more common than the reports to date would indicate. Winter temperatures are probably responsible for holding root knot in check since most of the horseradish is grown in climates with severe winters. Sets suspected of having nematode infestations should be covered lightly with 2 or 3 inches of dirt since soil temperatures below 10° F. will kill most parasitic nematodes. The disease is perpetuated on sets which are pitted deep enough to prevent hard freezes and the temperature in a standard well-covered pit seldom descends to 10° F. The disease has been followed thru the winter in such pits many times in Illinois; it was discovered that a prolonged cold spell was necessary to bring soil temperatures down sufficiently to kill the nematodes out of roots stored in the average storage pit.

Symptoms. The disease is first evident as small swellings, similar to those for clubroot, that are generally distributed on the lateral feeding roots. As the disease progresses, the swellings enlarge, preventing the normal activity of the roots and thus causing stunting and the premature death of infested plants. The root swellings contain small brownish cysts. Within these cysts are pearly-white bodies about the size of a pinhead. These bodies are the egg-bearing female nematodes, and they afford a fairly reliable method of distinguishing between root knot and clubroot. Another point which may aid in distinguishing these two diseases is that clubroot is known to occur only on cruciferous plants while a great variety of plants are affected with root knot.

Control. Where root knot is serious, crop rotation with immune plantings offers the most practical means of control. In climates with cold winters, rotations to control root knot have not been necessary, for under such conditions the eelworms do not survive the winter.

A very careful examination of sets for typical swellings should be made before they are planted. It is not safe to use apparently healthy young sets from pits which show serious nematode infestations, for the organism may be carried to the field in adhering dirt particles or by infestations too small to be readily recognized. If the primary source of the nematodes is small, field infestations will not be serious in an ordinary season, but if excessive rains occur the losses may be considerable.

Sets should not be stored year after year in the same pit, especially if the pit is protected somewhat by buildings.

MINOR ROOT ROTS

There have been a number of reports of horseradish diseases of definitely minor importance. Few of these have been encountered in the work of the authors, but some will be listed because of their interest to other investigators.

Waterlog. A disease characterized by a waterlogged condition of infected roots has been referred to in Europe under the name "Wasserschlündige." It was first reported in 1899 by Sorauer and reported again in 1923 by Kirchner.[63*] Sorauer states that the roots are smooth and grayish yellow, with a very bad odor. Dr. Blattný describes a disease under the name "Schilfrohrkrankheit," or reed sickness, which appears to be the same as the one above. The trouble is regarded as of minor importance. No explanations are given as to the cause.

Girdle disease. This disease was reported by Janson[59*] in 1929 under the name of "Ringelkrankheit." He regarded the trouble as of minor importance at the time but a potential danger to the industry. His article is abstracted as follows:

> "The first severe attacks generally occur about July 20 when the outer leaves rapidly die off. The hearts remain sound, but their growth is markedly arrested. The vascular bundles turn pale yellow, then brownish, and finally almost black. The affected plants are quite unsalable. The disease has been observed to occur in soils containing ferrous oxid and receiving heavy applications of lime and marl. Chemical analyses have shown that the sulphuric acid content of horseradish is exceptionally high, while its potash requirements appear to exceed that of any other plant. At present the only known measure of control is to rest diseased soils for at least four or five years."

Clubroot. Clubroot of crucifers was first reported on horseradish by Schleyer[99*] in 1907. He regarded the trouble as of minor importance and reported successful control by liming the soil. It has been identified several times from horseradish grown in Illinois on soil severely infected by clubroot. The disease is caused by the fungus *Plasmodiophora brassicae* Wor. Altho very serious on several crucifers, it is of no practical importance on horseradish. When horseradish is grown on soil severely infected with the organism, less than 1 percent of the roots show symptoms and then only on small side roots and occasionally at the crown. The symptoms are identical to those described for root knot except that the cysts cannot be seen when infected tissue is examined.

Other root rots. Many other kinds of root rot have been reported. *Pezizella dilutella* (Schroet) Rehm. and *Lachnum sulphureum* (Pers.) Rehm. were reported from horseradish by Jaap[57*] in 1922. Lind lists *Gibberella saubinetii* and *Fusarium oxysporum* Fries.[71*] Several Fusaria have been isolated from Illinois horseradish, but none of them proved parasitic when inoculated into healthy roots. Likewise *Rhizopus nigricans* Ehr. has been isolated several times from decaying roots but has never proved pathogenic when inoculated into healthy roots. Taubenhaus and Killough[109*] report that horseradish is moderately susceptible to Texas root rot, *Phymatotrichum omnivorum*. No mention was made of it occurring under field conditions.

Hollowroot. A trouble designated by its most conspicuous symptom, hollow roots, was first reported in 1888 by Henderson[52*] from England. It was quite serious in 1934 in the Cook county region. The season was extremely dry until quite late, when a vigorous growth was made while the soil had sufficient moisture and a very high nitrogen content. Altho the above condition may be related to the formation of hollow roots, the true cause remains to be demonstrated. This same condition has been observed in New Jersey by Dr. Haenseler who also considers it a function of growing conditions.

Hollowroot is found in apparently healthy roots of unusual size. The tissue on the sides of the cavities is usually normal in color. If the hollow condition continues to form growth cracks to the outside of affected roots, soil organisms will usually produce discoloration and secondary rots. This condition of discoloration and secondary rots is very common in the large roots of horseradish growing wild which seems to indicate that something more than climatic conditions is involved.

Sclerotinia sclerotiorum. This disease was reported by Böning[15*] in 1936 as the cause of a storage rot responsible for minor losses.

Crown gall. Crown gall (*Pseudomonas tumefaciens*) was also observed by Böning to cause typical root swellings under field conditions.

GENERAL CONTROL OF ROOT ROTS

Unfortunately control measures have not been devised that offer safe and satisfactory control of all the major root rot problems. Poole[90*] has recommended sulfur as a treatment for pitted roots, reporting both good and unsatisfactory results. He has also recommended a treatment of 1-1,000 corrosive sublimate for 15 minutes before pitting or planting the sets. Martin,[73*] however, reports that corrosive sublimate treatment caused sufficient injury to be reflected in yield. He reported similar results with Semesan Bel 1-64 and said that neither treatment lessened the rough bark condition of the roots. Dr. Baudyš[a] regards both "Germisan" (an organic mercury) and sulfur dust as effective treatments for the control of Rhizoctonia root rot.

During the spring and winter of 1935 twenty-one different chemicals were employed by the authors both in the field and in the green-

FIG. 23.—HORSERADISH SETS INJURED WITH BICHLORID OF MERCURY

These sets were treated for 15 minutes in a 1-2000 solution of bichlorid of mercury. As yet no root dip has been found that will control root rots without causing injury.

house in a study of root treatments. Most of the chemicals used, including several forms of copper, mercury, and formaldehyde, caused injury to the treated sets. They caused extensive killing of tissues at each end and often in places where small side roots had been broken off (Fig. 23). Sulfur was the only treatment that did not cause injury. It was effective in the prevention of Rhizoctonia and Penicillium rots, but it had practically no effectiveness against the more common bacterial troubles. The injury from the other treatments was sufficiently extensive to exclude them from further consideration.

Considering recommendations that have been published and the

[a]Correspondence of December 4, 1935.

results of their own observations and experiments, the authors feel that the following practices may be employed beneficially and safely.

1. All horseradish sets should be thoroly examined before they are pitted and again before they are planted in the spring. Examination before planting is especially beneficial. To make this examination most successful, the sets should be washed and dried beforehand. The ends should be inspected very carefully, but attention should also be given to the sides of the roots since many of the most destructive infections enter thru wounds in the sides.

2. After sets are selected for pitting, they should be dusted lightly with 325-mesh dusting sulfur. This treatment is easily applied and inexpensive altho it is not effective against any common troubles except Rhizoctonia and Penicillium root rots. Either or both of these troubles can be found in most stored horseradish and are often the cause of heavy losses. Sulfur treatment can also be effectively applied to mature roots pitted prior to marketing.

3. Roots should not be pitted in the same location year after year. If storage cellars are used, they should be washed each fall with 1-1,000 corrosive sublimate (bichlorid of mercury).

4. Pits should not be exposed to unnecessary changes in temperature. Roots that are protected from the north and get considerable direct sunlight often send out shoots prematurely. At the next cold snap these shoots freeze back, affording an excellent opportunity for rot organisms to enter the crown. Unprotected locations or those to the north of buildings are considered more satisfactory.

5. If nematodes are known to be troublesome, sets saved from infested plantings should be pitted very shallowly, allowing temperatures within the pits to go below 10° F., which is sufficient to kill parasitic nematodes. In districts where nematodes live over winter under field conditions, crops immune to them should be grown in a rotation.

GEOGRAPHICAL DISTRIBUTION

The geographical distribution of horseradish diseases in the United States is indicated in part by the following references to reports by plant pathologists to the Division of Mycology and Disease Survey, U. S. Department of Agriculture. These references are from the card files of that office.

State	*Disease*	*Reported by*	*Year*
Illinois	Cercospora armoraciae } Ramularia armoraciae }	Anderson and Tehon	1922
Indiana	Cercospora	Jackson	1916
	Macrosporium	Jackson	1917
Iowa	Alternaria herculea	Archer	1927
	Macrosporium herculeum	Arthur	1882
Kansas	Cercospora armoraciae	Melchers	1914
	Thielavia basicola	White	1922
Michigan	Corticium vagum solani	Coons	1919
Missouri	Alternaria brassicae	Archer	1926
	Cercospora armoraciae	Maneval	1923
	Cercospora armoraciae	Philpott	1919
New Jersey	Thielavia basicola } Bacteria root rot }	Cook	1919
	Macrosporium herculeum	Arthur	1882
New York	Mosaic	Chupp	1923
Ohio	Macrosporium herculeum	Arthur	1882
Pennsylvania	Alternaria brassicae	Orton	1924
South Dakota	Bact. campestre armoraciae	Walker	1930
Utah	Alternaria brassicae	Linford	1927
Washington	Rhizoctonia	Dana	1922
	Rhizoctonia	Frank	1921
	Rhizoctonia	Heald et al	1917
	"Black streak"	Heald et al	1917
	Phyllosticta decidua	Wheeler	1930
West Virginia	Cercospora armoraciae	Archer	1928
	Cercospora armoraciae	Haskell	1921

BIBLIOGRAPHY

An effort has been made to list here all reports of research on horseradish diseases. Many references simply reporting the diseases are also given, but no attempt to list all such references has been made. However, enough are listed to give a good idea of the reported distribution of any given trouble.

1. Adams, J. F. Plant disease survey of economic crops in Delaware during 1925. Del. State Bd. Agr. Quart. Bul. 15. 1926. (*Alternaria herculea* reported.)
2. Alcock, N. L., and Foister, C. E. List of fungous diseases received by the pathological department of the Department of Agriculture of Scotland. Bot. Soc. Edinb. Trans. and Proc. **30**, 338-350. 1931. (*Cystopus candidus* reported.)
3. Anderson, H. W., and Anderson, P. J. The parasitic fungi of Montgomery county. Ind. Acad. Sci. Proc. (1919), 175-221. 1921. (*Albugo candida* and *Ramularia armoraciae* reported.)
4. ————, and Thornberry, H. H. Bacterial diseases in 1938. Plant Disease Reporter **22**, 366. 1938.
5. Anderson, P. J. Index to American species of Phyllosticta. Mycologia **11** (2), 69. 1919. (*Phyllosticta decidua* reported.)
6. Bailey, L. H. Standard cyclopedia of horticulture. **3**, 1500-1501. Macmillan Co., New York. 1915.
7. Baudýs, Ed. Solbar—Seine Anwendungsmöglichkeit und Bedeutung für die Schädlings. Bekämpf. **6**, 97-124. 1931. (*Albugo candida* reported.)
8. Beattie, W. R. Production and preparation of horseradish. U. S. Dept. Agr. leaflet 129. 1937.
9. Bessey, E. A. Root knot and its control. U. S. Dept. Agr. Bur. Plant Indus. Bul. 217, 19. 1911. (*Heterodera radicicola* reported.)
10. Beauverie, M. A. Les maladies à ultravirus des plantes. Ann. du Serv. Bot. et Agron. [Tunis] **9**, 1-175. 1932.
11. Bisby, G. R., Conners, I. L., and Bailey, D. L. Canada Dept. Agr. Bul. 71, n. s., 81. Appendix 2. 1926. (*Ramularia armoraciae* reported.)
12. Bitancourt, A. A. Relacão das doencas e fungos parasitas obervados na secção de fitopatologia durante os anos 1931 e 1932. Inst. Biol. [São Paulo] Arch. **5**, 185-196. 1934. (*Peronospora parasitica* reported.)
13. Blattný, C. Černání kořenů (verticillosa) křenu. (Black discoloration (verticilliose) of the roots of horseradish.) Zeměděl. Arch. Prague **18**, 363-374. 1927. *Abstracted in* Rev. Appl. Mycol. **7**, 356. 1928.
14. Böning, Karl. Die wichtigsten Krankheiten und Schädlinge des Meerrettichs. Nachr. über Schädlingsbekämpf. **13**, 62-87. 1938.
15. ————. Untersuchungen über Meerrettichkrankheiten und deren Bekämpfung. Angew. Bot. **18**, 482-494. 1936.
16. Brenckle, J. F. North Dakota fungi, II. Mycologia **10**, 199-221. 1918. (*Ramularia armoraciae* reported.)
17. Brundza, K. Kai kurie parazitiniai grybeliai, surinkfi Liefuvoje 1927-1932. Lithuania Dept. Agr. (Žemés Ukio Akademijos Leidinys), 199-208. 1933. (*Ascochyta armoraciae* reported.)
18. Brzezinski, M. J. Les graines du raifort et les résultats de leurs semis. Akad. Umiejetnósci, Cl. des Sci. Math. et Nat., Bul. Internatl. Sér. B, Sci. Nat. **2**, 392-408. Cracaw. 1909. (Production of horseradish seed discussed.)

19. BUBAK, F., and KABAT, J. E. Mykologische Beiträge. Hedwigia **50**, 38-46. 1910. (*Ascochyta rusticana* reported.)
20. BURT, E. A. Missouri Bot. Gard. Ann. **5**, 131. 1918. (Reports *Corticium vagum* from horseradish stems.)
21. CHEMBEL, STEFAN IU. Aperçu des maladies de plantes de la région d'Astrakhan observées jusqu'à 1923. (A review of plant diseases observed in the Astrakhan region up to 1923.) Zapiski Astrahk. Stan. Zasch. Rast. ot Vred. (Comm. Inst. Astrach. Defens. Plant.) **1** (1), 1-58. 1923. (*Macrosporium herculeum* reported.)
22. CHUPP, CHARLES. Manual of vegetable garden diseases. Ch. 6. Macmillan Co., New York. 1925. (Several horseradish diseases reported.)
23. CLAYTON, E. E. A study of the mosaic diseases of crucifers. Jour. Agr. Res. **40**, 263-271. 1930.
24. CLINTON, G. P. Notes of parasitic fungi. Conn. (New Haven) Agr. Exp. Sta. Ann. Rpt. 27 (1902-3), 279-370. (*Macrosporium herculeum* reported.)
25. ————. Plant pest handbook for Connecticut. Conn. (New Haven) Agr. Exp. Sta. Bul. 358. 1934. (Several horseradish diseases reported.)
26. COBB, N. A. Notes on diseases of plants. Agr. Gaz. N. S. Wales **2**, 285-287. 1891. (*Albugo candida* reported.)
27. CONNERS, I. L. Ninth annual report on the prevalence of plant diseases in the dominion of Canada, 1929. Canada Exp. Farms Ann. Rpt. 9, p. 1-79. (*Ramularia armoraciae* reported.)
28. COOKE, M. C. Pests of the flower and vegetable garden. Roy. Hort. Soc. Jour. **27**, 1-45, 369-406, 801-831. 1902-3. (Several horseradish diseases reported.)
29. ————. The root-rot fungus. Gard. Chron. Ser. 3, **41**, 361. 1907. (Reported Thielavia on horseradish.)
30. COTTON, A. D. Report on the occurrence of insect and fungus pests on plants in England and Wales for the year 1919. [Gt. Brit.] Min. Agr. and Fisheries Misc. Publ. **33**, 1-68. 1921. (*Ramularia armoraciae* reported.)
31. ————. Report of the occurrence of fungus, bacterial, and allied diseases on crops in England and Wales for 1920-21. [Gt. Brit.] Min. Agr. and Fisheries Misc. Publ. **38**, 1-104. 1922. (*Cystopus candidus* reported.)
32. CRUCHET, DENIS. Recherches mycologiques à Montagny et aux environs d'Yverdon. Soc. Vaud. des Sci. Nat. Bul. 55, 37-51. 1923. (*Mycosphaerella brassicicola* reported.)
33. DANA, B. F., and MCWHORTER, F. P. Mosaic disease of horseradish. Phytopathology **22**, 1000. 1932. (Reported from Oregon.)
34. DAVIS, J. J. A provisional list of the parasitic fungi of Wisconsin. Wis. Acad. Sci. Arts, Letters, Trans. **17**, 846-984. 1914. (Several horseradish diseases reported.)
35. DELONG, D. M., and KADOW, K. J. Sugar-beet leafhopper (*Eutettix tenellus* Baker) in Illinois. Jour. Econ. Ent. **30**, 210. 1937.
36. DRAYTON, F. L. A summary of the prevalence of plant diseases in the dominion of Canada, 1920-1924. Canada Dept. Agr. Bul. 71, n. s., 36. 1926. (Reports Cercospora and Ramularia leaf spots.)
37. DUGGAR, B. M. Fungous diseases of plants. Ginn & Co. 1909. (Lists several fungi parasitic to horseradish.)
38. ELENKIN, A. A., and BONDARTSEV, A. S. (Chief inquiries received at the Central Phytopathological Station during the year 1912.) Boleznii Rastenii (Jour. Plant Prot.) **7** (3-4): 125-153. 1913. (*Macrosporium herculeum* reported.)

39. ELLIS, J. B., and EVERHART, B. M. North American species of Ramularia. Jour. Mycol. **1**, 73-83. 1885. (Reports *Ramularia armoraciae* from New York, Wisconsin, and Kansas.)
40. ————. The North American Phyllostictas. Vineland, New Jersey. 1900. (Reports *Phyllosticta orbicula.*)
41. FAIRCHILD, DAVID. The best horseradish varieties of Europe and methods of cultivation. U. S. Dept. Agr. Sec. of Seed and Plant Introd. Cir. 1. 1900.
42. FREEMAN, E. M. Minnesota Plant Diseases. p. 330. 1905. (Reports *Albugo candida* on horseradish from Minnesota.)
43. FRICKHINGER, H. W. Achtet auf die Meerrettichschädlinge. Obst und Gemüsebau **28**, 77-78.
44. FRIESE, WALTER. Meerrettich und Meerrettichkonserven. Ztschr. f. Untersuch. der Nahr. u. Genussmtl. **49**, 194-203. 1925.
45. GARDNER, M. W. Indiana plant diseases 1927. Ind. Acad. Sci. Proc. **38**, 143-157. 1928. (Reports *Cercospora armoraciae* on horseradish.)
46. GILBERT, W. W. The root-rot of tobacco caused by *Thielavia basicola.* U. S. Dept. Agr. Bur. Plant Indus. Bul. 158. 1909. (Reported on horseradish.)
47. GRAM, E., and ROSTRUP, SOFIE. (Survey of diseases of agricultural and horticultural cultivated plants in 1923.) Tidsskr. f. Planteavl. **30** (3), 361-414. 1924. *Abstracted in* Rev. Appl. Mycol. **3**, 506. 1924. (*Cystopus candidus, Ramularia armoraciae,* and Verticillium (black ring) reported.)
48. HALSTED, B. D. Notes upon Peronosporeae for 1891. Bot. Gaz. **16**, 338-340. 1891. (*Cystopus candidus* reported on horseradish.)
49. ————. Report of botanist. N. J. Ann. Rpt. 11 (1890), 360. (Reported *Ramularia armoraciae* and *Septoria armoraciae.*)
50. HEALD, F. D. The white rust of crucifers. Manual of Plant Diseases, 407-414. McGraw-Hill, New York. 1926.
51. ———— *et al.* Plant disease survey. Wash. Agr. Exp. Sta. Bul. 354, 56-57. 1938. (*Verticillium dahliae* on horseradish.)
52. HENDERSON, PETER. Gardening for profit. Judd Co., New York. 1888. (Discusses hollow root.)
53. HIURA, M. Biologic forms of *Albugo candida* on some cruciferous plants. Jap. Jour. Bot. **5**, 1-20. 1930. (Excellent treatment of this subject.)
54. HOGAN, I. A., and JOHNSON, J. A virus of crucifers and other hosts. Phytopathology **25**, 640-644. 1935.
55. HRUBY, JOHANN. Die Pilze Mährens und Schlesiens. Ein Versuch der Gliederung der Pilzdecke dieser Länder. Hedwigia **68**, 168. 1928. (Reports *Mycosphaerella armoraciae* and *Ramularia armoraciae* from horseradish.)
56. JAAP, OTTO. Pilze bei Bad Nauheim in Oberhessen. Ann. Mycol. **12**, 1-32. 1914. (Ramularia and Cercospora leaf spots reported.)
57. ————. Weitere Beiträge zur Pilzflora von Triglitz in der Prignitz. Bot. Ver. der Brandenb. Verhandl. **64**, 11. 1922. (Reports *Pezizella dilutella* and *Lachnum sulphureum* from horseradish.)
58. JACZEWSKI, A. A. Yearbooks of information on the diseases of plants. Russia. 1904, 1910, and 1911-12. (Reports several diseases of horseradish.)
59. JANSON, A. Ringelkrankheit des Meerrettich. Gartenwelt **33**, 512-513. 1929. *Abstracted in* Rev. Appl. Mycol. **9**, 156. 1930.
60. JONES, H. A., and ROSA, J. T. Truck crop plants. McGraw-Hill, New York. 1928. (Good discussion of horseradish culture.)

61. KADOW, K. J., and ANDERSON, H. W. Brittle root of horseradish in Illinois. Plant Disease Reporter **20**, 288. 1936.
62. KARSTEN, P. A. Sphaeropsideae hucusque in Fennia Observatae. Acta. Societatis pro Fauna et Flora fennica **1** (3), 86. 1890. (Several diseases of horseradish listed.)
63. KIRCHNER, OSKAR. Die Krankheiten und Beschädigungen unserer landwirtschaftlichen Kulturpflanzen. 3d ed., 373-376. 1923. (Several diseases of horseradish listed.)
64. KIRK, T. W. New Zeal. Dept. Agr. Ann. Rpt. 15 (1907), p. 158. (Reports *Cercospora armoraciae* from horseradish in New Zealand.)
65. KLEBAHN, H. Untersuchungen über Krankheiten des Meerretichs. Ztschr. f. Planzenkrank. **45**, 16-41. 1935. (Discusses root rot (Schwarzwerden) and white rust.)
66. ————. Untersuchungen über die Krankheiten des Meerretichs. Phytopath. Ztschr. **10**, 121-167. 1937.
67. KLIKA, JAROMIR. Contributions à la connaissance de la flore mycologique de la Bulgarie. Acta Botanica Bohemica **8**, 119-128. 1929. (Reports *Ramularia armoraciae* on horseradish.)
68. KORFF, G., and BÖNING, K. Die Meerrettichschwärze und ihre Bekämpfung. Prakt. Bl. f. Pflanzenbau. u. Pflanzenschutz **11**, 9-10, 273-277. 1934. (Discusses principally Verticillium wilt.)
69. LAUBERT, R. Schmarotzerpilze und Pflanzenkrankheiten aus Polen und Masuren. Centbl. f. Bakt. Parasitenk. u. Infektionskrankh. **52**, 236-244. 1920. (Cercospora and Ramularia leaf spots reported on horseradish.)
70. ————. Schmarotzerpilze aus dem Ruhrgebiet. Ztschr. f. Pilzk. **18**, 49-53. 1934. (*Cystopus candidus* reported on horseradish.)
71. LIND, JENS. Danish fungi as represented in the herbarium of E. Rostrup. 648 pp. Gyldenalske boghandel, Copenhagen. 1913. (Several diseases of horseradish listed.)
72. MALKOFF, KONSTANTIN. Erster Beitrag zur Kenntnis der Pilzflora Bulgariens. Ann. Mycol. **6**, 29-36. 1908. (Reports *Ramularia armoraciae* from Bulgaria.)
73. MARTIN, W. H. N. J. Agr. Exp. Sta. Ann. Rpt. 44 (1922-23), 342; 45 (1923-24), 377; 46 (1924-25), 450; 47 (1925-26), 319; 48 (1926-27), 211; 51 (1929-30), 244; 52 (1930-31) 311; 53-54 (1931-33), 62. (Many different horseradish diseases and experiments on them reported.)
74. MAYOR, E. Notes mycologiques. Soc. Neuchâteloise des Sci. Nat. Bul. 48, 367-396. 1924. (Reports *Erysiphe polygoni* on horseradish.)
75. MCCULLOCH, LUCIA. A bacterial leaf spot of horseradish caused by *Bacterium campestre* var. *armoraciae* n. var. Jour. Agr. Res. **85**, 269-287. 1929.
76. MCCURRY, J. B., and HICKS, A. J. Fifth annual report on the prevalence of plant diseases in the Dominion of Canada, 1925. Canada Exp. Farms Ann. Rpt. 5, 1-93. (*Cercospora armoraciae* reported.)
77. MCCURRY, J. B. Report on the prevalence of plant diseases in the Dominion of Canada for the years 1927-1928. Canada Exp. Farms Ann. Rpt. (1927-28), p. 61. (Reports *Ramularia armoraciae* from Quebec.)
78. MELHUS, I. E. Experiments on spore germination and infection in certain species of Oomycetes. Wis. Agr. Exp. Sta. Res. Bul. 15, 25-83. 1911.
79. MIDDLETON, T. H. Horseradish disease in Cheshire (*Pseudomonas campestre*.) House of Commons sessional papers 8. Great Britain Bd. Agr. and Fisheries, Intel. Div. Ann. Rpt. (1909-10), 66-67.
80. NAPPER, M. E. Observations on spore germination and specialization of parasitism on *Cystopus candidus*. Jour. Pomol. and Hort. Sci. **11**, 81-100. 1933.

81. NISSLEY, C. H. Horseradish culture. N. J. Agr. Col. Ext. Bul. 43. 1925. (A general treatment of horseradish production.)
82. ORTON, W. A. A second partial list of the parasitic fungi of Vermont. Vt. Agr. Exp. Sta. Ann. Rpt. 12 (1899), 164-182. (*Ramularia armoraciae* reported.)
83. ————. Plant diseases in 1907. Yearbook of U. S. Dept. of Agr. 1907, 577-589. (Reports Cercospora and Ramularia leaf spots on horseradish.)
84. OSNER, G. A. Additions to the list of plant diseases of economic importance in Indiana. Ind. Acad. Sci. Proc. 1916, 327-332. (Lists *Macrosporium herculeum* on horseradish.)
85. PARK, M. Report on the work of the mycological division. Ceylon Dept. Agr. Rpt. Dir. Agr. (1932), D116-D122. (Reports *Heterodera marioni* from horseradish.)
86. PELTIER, G. L. Parasitic Rhizoctonias in America. Ill. Agr. Exp. Sta. Bul. 189, 283-390. 1916.
87. PETCH, T. Additions to Ceylon fungi. Ann. Roy. Bot. Gard. Peradeniya (Ceylon) **6**, 195-256. 1917. (Reports *Macrosporium herculeum* from horseradish.)
88. PETRAK, F. Beiträge zur Pilzflora von Mähren und Österr.-Schlesien. Ann. Mycol. **19**, 273-295. 1921. (*Ramularia armoraciae* reported.)
89. PICBAUER, RICHARD. Addenda ad floram Čechoslovakiae mycologicam, V. Sbornik Vysoké Školy Zeměd. Brně ČSR. Fak. Lesn. (Bul. Inst. Nat. Agron. Brno RČS Fac. Silvicult.) D18, 29. 1931. (*Cercospora armoraciae* reported.)
90. POOLE, R. F. N. J. Agr. Exp. Sta. Ann. Rpt. 41 (1919-20), 610; 42 (1920-21), 464; 43 (1921-22), 560. (Reports many different horseradish troubles.)
91. ————. Bacterial root rot of horseradish in New Jersey. Phytopathology **12**, 49. 1922.
92. POTSCHKE, A. Über das Schwarzwerden des Meerrettichs. Biol. Reichsanst. f. Land u. Forstw. Arb. **11**, 337-338. 1923. (Regards Verticillium as cause of Schwarzwerden.)
93. RAEDER, J. M. Studies of the Phycomycetes of Iowa. Iowa Acad. Sci. Proc. **28**, 283-291. 1921. (Reports *Cystopus candidus* on horseradish.)
94. RANOJEWÍC, N. I. Bericht der Abteilung für Pflanzenschutz der königl. serbischen landwirtschaftlich-chemischen Versuchsstation zu Belgrad für die Jahre 1903-1905. Ztschr. f. Pflanzenkrank. **16**, 207-212. 1906. (Reports *Cercospora armoraciae* on horseradish.)
95. RUHMWERTH, R. R. VON. Phytopathologische Beobachtungen in Debrecen (Ungarn). Ztschr. f. Pflanzenkrank. **24**, 211-218. 1914. (Several diseases of horseradish reported.)
96. SACCARDO, P. A. Fungi Verseti novi vel critici. Nuovo Gior. Bot. Ital. **8**, 161-211. 1876. (Original description of *Cercospora armoraciae*.)
97. SAVULESCU, T., and SANDU-VILLE, C. Beiträge zur Kenntnis der Micromyceten Roumäniens. Hedwigia **73**, 71-132. 1933. (Reports *Cercospora armoraciae*.)
98. SCHLEYER, A. Das Schwarzwerden des Meerrettichs. Prakt. Bl. f. Pflanzenbau u. Pflanzenschutz. p. 138. 1903. *Abstracted in* Ztschr. f. Pflanzenkrank. **14**, 223. 1904.
99. ————. Der Anbau des Meerrettichs in der Nurnberg-Erlangener Gegend, die hauptsächlichsten Krankheiten der Meerrettichpflanze und deren Bekämpfung. Vrtljschr. Bayer. Landw. Rat. **12**, 1-68. 1907.
100. SCHWARZE, C. A. The parasitic fungi of New Jersey. N. J. Agr. Exp. Sta. Bul. 313. 1917. (Several fungi parasitic to horseradish are listed.)

101. SEAVER, F. J. Phyllostictaceae (Pars). North American Flora **6**, 1-84. 1922. (Reports *Phyllosticta orbicula* on horseradish.)
102. SEVERIN, H. H. P. Additional hosts plants of curly top. Hilgardia **3**, 595-636. 1929.
103. SHEMIN, R. Plant Disease Reporter **15**, 9. 1931. (Reports nematode infected horseradish intercepted from German shipments.)
104. SHROPSHIRE, L. H., and KADOW, K. J. Diseases and insect pests of cabbage and related plants: identification and control. Ill. Agr. Exp. Sta. Cir. 454. 1936. (Several diseases parasitic to horseradish are discussed.)
105. SMITH, K. M. A textbook of plant virus diseases. P. Blakeston's Sons & Co., Philadelphia, Pa. 1937.
106. SORAUER, PAUL. Kernfäule und Schwarzwerden des Meerrettich. Ztschr. f. Pflanzenkrank. **9**, 132-137. 1899. (Very good early account of horseradish troubles.)
107. SWINGLE, W. T. A list of the Kansas species of Peronosporaceae. Kans. Acad. Sci. Trans. **11**, 63-87. 1887-88. (Early listing of *Cystopus candidus* on horseradish from Kansas.)
108. SYDOW, P. Beiträge zur Kenntniss der Pilzflora der Mark Brandenburg. I. Hedwigia **36**, 157-164. 1897. (Lists *Vermicularia herbarium* and *Phoma armoraciae* from horseradish leaves.)
109. TAUBENHAUS, J. J., and KILLOUGH, D. T. Texas root rot. Tex. Agr. Exp. Sta. Bul. 307, 21. 1923. (Lists *Phymatotrichum omnivorum* as parasitic to horseradish.)
110. TOGASHI, K., and SHIBASKI, Y. Biometrical and biological studies on *Albugo candida* (Pers.) O. Kuntze in connection with specialization. Imp. Col. Agr. and Forestry, Japan, Bul. 18, 1-88. 1934.
111. TRELEASE, WILLIAM. Preliminary list of Wisconsin parasitic fungi. Wis. Acad. Sci., Arts, Letters, Trans. **6**, 109. 1881-83. (Reports *Peronospora parasitica* on horseradish.)
112. VERWOERD, L. V. A preliminary list of fungi from the Bloemfontein District of the Orange Free State. Union So. Africa Agr. Jour. **28**, 298-301. 1931. (*Cystopus candidus* reported on horseradish.)
113. WAKEFIELD, E. M. The genus Cystopus in South Africa. Bothalia **2**, 242-246. 1927. (Reports *Cystopus candidus* on horseradish.)
114. WILLIAMS, T. A. Torrey Bot. Club Bul. 19, 81-84. 1892. (Reports *Peronospora parasitica* and *Albugo candida* from South Dakota on horseradish.)
115. WILSON, G. W. Preliminary list of the parasitic fungi of Fayette county, Iowa. Iowa Acad. Sci. Proc. 17, 47-80. 1910. (*Ramularia armoraciae* reported.)
116. WUTZKE, C. R. Bacterial pathogenes of horseradish roots. University of Illinois thesis. (Unpublished) (An excellent treatment of bacterial root rots.)

3M—9-40—19383

AUTHOR INDEX

PAGE

1. ACKERMAN, J., and NORTON, L. J. Factors Affecting Success of Farm Loans............457–528
2. ACKERMAN, J. *See* HANNAH 15
3. ANDERSON, H. W. *See* KADOW 18
4. BIGGER, J. H. *See* COPPER 10
5. BOLIN, O. *See* COPPER 10
6. BONNETT, O. T. *See* DUNGAN 12
7. BURLISON, W. L., VAN DOREN, C. A., and HACKLEMAN, J. C. Eleven Years of Soybean Investigations.............121–167
8. BURLISON, W. L. *See* DUNGAN 12
9. CASE, H. C. M. *See* WILCOX 28
10. COPPER, R. R., DUNGAN, G. H., LANG, A. L., BIGGER, J. H., KOEHLER, B., and BOLIN, O. Illinois Corn Performance Tests, 1939..............169–216
11. DORSEY, M. J. A Study of the Cause of "Buttons" in the J. H. Hale Peach..............1–43
12. DUNGAN, G. H., BURLISON, W. L., KOEHLER, B., and BONNETT, O. T. Winter Wheat Varieties for Illinois.......85–104
13. DUNGAN, G. H. *See* COPPER 10
14. HACKLEMAN, J. C. *See* BURLISON 7

PAGE

15. HANNAH, H. W., and ACKERMAN, J. Legal Aspects of Farm Tenancy in Illinois...........237–276
16. HUELSEN, W. A. Sweet-Corn Inbreds and Crosses......277–356
17. HUELSEN, W. A. Three New Varieties of Bush Lima Beans: Baby Potato, Early Baby Potato, and Illinois Large Podded....................105–120
18. KADOW, K. J., and ANDERSON, H. W. A Study of Horseradish Diseases and Their Control....................529–584
19. KOEHLER, B. *See* COPPER 10
20. KOEHLER, B. *See* DUNGAN 12
21. LANG, A. L. *See* COPPER 10
22. LLOYD, J. W., and MCCOLLUM, J. P. Fertilizing Onion Sets, Sweet Corn, Cabbage, and Cucumbers in a Four-Year Rotation................217–236
23. MCCOLLUM, J. P. *See* LLOYD 22
24. NORTON, L. J. *See* ACKERMAN 1
25. TRACY, P. H., and TUCKEY, S. L. Accuracy of Methods of Sampling Milk Deliveries at Milk Plants...............45–84
26. TUCKEY, S. L. *See* TRACY 25
27. VAN DOREN, C. A. *See* BURLISON 7
28. WILCOX, R. H., and CASE, H. C. M. Twenty-five Years of Illinois Crop Costs 1913-1937 357–456

INDEX

PAGE

Beans, bush lima
- Baby Potato, summary of descriptive characters 113
- canning tests 113, 114, 115–116
- Early Baby Potato, summary of descriptive characters 113
- freezing tests 114, 116
- Illinois Large Podded, summary of descriptive characters 119

BEANS, BUSH LIMA, THREE NEW VARIETIES: BABY POTATO, EARLY BABY POTATO, AND ILLINOIS LARGE PODDED 105–120
- literature cited 120
- *See also* Contents in bulletin 106

CABBAGE, CUCUMBERS, ONION SETS, SWEET CORN, FERTILIZING IN A FOUR-YEAR ROTATION 217–236
- summary 235–236
- *See also* Contents in bulletin 218

Corn
- cost of production, *see* CROP COSTS, ILLINOIS, TWENTY-FIVE YEARS 1913-1937
- Diplodia stalk rot 175–177
- ear rots 179
- insect damage during 1939 growing season 174–175
- lodging 175, 183, 193, 195, 199
- stalk breaking 177
- Stewart's disease 177–179

CORN, SWEET, CABBAGE, CUCUMBERS, AND ONION SETS, FERTILIZING IN A FOUR-YEAR ROTATION 217–236
- summary 235–236
- *See also* Contents in bulletin 218

CORN, SWEET, INBREDS AND CROSSES 277–356
- literature cited 355
- summary and conclusions 352–355
- *See also* Contents in bulletin 278

Corn, sweet, number of cases packed in 1936, 1937, 1938 280

Corn hybrids
- performance tests in Illinois 169–216
- yields compared with open-pollinated varieties 1927-1939 .... 185, 214–215

CORN PERFORMANCE TESTS, ILLINOIS, 1939 169–216
- summary 214–215
- *See also* Contents in bulletin 170

CROP COSTS, ILLINOIS, TWENTY-FIVE YEARS 1913-1937 357–455
- summary 405–407
- *See also* Contents in bulletin 358

CUCUMBERS, ONION SETS, SWEET CORN, AND CABBAGE, FERTILIZING IN A FOUR-YEAR ROTATION 217–236
- summary 235–236
- *See also* Contents in bulletin 218

Ear rot in corn 179

Elberta peach, "buttons" 6, 10, 11, 20, 29, 35

Farm accounting, cost study based on records of, 1913–1937 357–455

FARM LOANS, FACTORS AFFECTING SUCCESS OF 457–527
- conclusions 523–525
- summary 519–523
- *See also* Contents in bulletin 458

FARM TENANCY IN ILLINOIS, LEGAL ASPECTS OF 237–276
- *See* Index in bulletin 274–275

HORSERADISH, A STUDY OF DISEASES AND THEIR CONTROL 529–583
- bibliography 578–583
- *See also* Contents in bulletin 530

Horseradish, cultural practices 534–536

PAGE

J. H. Hale Peach, a Study of the Cause of "Buttons" ... 1–43
literature cited ... 43
summary and conclusions ... 41–42
See also Contents in bulletin ... 2

Lima beans, bush, *see* Beans, bush lima
Lodging in corn ... 175, 183, 193, 195, 199

Milk, Accuracy of Methods of Sampling Milk Deliveries at Milk Plants ... 45–84
literature cited ... 84
summary and conclusions ... 83–84
See also Contents in bulletin ... 46

Oats
cost of production, *see* Crop Costs, Illinois, Twenty-Five Years 1913-1937
Onion Sets, Sweet Corn, Cabbage, and Cucumbers, Fertilizing in a Four-Year Rotation ... 217–236
summary ... 235–236
See also Contents in bulletin ... 218

Peaches, "buttons" in the J. H. Hale peach, a study of the cause ... 1–43

Soil characteristics of corn testing fields ... 173
Soybean hay
acreage and yield ... 124, 125, 128, 130, 132, 134, 137, 139, 142
quality ... 137–141
Soybean Investigations, Eleven Years of: Varieties, Seeding, Storage ... 121–167
summary and recommendations ... 163–165
See also Contents in bulletin ... 122
Soybean seed, acreage and yield ... 124, 125, 127, 130, 131, 135, 137, 138, 143
Soybean straw, yields ... 129, 130, 133, 136, 137
Soybeans
cost of production, *see* Crop Costs, Illinois, Twenty-Five Years 1913-1937
germination tests of stored beans ... 155–159, 160
performance tests of different varieties ... 126–141
publications of Illinois station ... 123
seeding practices, effects on yields ... 141–149
storage, effect on quality ... 149–155
Stalk rot in corn ... 175–177
Stewart's disease ... 177–179

Wheat, cost of production, *see* Crop Costs, Illinois, Twenty-Five Years 1913-1937
Wheat, winter
baking qualities ... 100–101, 103
diseases ... 99–103
soil treatment ... 88–89, 103–104
yields on Illinois soil experiment fields, *see* Wheat, Winter, Varieties for Illinois
Wheat, Winter, Varieties for Illinois ... 85–104
See Contents in bulletin ... 86

UNIVERSITY OF ILLINOIS-URBANA
Q.630.7IL6B C002
BULLETIN. URBANA
458-469 1939-40
3 0112 019529293