BULLETIN OF THE
U.S. DEPARTMENT OF AGRICULTURE

No. 64

Contribution from the Bureau of Plant Industry, Wm. A. Taylor, Chief.
February 10, 1914.

(PROFESSIONAL PAPER.)

POTATO WILT, LEAF-ROLL, AND RELATED DISEASES.

By W. A. Orton,
Pathologist in Charge of Cotton and Truck Disease and Sugar-Plant Investigations.

INTRODUCTION.

During recent years there has been much doubt and misunderstanding among plant pathologists and observant farmers concerning the group of potato diseases variously referred to as wilt, leaf-roll, leaf-curl, Fusarium blight, bacterial ring disease, etc., which in different countries of the world appear to constitute problems of increasing importance to practical agriculture.

This bulletin seeks to clear up the situation and to open the way for more efficient measures of control by differentiating these previously confused diseases and fully describing the methods of diagnosis. The results afford a strong argument to pathologists for a broader outlook over the field and for international as well as national comparisons of conditions. The fundamental importance of thorough laboratory investigations is not minimized, but the interpretation of results in their relation to the basic principles of plant pathology and to the general problems of agriculture require a better conception of the different environmental influences to which crops are subjected in the several States and in foreign countries.

To the practical potato grower to whose attention these new potato diseases are brought, the feature of greatest significance will be their effects in impairing the vigor of his seed stock and on the deterioration of varieties. New evidence is presented that large but insidious losses have been suffered from seldom-recognized weaknesses in vegetative vigor and from diseases transmitted through the seed—losses that threaten to be greater in the future unless active measures are taken at once to secure more vigorous and disease-free strains or varieties through seed selection and breeding.

Note.—This paper is of interest to plant pathologists; it is suited to the potato-growing sections of the North, West, and South.

The more clearly this danger is made apparent to the growers and the more general and concerted their efforts to combat it the greater the likelihood that the final result will place the potato industry on a higher plane than it occupies to-day. The same system of seed selection and treatment and crop rotation that will free the potato fields of wilt, leaf-roll, and curly-dwarf will at the same time not only bring under control the blackleg and some other diseases, but will insure the maintenance of the strains cultivated in their most vigorous and productive condition and free from objectionable mixtures with other varieties.

Past experience warrants these statements. The history of potato pathology is a story of the gradual recognition and differentiation of previously confused diseases and the introduction of control measures that brought with them more progressive cultural practices. From about 1845 the late-blight, *Phytophthora infestans*, occupied the center of the stage and is still one of the most destructive diseases (Jones, Giddings, and Lutman, 1912).[1] It causes heavy losses in nearly all the potato districts of the world, especially in cool and humid seasons. In the United States, however, there are many sections where Phytophthora occurs somewhat rarely. An examination of a map prepared by Dr. Erwin F. Smith and published in the Annual Report of the Department of Agriculture for 1885 shows that the losses from late-blight and rot were even then recognized to be mainly in the northern tier of States. This has been confirmed by an annual plant-disease survey of the United States, which has been made during the past 12 years under the direction of the writer. This survey shows conclusively that Phytophthora as a common parasite of the potato is limited to the Northeastern States east of the Mississippi River, with only sporadic outbreaks in southeastern trucking regions, in the Puget Sound district, and occasionally elsewhere. This disease is now successfully combated by spraying with Bordeaux mixture, and it is to be expected soon that more disease-resistant varieties will introduce a new era of late-blight control.

To the southward it has been found that early blight, *Alternaria solani* (E. and M.) J. and G., and tip-burn play a greater rôle than Phytophthora in the injury to the potato crop. Early blight is apparently not so common in the cooler and more uniform climate of northern Europe. Nor does one find there that tip-burn is as common as here, where high summer temperatures combine with the injuries of flea beetles and other insects to cause excessive transpiration and its consequent marginal burning of the leaves. Here also the logical line of attack seems to be the production of varieties possessing heat resistance.

[1] All references to literature are indicated in the text by the name of the author and the year of publication. For full citations, see the list at the end of this bulletin.

With the progress of pathological studies, other diseases were recognized in the United States, some of which, like the southern bacterial wilt or brown-rot (Smith, Erwin F., 1896), had doubtless been long prevalent, if not actually endemic, in the United States, while others, like the blackleg (*Bacillus phytophthorus* Appel and related forms), appear to have been recently introduced into this country from Europe.

APPEARANCE OF NEW TROUBLES.

About 1904 there began to come into prominence a group of potato diseases hitherto not generally recognized as of economic importance. In that year there was published by Smith and Swingle a bulletin which described a wilt and dry rot due to *Fusarium oxysporum*, found in the District of Columbia, Michigan, and elsewhere. This was the first important work of the sort in the United States, though a disease that was very likely the same Fusarium wilt was mentioned by Clinton in 1895 as "bundle blackening of tubers." No mention was made of its relation to any disease of the plants, and it was considered "not a very serious malady." The cause was said to be a fungus "quite similar to" the one causing dry end-rot.

The disease described by Stewart (1896), and thought by Smith and Swingle to be probably the same, was stated by Prof. Stewart at a recent meeting of the American Phytopathological Society to be not due to a Fusarium.

In the year 1905 there occurred in Europe an outbreak of a disease which was named leaf-roll (Blattrollkrankheit). This recurred in 1907 with such virulence as to excite general alarm, and the attention of many pathologists and other agricultural workers was directed toward its study and prevention. Leaf-roll has continued to cause heavy losses in Germany, Austria, and elsewhere, though it has not become as generally destructive as was feared. Its nature remains a subject for debate. In the early years its resemblance to the American disease described by Smith and Swingle led to the general adoption of the theory that it was due to or associated with a Fusarium. The evidence on this point was very contradictory, and there have developed nearly as many opinions as there are investigators.

In America little was done after the work of Smith and Swingle until 1908, when an outbreak in an important potato district in California was studied by the present writer and found to be the same Fusarium wilt (Orton, 1909).

The writer continued his survey of the country in 1909 and 1910, finding the Fusarium wilt very widespread. In 1911 he studied potato diseases in Europe with the particular purpose of comparing the American Fusarium wilt with the European leaf-roll disease.

In the same year there occurred in eastern Colorado, western Nebraska, and adjacent districts a very serious outbreak of a potato disease which was at the time locally attributed to Fusarium (Fitch, C. L., in numerous newspaper articles).

The many discrepancies and confused points in the description of these diseases as presented in the European literature, in comparison with American conditions, were further cleared up by the study in 1912 of disease phenomena in a collection of seedling varieties grown in Maine and New York by Prof. William Stuart, of the Bureau of Plant Industry. Pure types of several of these troubles were presented, thus greatly facilitating their diagnosis and differentiation.

A visit to several other potato centers in Wisconsin, Minnesota, Colorado, Utah, Idaho, and California assisted in verifying the conclusions reached, which are given in detail in this bulletin.

Briefly stated, it appears that several distinct diseases have been confused to a greater or less degree by both American and European writers, and the widely differing opinions and results are due to the fact that none of the investigators had seen conditions in all the countries. In particular, the American and European troubles had not been compared.

In the present article several types of disease are to be distinguished as of some importance, at least in the United States, viz:

Fusarium wilt.—A disease characterized by the wilting or prematuring of the plant, accompanied by a browning of the vascular bundles of stem and tuber, which are infected by *Fusarium oxysporum* (Schlecht) Sm. and Sw. Widespread in America, but not yet identified from Europe.

Verticillium wilt.—A wilt resembling the foregoing, often more rapid and with fungus mycelium higher in the stem. Due to *Verticillium albo-atrum* Reinke and Berth. Described by Reinke and Berthold in 1879. Present in both America and Europe.

Leaf-roll.—An inheritable disease marked by rolling of the leaves, reduced yield, and other symptoms. Probably not due to a parasite. Common in Europe and lately appearing in America (Blattrollkrankheit).

Curly-dwarf.—An inheritable, nonparasitic trouble in which dwarfing of the vascular elements is a prominent characteristic. Found in Europe and America (Kräuselkrankheit).

Rosette.—A stunted or dwarfed condition of the potato associated with injuries of the underground stems and roots caused by the fungus Rhizoctonia; most conspicuous in the western United States.

Mosaic.—A pathological condition marked by a mottling and distortion of the foliage. Not previously described, but present in Europe as well as America.

It is not unlikely that future studies will enable us to add still other diseases to this group, and it may become convenient to differentiate more types of leaf-roll and of curly-dwarf from within the rather wide limits established in this paper.

The disease described by Appel as bacterial ring disease should be mentioned. It appears that in Germany this was formerly confused

with the leaf-roll group, but the writer has not seen this disease and has been unable to arrive at a satisfactory conclusion concerning its relationship to any known American trouble. The causal organism has not yet been properly described.

A second bacterial disease of German potatoes is referred to by Spieckermann (1911) as different from Appel's ring disease. This the writer saw at Muenster and found to be unlike any of the well-known American diseases.

FUSARIUM WILT.

DESCRIPTION OF DISEASED PLANTS.

The distinctive characteristics of this disease are a rolling or wilting of the leaves, premature death of the foliage, and the occurrence of the fungus *Fusarium oxysporum* (Schlecht) Sm. and Sw. in the lower part of the stem, in the stolons, and frequently in the tubers also.

In detail, the appearance of potatoes attacked by Fusarium wilt varies according to the severity of the infection, the age of the plants, and the variety.

The time of onset varies with the degree of infection. Where diseased seed stock has been used, there is often defective germination and an irregular stand of plants of uneven size. As a rule, however, the disease is not noticeable till the plants are a foot or more high, and in most cases it does not become generally prevalent till midsummer, while it is characteristic of moderate infections that the plants die only two or three weeks in advance of their normal time of maturity.

Wilting of the foliage is to be observed in the more rapid types of the disease, but is less marked than in some other Fusarium wilts, such as that of watermelon, for instance.

The name "wilt" has been retained because it is in common use for this and related maladies, though the name "Fusarium blight of potatoes" has also been applied. The foliage symptoms may be described by either term. They are those of a plant whose water supply has been gradually shut off by fungus invasion of the lower stem.

The lower leaves droop and die first, the upper ones wither or wilt, and the entire plant dies prematurely. (Pl. I.) The leaf-roll that accompanies wilt differs from the true leaf-roll in that the former lacks turgidity and the leaves die within a few days.

The color of plants in the first stages of wilt may be a lighter green than is normal. This frequently turns to yellow, especially if the progress of the disease is slow, when the entire plant becomes yellow and the field takes on a very spotted appearance. It is different with the true leaf-roll, where the yellowing is, in the American types, more confined to the upper leaves and is accompanied on many

varieties by reddish or purplish tones, which the writer has not observed with Fusarium wilt.

OCCURRENCE OF THE CAUSAL FUNGUS.

In the stem.—The lower portions of the potato stems show a brown discoloration, which extends throughout the underground portion and for several centimeters in the aboveground stems. The brown color is by no means as pronounced as in cotton wilt or in the Verticillium wilt of potatoes, nor does it extend upward through the whole stem and branches, as in the two other wilts mentioned. The Fusarium conidia are not formed in such abundance on dying or dead stems as those of other wilt diseases.

Microscopic examination shows the presence of mycelium in most of these browned stems, and cultures yield for the most part a single species of fungus (*Fusarium oxysporum*), though other Fusaria occasionally develop in advanced stages of wilt and bacteria as well, as might be expected in such moribund tissues. These other Fusaria have not been found to be uniformly associated with wilt, nor are they inhabitants of the vascular bundles, like *F. oxysporum*. A sharp distinction may be made between this typical and widespread wilt and the infrequent cases where other fungi which have entered through wounds or cracks have so injured the hypocotyl that a wilting of the foliage results. For example, Jamieson and Wollenweber (1912) produced a decay of potato stems followed by wilting of the foliage through inoculations with *F. tricothecioides*, but these writers do not believe or suggest that this fungus causes wilt in nature.

The amount of fungus in the vessels of the stem and the degree of discoloration varies, but not always in proportion to the effect on the life of the plant. It is not uncommon to find prematurely dead hills in infected fields which show comparatively slight vascular browning, while others remain living, yet when examined they prove to have both stems and tubers heavily infected with *Fusarium oxysporum*. This apparent resistance may be explained by the fact that such hills are either accidental admixtures of later varieties, or bud sports, called "run-out hills." In either case they are plants that remain in an active vegetative condition longer and thus resist the effects of the wilt. Still other hills are to be found which remain healthy till the normal time for maturity and are also free from fungus infection, thereby supporting the hope that resistant strains may be developed by selection. Unfortunately, the experiments have not yet demonstrated that these hopes can be realized, for all of the numerous selections made were attacked by wilt the following year. This work was done at Middle River, Cal., in 1909 and 1910, principally with the Burbank variety.

In contrast with the slow-developing cases described, one finds many hills where there is actual wilting and rapid death of the plants, due to the water supply having been cut off by the fungous mycelium in the vascular bundles. Weekly examinations of fields during August and September show that the plants are dying prematurely and in increasing numbers as the season advances.

It will be brought out later in describing leaf-roll that the latter does not cause such a rapid and early death as the wilt, but that plants showing distinct symptoms of leaf-roll in June may live till harvest time.

In the root.—The fungus appears to enter through the smaller roots, and there are some indications that its injuries to the feeding roots are the cause of the dwarfed and checked development of the plant during the early stages of the disease. As a result of partial destruction of the roots, the plants are easily pulled up, and the roots are partly dead and brittle. As Smith and Swingle (1904) write:

> All the smaller roots are so friable that they can be broken with almost no effort, and some can even be rubbed to pieces between the thumb and finger. The main root also is much more tender and brittle than that of healthy plants, and this condition extends nearly to the line marked by the surface of the ground. Such diseased roots are usually covered with a white, pink, or even reddish growth of mycelium, which is distributed very unevenly and is much more conspicuous in some places than in others. Microscopical examination shows that this mycelium invades all parts of the root, though the bark is most affected.

It is possible, and from some recent observations it seems quite likely, that some of this root injury is due to secondary invasion of other species of fungi.

> The underground stems on which the tubers are borne are nearly always attacked, but they do not as a rule become so soft and brittle as roots of the same size. The mycelium passes through the whole extent of these underground stems into the base of the tubers.

In the tuber.—The infection of the tubers by the Fusarium is in well-marked cases almost universal. This is evidenced by the distinct browning of the vascular ring shown when tubers are cut across at the stem end (Pl. II, fig. 1). From these browned vessels *Fusarium oxysporum* can readily be isolated. To quote again from Smith and Swingle (1904):

> Numerous cultures made from the extreme ends of the discolored portions of the bundles very seldom failed to develop the fungus. These cultures were made by carefully paring especially favorable pieces of diseased tubers with a hot scalpel, heating it nearly to redness before each stroke and cutting out pieces a few millimeters in diameter, containing a length of about two millimeters of the extreme end of the discolored part of the bundle. These pieces were cut from the main part of the specimen with the hot scalpel and allowed to drop directly into a tube of sterile culture media. Potato cylinders were used principally for media. Slant tubes of beef agar (+15 on Fuller's scale) also were sometimes used. One hundred and twenty-two

cultures on potato and sixteen on agar were made, and in all but two cases on the potato and in every case on the agar the fungus appeared after a day or two as a white mycelium, sparse at first, growing directly out from the blackened bundle, and spreading into the media. Forty-two cultures on potato and four on agar were also made from older parts of the discolored ring nearer the basal end, and of these all but one on the potato and all on the agar produced a growth of the fungus.

The relation of these tuber infections to stem-end dry-rot will be described more fully in another publication. A dry-rot of the tuber was considered by Smith and Swingle to be caused by the same Fusarium which produces the wilt of the foliage, but the recent studies of Wollenweber (1913) have shown that *Fusarium oxysporum* is a vascular parasite causing wilt and wintering over in the tubers, where it produces a stem-end vascular discoloration, but no decay. Tuber dry-rot is caused by one or another of the following fungi, which follow *F. oxysporum* or infect through wounds, viz: *F. coeruleum* (Lib.), *F. trithecioides* Wr., *F. discolor* var. *sulphureum* Schlecht, *F. ventricosum* App. and Wr.; and probably sometimes also the less parasitic *F. gibbosum* App. and Wr., and *F. subulatum* App. and Wr.

SOIL RELATIONS OF FUSARIUM WILT.

The Fusarium wilts of cotton, watermelon, and cowpea occur principally on sandy and sandy-loam soils and are practically restricted to them. That such is the case with the potato wilt is by no means clear, though there is evidence indicating that light soils are more liable to infection. The California tule lands, where wilt is perhaps more prevalent, are reclaimed and artificially drained peat islands, with a very light and friable soil, composed almost wholly of organic matter. In Oregon, Utah, and Colorado, however, wilt occurs on heavier soils, varying from sandy loam to clay loam. Potatoes thrive best in light, deep, and well-drained fertile soils, and it appears that the wilt is more likely to develop in any such good potato soils than under conditions unfavorable to the crop.

THE PARASITISM OF FUSARIUM OXYSPORUM.

That the fungus *Fusarium oxysporum* is parasitic upon the potato plant has now been proved with reasonable certainty. Smith and Swingle established the fact of its constant occurrence in the vascular tissues of plants suffering from the wilt disease, by means of very numerous pure cultures. No inoculation experiments were undertaken by them, but successful infections have since been reported by Manns (1911) from the Ohio Agricultural Experiment Station, and cultures of the Ohio strain have been studied by Dr. H. W. Wollenweber in comparison with a large number of others isolated from collections made by the writer from different parts of the United States or sent in by correspondents, and nearly all have proved to be the species we continue to call *F. oxysporum* Schlecht.

POTATO FUSARIUM WILT. A FRESHLY WILTED PLANT. (AFTER SMITH AND SWINGLE.)

FIG. 1.—STEM-END BROWNING OF POTATOES DUE TO FUSARIUM OXYSPORUM. TUBERS FROM WILTED PLANTS, BURBANK VARIETY, MIDDLE RIVER, CAL.

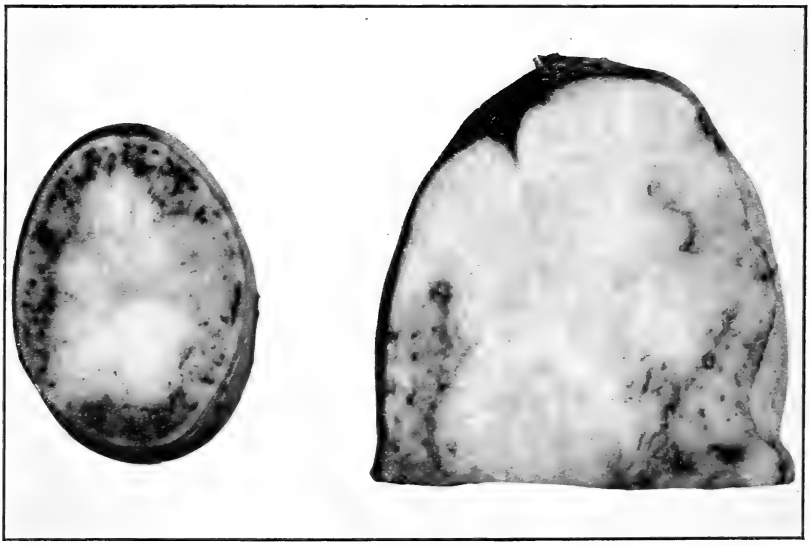


FIG. 2.—NET NECROSIS OF POTATO, SHOWING NONPARASITIC INTERNAL DISCOLORATION OF TUBERS.

The point of view toward the genus Fusarium has changed greatly since 1904. At that time Smith and Swingle reviewed all species of Fusarium that had been described as occurring on the potato and concluded that as far as the description went it was impossible to distinguish these from each other or from the cause of wilt. They therefore took the oldest name, *Fusarium oxysporum*, for their species and considered the others, including *F. solani*, to be synonyms. A little later, when the relation of Fusarium to leaf-roll was taken up by Dr. O. Appel, of the Kaiserliche Biologische Anstalt in Dahlem, Berlin, he caused to be inaugurated some morphological studies based on his conclusions that, up to the present, mycologists had not described Fusarium species in a way that permits their reidentification; that the insufficiency of the characters utilized for systematic description had led to a widespread belief that the genus was exceedingly variable, and that they had been differentiated by their host or substratum to too great an extent.

Appel therefore concluded that before a proper study of Fusarium diseases could be made it would be necessary to learn more about the fungi and to be able to distinguish the species with certainty through their morphological characters. Much progress has been made in this direction through the work of Appel and Wollenweber (1910), whose monograph has laid the foundation for the separation of the species by their morphological characters. Further publications by Dr. Wollenweber have thrown still more light on this hitherto confused problem. (Wollenweber, 1913.)

It has already been found that the Fusaria are not so variable as was formerly thought. Artificial cultures lend great help in the work of identification, in which many characters are utilized which had been previously neglected, viz: The character of the curvature of the conidia, constancy of septation, development of the basal and apical cells of the conidia, etc.

It has also been shown that the pure cultures must be grown on such media as will produce a normal development of the fungus. Agar, for instance, is poorly adapted for the culture of Fusaria, as it tends to produce constricted conidia. Vegetable media are best, as a rule, and many plant stems are especially favorable for the development of conidia and sporodochia in a normal manner.

A culture derived from mycelium gives a less normal culture than one from conidia and must be grown till spores are produced to start new and typical cultures. Young cultures are not favorable for morphological study, as they contain many abnormal forms. Neither are old cultures good, as they exhibit hunger forms not typical of the species.

For these reasons many substrata must be tried and the cultures grown to their best development, designated by Dr. Wollenweber as

a "high culture." Color differences of both spores and mycelium are to be noted, and for the latter purpose potato cylinders and rice are excellent.

The final result of this line of work will be a great simplification of the Fusarium problem. The number of species in the genus will be diminished and the parasitic forms can be identified, for the most part, by their morphological characters. It has been found that the genus is divisible into sections, on the basis of form of conidia and other morphological characters, and that all of the wilt parasites are included in the single section, Elegans. Thus far *Fusarium oxysporum* appears to be the only Fusarium causing potato wilt; and, as already stated, this is not connected with the dry-rot of tubers, which may be due to one or another of four or more other Fusaria. The diagnosis of these tuber troubles will be treated more at length in another publication.

CLIMATIC RELATIONS AND GEOGRAPHIC DISTRIBUTION OF FUSARIUM WILT.

Fusarium wilt is apparently a disease of warmer climates. States like California and Arizona, with high summer temperatures, and the middle States, Ohio, Missouri, and Nebraska, which are near the southern border of profitable main-crop potato culture, suffer much more than the States of the northern border, where wilt is, at least, uncommon. Most of the Fusarium wilt diseases of other crops are southern in their range. Owing to the fact that other species of Fusarium, such as *Fusarium coeruleum* and *F. discolor* var. *sulphureum* also occur in the Northern States and have not hitherto been clearly differentiated from *F. oxysporum*, there is some doubt as to the actual range of the latter, especially in New York and New England. Going westward, the wilt fungus is found farther north, and it is likely that the disease will continue to spread northward.

In the States from New Jersey and Maryland southward to Florida and westward to Texas the Irish potato is relatively a minor crop, except in the trucking districts, where planting takes place in winter or early spring, and the harvest for the northern markets occurs from April to July, generally in advance of maturity. Fusarium has never played a visible rôle in these early crops, but has been found in the second or fall crop.

As already stated, New England and New York are relatively free from the disease. Suspected cases there have generally proved to be the Verticillium wilt. The conditions in Pennsylvania are not as well known to the writer, but are probably not far different from those in Ohio, where Selby and Manns have found wilt to be widely distributed. The latter says:

> In this Fusarium blight we have the most persistent and destructive disease factor with which the Ohio potato grower has to contend. Its subtle work in the past, though

greatly reducing our yields, has been entirely overlooked. The seed potatoes throughout Ohio are infected to a much greater extent than would have been supposed. This indicates that much of our potato land is already carrying the fungus to a greater or less amount, and as a result our yields are probably being reduced considerably. (Manns, 1911.)

The writer has found many Michigan fields infected with wilt. The original material studied by Dr. Erwin F. Smith also came from this State. In Illinois and southern Wisconsin and in Minnesota wilt appears to be present in the older communities, where potatoes have long been grown, but in the newer districts of Wisconsin and Minnesota the growers still have an opportunity to protect themselves against this danger.

There are important potato districts in western Nebraska where Fusarium wilt occurs, although the leaf-roll and the powdery dry-rot (*Fusarium trichothecioides*) are also factors there. (Orton, 1913.) All the older irrigated districts of the West are infected, and the newer ones are rapidly becoming so, with the possible exception of the higher and cooler valleys, concerning which definite information is lacking at present. The wilt has been long present in Colorado and caused much injury, especially when attempts were made to grow two or three successive crops of potatoes. In Utah it is much the same, and the newly opened districts in Idaho are rapidly introducing the fungus in seed potatoes brought from older localities. Nor is the wilt confined to the irrigated parts of the West. It also occurs on the "dry farms," and is not the least of the problems which the settlers in these areas have to solve. The potatoes at the field station of the Bureau of Plant Industry at Akron, Colo., have been attacked by wilt for several years and the yield much diminished.

It is, however, in potato growing under irrigation that wilt plays the largest rôle. These lands are all high priced, from $200 an acre up. The farmer has to carry fixed charges in the way of interest, water rents, irrigation bonds, and the like that make it necessary for him to grow a crop more remunerative than grain or alfalfa. Sugar beets and potatoes are, in most cases, the only crops that answer this requirement in these districts. The farmers naturally desire to grow potatoes as frequently as possible, but are prevented from doing so by the wilt, which forces a rotation.

In California wilt is the principal factor limiting the production of potatoes in the famous delta district of the San Joaquin Valley (Orton, 1909). Here the reclaimed moor, or tule, soils are wonderfully productive when first planted, but the yield of potatoes falls off with each succeeding crop until very small yields are secured unless rotations with barley or other crops are practiced. The potatoes from these diseased fields show almost universal infection with *Fusarium oxysporum*, which is there the principal, if not the

sole, cause of the early maturity and diminished harvests. This tule land for potatoes commands a cash rental of $20 to $25, while for barley growing only $8 to $12 is paid, but after the second crop of potatoes the less profitable crop must intervene (Irish, 1913).

One of the leading potato districts north of California is the Willamette Valley, in Oregon. Here wilt is present to a serious extent. During visits in 1909 and 1910 the writer saw fields liberally dotted with yellow and dying plants. This valley furnishes most of the seed potatoes brought into California, and inspection of such potatoes has revealed much stem-end browning.

It is certain that the Fusarium wilt is a nation-wide problem and one that will have a marked influence upon American agriculture. At present it causes losses which probably run into millions of dollars; but, if in the end the growers are forced to adopt better rotation systems, who shall say that the final influence of this disease factor may not be beneficial?

Estimates of the money losses from Fusarium wilt must be largely speculative, as so little exact information is available. At the Ohio experiment station in 1909 the result of the disease was that "the station plats averaged 69 bushels per acre and the county averaged 186 bushels. The preceding 4-year average for the station was 180 bushels, while that for the county was 101 bushels." The county was also infected with wilt, as the same writer shows; but, disregarding this and the fact that the station yield should have been nearly double the county yield, and estimating that only 5 per cent of Ohio fields were as badly affected, the loss totals over 870,000 bushels for Ohio alone.

CONTROL OF FUSARIUM WILT.

The problem of control has not yet been worked out for Fusarium wilt. The most promising lines of attack are three: (*a*) A healthy seed supply, (*b*) rotation of crops, (*c*) the development of resistant varieties.

The use of Fusarium-infected seed should be avoided even where the disease is already in the land. It not only increases the severity of the wilt trouble, but gives defective germination. Failures due to decay of the seed potatoes after planting are especially frequent in the West, as, for example, in Colorado in 1908 and in California in 1912. These are attributed to Fusarium, but the recent studies of Wollenweber show that *Fusarium oxysporum* does little more than lower the vitality and afford an entrance for other organisms which destroy the seed potatoes after planting. *F. trichothecioides* in the West and *F. coeruleum* in the East are the best known of these tuber-decay producers. To what extent other organisms are involved remains to be determined.

TESTS FOR FUSARIUM INFECTION OF SEED POTATOES.

The most effective method of selecting seed stock free from wilt is to examine the fields where it is being grown as late as possible in the autumn, but before the foliage has died down or been frosted. The wilt is more readily detected at this time than at any other through the premature ripening or actual wilting which it causes, coupled with the characteristic brown discoloration of the woody part of the lower stem.

Another indication much relied on is the browning of the vascular ring shown when the stem ends of the tubers of diseased plants are cut off. (Pl. II, fig. 1.) This is an important test to apply, and it is an excellent rule to reject for planting purposes all lots of potatoes any considerable number of which show such a ring discoloration, as some other diseases produce a similar effect.

It is desired to emphasize here, however, that not all tubers from infected fields show stem-end browning. The writer has hundreds of times observed tubers from wilted hills which showed no discoloration or only a very slight one. The fungus had apparently not gone far in its usual course down the stolons and into the tubers, yet the fields were thoroughly infected, and the circumstances warranted grave doubts as to the value of such tubers for planting. It is probably inadvisable to endeavor to select, for seed purposes, from stock containing a large percentage of infected potatoes, any fungus-free tubers on the basis of this stem-end test when it is at all feasible to secure for planting potatoes entirely free from suspicion. As a practical farm procedure, however, growers should be urged to discard all stem-end pieces which show any brown stain, and it is likely that the greater part of the infection would be avoided if the stem ends of the seed tubers were cut off and not planted.

Some confusion may result in the application of this stem-end browning test by those unfamiliar with the subject, on account of difficulty in distinguishing in certain cases a natural browning in many potato varieties, like Irish Cobbler, for example, which have a deep depression at the stem end into which the stolon fits. The cork layer in these varieties may be bared by a shallow section through the stem end and show a brown color quite natural to the variety.

It is necessary to cut deep enough to reach below the point where the vascular bundles diverge from the stolon to form the tuber ring. Any browning at this point is highly suspicious, but not positive proof. The weakening of the plant by leaf-roll or other diseases may hinder the formation of a cork layer at the stem and permit the entrance of saprophytic fungi which produce a discoloration. The discussion of this point in the European literature on leaf-roll will be of interest.

That parasites other than *Fusarium oxysporum* also produce stem-end browning has already been mentioned. *Verticillium albo-atrum* can often be differentiated by an experienced eye by the blacker and deeper discoloration, though the plant symptoms give a better basis for the diagnosis of this disease also. A stem-end browning is found in the late stage of blackleg, *Bacillus phytophthorus* Appel, etc., and of brown rot, *B. solanacearum* Erw. Sm., diseases hardly less dangerous than wilt.

Mention should also be made of a form of internal browning that has been known to the writer for five or six years. It may be confused with Fusarium ring discoloration, though it is probably more closely related to the physiological trouble, internal brown-spot. The term "net necrosis" has been suggested for the disease by Dr. H. W. Wollenweber. It is characterized by the occurrence of narrow streaks or dots of browned tissue outside of the vascular ring and extending from the stem end into the tuber for a considerable distance or entirely through it. (Pl. II, fig. 2.) These brown tissues are free from fungi or bacteria. The cause is unknown. A fuller description will be published soon.

The final conclusion of the writer on this point is that tuber-ring discoloration, if clearly marked, should cause the rejection of potatoes for seed purposes, but that negative results from cutting tubers are less valuable as proof of freedom from wilt than a field inspection in autumn. A system of official certification of freedom from wilt and other diseases would be of great value, if based on such field observation.

SOURCE OF SEED POTATOES.

In all probability, the best seed for areas possessing a climate where potatoes retain their vigor without renewal for long periods, is that of the home locality. In many districts, however, and particularly those in the Central and Southern States, it is necessary to bring in seed from northern sources. Many western districts seem to have the same need, particularly those where Fusarium wilt already prevails, and have not yet discovered a source of seed as satisfactory for them as New England seed is to the South. There must be developed somewhere in the West communities where growing seed potatoes will be a special industry and where every means will be taken to produce a perfectly healthy article. The accomplishment of this aim well merits attention from a cooperative association of buyers and seed growers.

CONTROL OF WILT THROUGH ROTATIONS.

Rotation of crops appears to be the most effective means for lessening the injuries from Fusarium wilt. What is known regarding the effect of rotation is from observation and general farm experience

rather than the result of definitely planned and carefully controlled experiments. There is great need for such experiments.

In the San Joaquin district of California the principle is found to be established that potatoes yield better after rotation with barley. In no case known to the writer has the Fusarium wilt been eliminated by rotation, but it seems that the amount of infection diminishes after a few years to a point where a potato crop can again be grown. In Ohio a 3-year rotation was not sufficient to prevent a general epidemic on the station plats.

A rotation of five to eight years could, however, be readily practiced in all districts, except those where the potato is the sole money crop, and it is believed that such a rotation would make the losses from wilt negligible.

The infection of the ground through potatoes left in digging is a factor to be considered, and in warm climates like California, where such potatoes grow as volunteers for one or two seasons or longer, the disease is steadily carried over. Some means of ridding the land of such potatoes seems necessary.

RESISTANCE OF VARIETIES TO WILT.

The results of variety tests of potatoes to date offer hope that the future may give sorts resistant to Fusarium wilt, but there are none at present that can be recommended as adapted for commercial cultivation. There are now under trial in the Bureau of Plant Industry several thousand seedlings, the best of which will later be tested for resistance to this disease.

EFFECT OF FERTILIZERS ON WILT.

Smith and Swingle made rather extended experiments on the effect of fertilizers on wilt, with results that were entirely negative. Nothing has since been observed that would materially support the suggestion that the disease may be connected with a deficiency of any element of plant food. It occurs in some of the richest western soils, both irrigated and nonirrigated. In California the soils were almost pure organic matter, and the reduction in yields that followed the appearance of wilt was at first attributed to soil exhaustion, but the fungus factor is fully sufficient to explain the results, and fertilizer experiments that were made by the writer gave negative results. Further work along similar lines has been reported by Irish (1913).

QUARANTINE MEASURES.

In connection with the seed problem, there comes into consideration the desirability of keeping the disease out of those districts where it does not yet occur. Does this warrant quarantine restrictions by State or Federal authorities? Would such a quarantine be effective?

It is the writer's opinion that under present conditions this is not a quarantinable disease. It is very widely distributed in the United States, as already shown. It would be difficult to establish the boundaries of infected areas, and almost impossible to apply quarantine restrictions without serious injury to commerce. Nor is it certain that the aim desired would be accomplished in this way. There are so many avenues for the spread of plant diseases that it often seems as if only ocean barriers were of avail. (Lounsbury, 1909, 1910.)

OCCURRENCE OF AMERICAN FUSARIUM WILT IN EUROPE.

The bulletin by Smith and Swingle had its influence on European pathology, inasmuch as the leaf-roll epidemic, which began in 1905, was at first believed to be a Fusarium disease. The fact that none of the European workers had seen the American disease and that no American pathologist familiar with wilt had seen the leaf-roll in Europe led to further confusion.

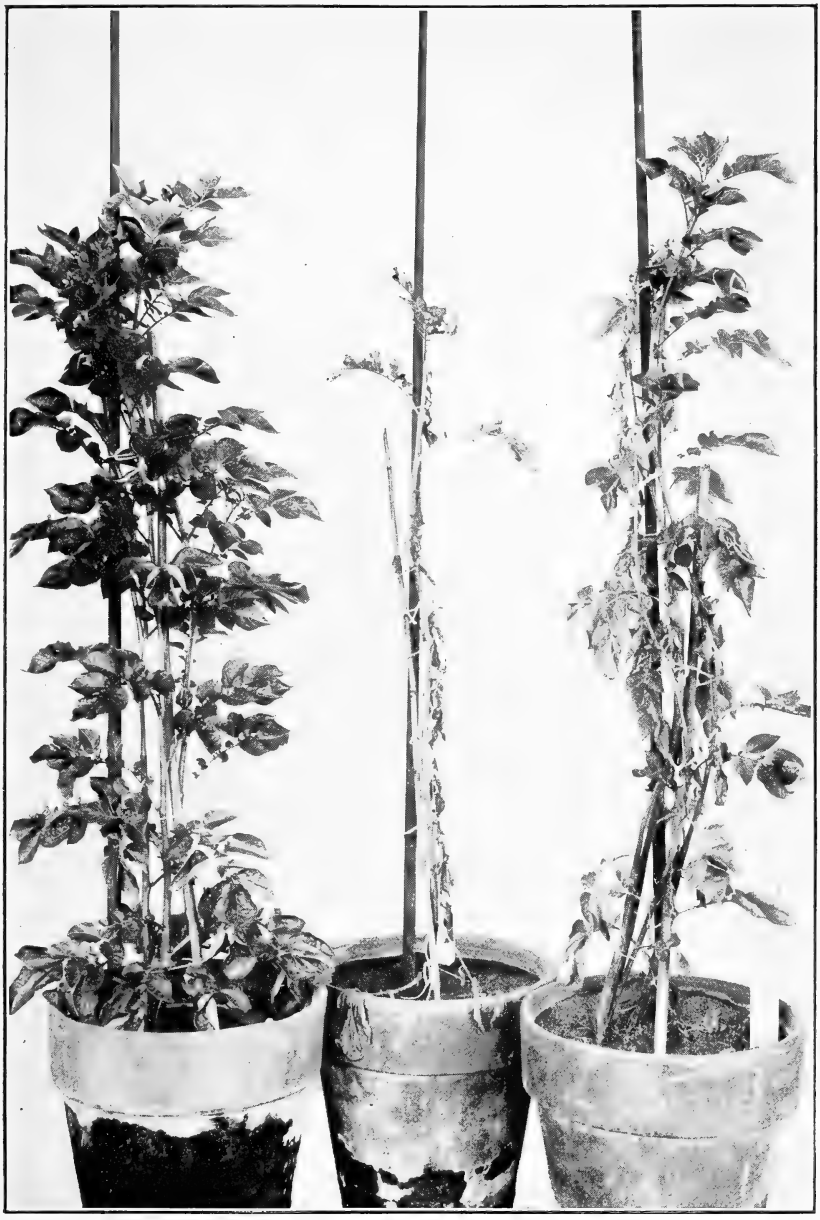
The writer now believes that there is no evidence that the American wilt disease occurs in Europe. This statement is based on observations made in the course of a study trip through Germany, Austria, and England in 1911. No cases of typical Fusarium wilt were seen. Furthermore, Dr. Wollenweber, in the morphological studies later mentioned, has been able to differentiate the *Fusarium oxysporum* of Smith and Swingle from other potato Fusaria, and he finds this to be distinct from any European form. Inasmuch as he studied critically the Fusaria isolated from leaf-roll material while at Dahlem, Berlin, this result is very significant and goes far to explain the difficulty German workers have had in verifying the observations of Smith and Swingle. Himmelbaur (1912) reports Fusarium to occur in much of the leaf-roll material studied by him in Austria, but he has not identified the species, and until this is done his results can not be correlated with the results of American workers.

VERTICILLIUM WILT.

DESCRIPTION OF THE DISEASED PLANTS.

The Verticillium wilt of potatoes is characterized by a wilting or blighting of the foliage, resulting in the premature death of the hill. The vascular bundles of the stem, the stolons, and usually of the tubers, are filled with the mycelium of *Verticillium albo-atrum*. The spores of this fungus often cover the dead stalks, so that they become conspicuous from their gray color.

As observed by the writer in this country and in England in 1911, plants attacked by Verticillium wilt generally die quickly. There may be yellowing of the foliage, but the drooping and wilting has been pronounced in most of the cases observed. The Verticillium wilt

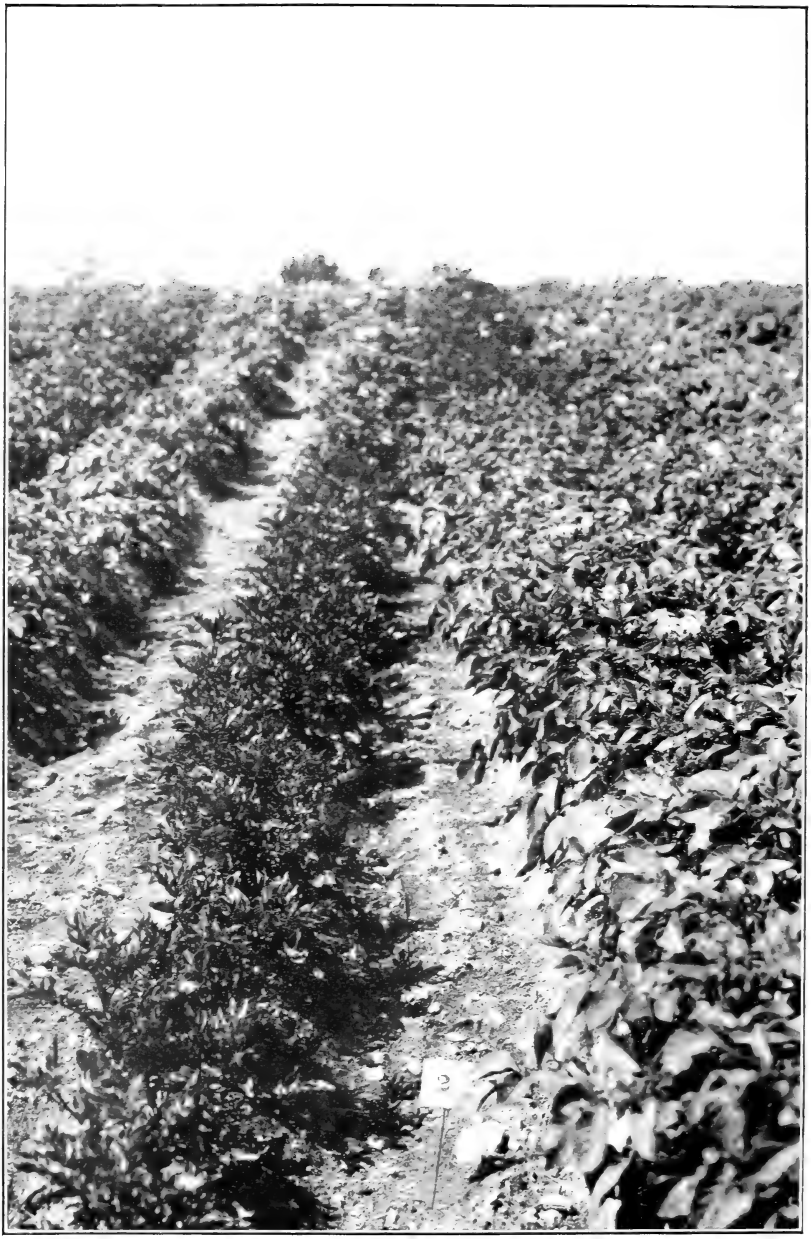


VERTICILLIUM WILT OF POTATOES IN GREENHOUSE. CENTER AND RIGHT-HAND PLANTS INOCULATED WITH PURE CULTURES OF VERTICILLIUM ALBO-ATRUM; LEFT-HAND PLANT HEALTHY, NOT INOCULATED.

FIG. 1.—TYPICAL POTATO LEAF-ROLL IN SEEDLING NO. 16472, ALEXANDER NO. 1 RED × KEEPER. HOULTON, ME., AUGUST, 1912.

FIG. 2.—POTATO LEAF-ROLL. ADVANCED STAGE IN SEEDLING NO. 304, GEHEIMRAT THIEL × KEEPER. HOULTON, ME., AUGUST, 1912.

POTATO LEAF-ROLL. PLANTS OF SEEDLING NO. 2171, SOPHIE × KEEPER. HOULTON, ME., JULY 29, 1913.



POTATO LEAF-ROLL, SHOWING ENTIRE ROW, NO. 2171, SOPHIE × KEEPER, STRONGLY AFFECTED, WITH ROW NO. 2165 (AT THE RIGHT) AND OTHER ADJACENT ROWS HEALTHY. HOULTON, ME., JULY 29, 1913.

seen in Germany appears to be slower in causing the death of the plants, a difference possibly attributable to temperature and rainfall factors. The browning of the vessels is also marked, often extending to the tips of the stems and into the leaf petioles. There has been also a pronounced discoloration of the stem end of the tubers in all the cases observed.

Verticillium wilt is often not strikingly different from Fusarium wilt in outward appearance, though it may induce a more rapid wilting. The presence of the mycelium and vascular browning in the upper portions of the plants is indicative of Verticillium, as Fusarium does not usually extend into the tips of the stalks. The profuse production of conidia on the stalks, often before they are entirely dead, is still more characteristic. The stain in the stem end of the tubers is blacker, and in cross sections under the microscope the vascular bundles are found to contain hyaline mycelium smaller than that of *Fusarium oxysporum*. The final proof of the identity of the disease comes, of course, when cultures made from the internal mycelium yield *Verticillium albo-atrum*.

So far as observations go, Verticillium wilt occurs in scattered hills here and there over the fields. The destruction of entire crops, such as is frequently caused by *Fusarium oxysporum*, has not been seen.

GEOGRAPHIC DISTRIBUTION.

Verticillium wilt has been collected by the writer since 1909 from the State of Washington (La Conner) to Maine, but only in the more northern States. It has been seen in Vermont (Franklin County) and western New York, but in neither case in abundance. The varieties most attacked were Factor and Up-to-date, from seed originally from England. It is believed that the Verticillium infection came with the seed potatoes. The same fields planted to other varieties in 1913 were free from wilt on August 1 and 4.

The writer collected the same disease in Olmskirk, England, September 11, 1911, and the fungus was isolated from a tuber (said to have come from Scotland) found in Reading, England. Its occurrence in Ireland is vouched for by Pethybridge (1911). It appears to be common in Germany, judging by the frequency with which it is mentioned in connection with leaf-roll investigations there. Indeed, it was described by Reinke and Berthold as long ago as 1879, and the writer saw it at Munster in Westphalia in October, 1911, where it was studied by Spieckermann (1911), who pointed out the difference between this wilt and the fungus-free leaf-roll. Verticillium wilt is apparently a northern disease as compared with Fusarium, though the ranges of the two undoubtedly overlap.

Pethybridge (1911) in Ireland describes this disease under the name "leaf-roll," distinguishing it from "curl," the latter being the

trouble here described as "curly-dwarf" (Kräuselkrankheit). He emphasizes the rolling of the leaves, but does not mention that they wilt. The discoloration of the vascular bundles of stem and tuber is remarked, and experiments are cited which show that the disease is transmitted through affected seed tubers.

The same author (1912) further illustrates the distinction between curly-dwarf ("curl") and leaf-roll, and reports having found cases of leaf-roll in which no Verticillium or other fungus was present. Tubers from such plants gave rise to healthy plants, whence it is concluded that the occurrence of the true leaf-roll in Ireland is not yet established.

These facts, together with his personal observation in Great Britain in 1911, led the writer to believe that no cases of true leaf-roll or of Fusarium wilt have yet been proved to occur in Great Britian, but that Verticillium wilt is not uncommon there.

Some confusion still remains concerning the parasitism of *Verticillium albo-atrum*, inasmuch as there are many reports of its occurrence where the marked pathological effects here described were not present. Reinke and Berthold report successful inoculations, and Wollenweber obtained infections in Friedenau, Berlin, which, in the light of his later work, are to be considered as added evidence of the parasitism of this species. The result of a later successful infection experiment performed by Wollenweber with pure cultures in the Washington greenhouse is shown in Plate III. The parasitism of Verticillium on other plants has also been demonstrated by him and will soon be published in full. It is not to be understood that the relatively minor rôle now played by Verticillium as a potato parasite in the United States indicates that it is a disease that should not be feared, for, if control measures are neglected, it might easily become epidemic and as destructive as the Fusarium wilt.

The disease should be easily brought under control, however, by seed selection and rotation of crops. Whenever a wilted hill is observed in a field it should be taken up and both vines and tubers carried out and destroyed. When cutting seed, any with a brown stain at the stem end should be rejected. When a field is much affected by this trouble, none of the crop should be used for planting, and the ground should be given a longer rotation than usual.

LEAF-ROLL.

LITERATURE OF THE DISEASE.

No plant disease in this generation has been the subject of such general discussion as that known in Germany as the "Blattrollkrankheit," herein named "leaf-roll." None has aroused greater difference of opinion as to its nature and cause, and no other single malady of plants is to-day receiving so much investigation by skilled

pathologists as this. Possibly no disease which has appeared since the advent of *Phytophthora infestans* in the forties presents a greater menace to potato culture.

The literature on leaf-roll has become so voluminous that few will undertake to peruse all the contributions, which are, indeed, of very uneven merit, and anyone who attempts it is likely to emerge with his concepts of the disease more confused and hazy than at the start.

This bulletin is intended as a guide in the diagnosis of leaf-roll and a summary of present knowledge. It is the result in part of the writer's personal investigations, but much is owed to other writers, and particularly to Appel and Schlumberger (1911), whose critical summary of the literature on this disease is commended to all readers.

DESCRIPTION OF LEAF-ROLL.

Leaf-roll is a disease characterized by an upward rolling of the leaves, by a decreased yield of tubers, and by transmission of the diseased condition through tubers planted. Its symptoms vary so much in detail that they can be most clearly outlined by separate treatment.

The rolling of the leaves is the most constant and conspicuous symptom of this disease. The leaflets curl or roll upward on their midrib, often assuming a nearly tubular shape, and giving a plant a staring appearance (Pl. VII). This rolling is sometimes restricted to the upper leaves, while in other cases all or nearly all of the leaves on the plant exhibit it. (Pl. IV, fig. 1, and Pl. V and Pl. VIII.) This type of roll is distinct from the curly-dwarf condition described on page 37, but a very similar roll may be induced by other causes, such as wet soil, blackleg, and other diseases, as shown on page 26.

The color of the foliage changes with the advent of leaf-roll, but these color-symptoms vary greatly, from cases where the leaves assume an unhealthy, light-green color to those marked by pronounced yellowish, reddish, or purplish colors. These variations appear to depend in part upon the severity of the disease, but they are also to a large extent varietal reactions. The Peachblow, for example, develops considerable red in the upper leaves while the Pearl under the same conditions turns yellowish green. In general, early stages of leaf-roll may not be much yellowed, while more advanced cases, and particularly those in the second or third year, i. e., grown from the tubers of diseased plants, are likely to be quite yellow with reddish or purplish tints. The development of reds and purples will probably be found to take place in the different varieties according to the natural pigmentation of the sprouts and stems. The greatest variety of colors could be observed in the several numbers of the collection of seedlings which became affected by leaf-roll. Appel and Schlumberger state of this color character that, according to the

variety, it tends to be yellow-green or more reddish. With some varieties there occurs also an almost violet color, as for example, in the German sort, Hetmann. The intensity of the color varies in different years, and it appears that dry seasons bring a more intense color than moist seasons.

The time of onset is early, as compared with Fusarium wilt. The first case observed by the writer in Germany was in Giessen about June 20. Reference to the German records will show that the date when leaf-roll is first observed varies in different years. In 1907, for instance, many varieties were strongly attacked as early as June 24, while in 1909 the corresponding date in July saw less leaf-roll in their experimental plants. The date when leaf-roll appears in this country is not well fixed. Growers in the Greeley, Colo., district, where late planting is the rule, report having noticed the rolling of the leaves late in July. Leaf-roll did not develop last year (1913) in the Mitchell (Nebr.) district until about August 15, whereas the preceding outbreaks had come much earlier.

The effect on the plant is to check development. There is a lessening or cessation of growth. The shoots remain short and the leaves stand more upright.

> In this respect varieties differ. The following show the staring growth very clearly: Magnum Bonum, Hetmann, Richter's Imperator, etc., while Daber shows it but little. On such stalks the leaves, flowers, and berries are frequently smaller. For example, the berries of Hetmann on badly diseased plants in 1908 were only the size of peas, while those from healthy stalks were the size of cherries. Badly diseased plants have often no tubers or only a few. Such plants are either very weak and die early or the foliage may be comparatively well developed and remain living to the end of the vegetation period. (Appel and Schlumberger, 1911.)

The different degrees of leaf-roll are also shown in the illustrations. Plate V shows large plants with the upper leaves strongly rolled, while the plant in Pl. IV, fig. 2, is small and weak and represents the last stage of leaf-roll, having doubtless come from a tuber produced by a diseased plant. There is, however, no such shortening of stems and leaf ribs as occurs in curly-dwarf, with its resultant deformation of the plant.

The duration of life of the plant in most cases appears to be shortened by leaf-roll. This is a relative matter, since (in comparison with healthy plants) the leaf-roll cases may die earlier, as would be expected of sick plants, or they may stand until killed by frost, while (in comparison with the rapid death of American potatoes attacked by Fusarium wilt) the endurance of leaf-roll is one of the striking differences between these diseases.

The endurance of the seed piece as a character of leaf-roll is an interesting point frequently mentioned in the German literature. When Schultz [Soest] (1905) called attention to the first outbreak of leaf-roll, he laid special emphasis on the fact that the seed tubers

planted were still firm and sound at harvest time and that they were even larger in size. This observation has been verified by others, and the endurance of the seed tuber is considered by Appel and Schlumberger to be one of the symptoms of leaf-roll, though they point out that this varies greatly on different soils. They further show that the enlargement of the seed piece is not a symptom of disease, but that the same thing occurs with healthy plants. The significance of these observations relative to the endurance of the seed piece has not been made fully clear, though the discovery of Quanjer that the phloem strands in the stems of leaf-roll plants are shrunken and lignified suggests that the seed piece remains because it can not be used up by the plant. Its endurance argues against the relation of parasites to leaf-roll, since if the disease were caused by fungi or bacteria at the root, one would reasonably expect the seed piece to be decayed. The writer is unable to state whether it is the case also in the United States that the seed piece endures longer with leaf-rolled than with healthy plants. Certainly sound hills are to be found with sound seed, and many leaf-rolled plants have been dug whose seed piece had decayed. According to the writer's observation, sound mother tubers are to be found as often in the curly-dwarf disease as with leaf-roll.

The effect of leaf-roll on the tubers is strongly marked. In general, the yield is very much reduced (Pl. XIII, fig. 1) Appel (1907) states:

> The growing apprehensions find their confirmations at the harvest. The diseased hills have numerous tubers very much smaller than normal, so that the yield is only about half that of a healthy field. If one uses these potatoes again for seed, the greater part fail to develop, and an uneven stand is the result. Others only germinate without sending their shoots through the earth, but branch below ground and form a considerable number of roots, so that frequently the seed tuber lies in a more or less thick tangle of roots and thin shoots. Stronger tubers succeed in growing, but the stem remains weak, the leaves are from the beginning considerably rolled, and, according to the variety, more or less colored. These colors are in this stage of all gradations from dark red to blue-red. Few or no tubers are found in such hills, so that a complete crop failure results.

Appel and Schlumberger (1911) say:

> Badly diseased plants have often no tubers or only a few. When there is a setting of tubers, these are almost always very small. They are borne frequently on shortened stolons, or clustered on the underground part of the stem. This shortening of the stolons is occasionally very commonly observed, as for example, in 1908, in Eisgrub with the varieties Eduard Lefort and Long Six Weeks. This character is, however, not constant. More often hills occur where the stolons are normally developed but bear a great number of small tubers the size of hazelnuts.
>
> A striking circumstance which must here be given special attention is that slightly diseased hills under certain conditions give an exceptionally high yield, which, however, falls rapidly in succeeding years. Such an example was afforded by the variety Modell during its cultivation in Grobzig. This sort had just come in 1907 from the breeder, and had been distributed by the German Potato-Culture Station to its experimental fields. It showed itself to be diseased on all fields, but, notwithstanding this,

gave in Groebzig a yield of 274 bushels per acre. The next year, however, the yield decreased so much (the exact record is not known) that the breeder, Gen. Oekonomierat Säuberlich, discarded it as unworthy of cultivation. To what extent such varieties not too badly diseased have their yield influenced by external conditions is shown by a comparison of the yields of this sort on the different trial grounds of the German Potato-Culture Station, which in the year 1907 were planted with the same seed from Holland. There were harvested in double centners per hectare:

No.	Trial ground.	Double centners.	No.	Trial ground.	Double centners.	No.	Trial ground.	Double centners.
1	Groebzig	407.8	10	Hadmersleben	187.2	19	Loehme	140.0
2	Greisitz	258.2	11	Scharrau	182.6	20	Erbesbuedesheim	131.8
3	Calvoerde	245.6	12	Marienfelde	181.0	21	Gross-Saalau	130.0
4	Klein-Raudchen	228.7	13	Klein-Spiegel	180.8	22	Hohenheim	129.6
5	Dahlem	213.3	14	Schaeferhof	176.2	23	Singlingen	128.0
6	Freistatt	212.8	15	Siegersleben	164.4	24	Dolgen	128.2
7	Altneuhaus	197.6	16	Mittlau	154.8	25	Neckarau	128.0
8	Koetzig	192.0	17	Althoefchen	151.2	26	Gieshuegel	98.0
9	Neudorf	187.2	18	Ostrowitt	150.0	27	Altkluecken	78.2

Of the destructive effect of leaf-roll on the potato yield, this country has altogether too good an example in the outbreak of 1911 and 1912 in Colorado. (See p. 31.)

Stem-end browning of tubers is no longer considered a reliable evidence of leaf-roll, nor is there any other character by which the disease may be detected through an inspection of the tubers. In European potatoes more or less discoloration of the vascular tissue is frequently to be found near the stem end, though this is never so conspicuous, according to the writer's observation, as the familiar stem-end browning associated with Fusarium wilt in the United States, except when *Verticillium albo-atrum* is present. When leaf-roll first appeared Appel commented on its striking similarity to the Fusarium wilt described by Smith and Swingle (1904) and wrote of the German disease:

> If one cuts through the stem ends of diseased tubers, one finds that the vessels for one-half to 1 centimeter under the skin have a yellow discoloration. This discoloration is at harvest time to be seen more clearly near the stem end, but later extends until in spring it can often be traced into the eyes. Generally such tubers are less rich in starch than the healthy ones.

This discoloration was then thought to be characteristic of leaf-roll and evidence of the causal connection of a Fusarium with it. More extended observations threw doubt on this point, and it is now generally agreed that stem-end browning of the tubers is not an inseparable feature of the leaf-roll. Appel and Schlumberger (1911) say:

> The discoloration of the vascular bundles was at first understood to be a characteristic of the leaf-roll, as announced by Appel on the basis of conditions observed in 1905 and 1906. This discoloration should consist in a partial browning of the bundles of the stem and in a yellow color of the tuber bundles, which in mild cases confines itself to the vicinity of the stem end but in severer cases extends through the entire vascular ring. Later, however, in the year 1907, when the potatoes almost everywhere

showed this appearance, the question was again investigated with an abundance of material, and it turned out that the discoloration had no connection with the disease, but that it might be produced by the weather conditions during the vegetation period. It was further proved that the discoloration is not present in the most pronounced final stages of the disease. Since the vascular discoloration is frequently associated with the appearance of mycelium, it will be taken up again in the chapter on the causes of leaf-roll. When Spieckermann states, as a characteristic symptom of leaf-roll diseased plants, that the vascular bundles are not discolored, and in particular that there is no yellow color of the vascular ring, he only means that this appearance can not be utilized as a character of the disease, for the discoloration may naturally be present in diseased plants just as in healthy ones.

HEREDITARY NATURE OF LEAF-ROLL.

The true leaf-roll is inheritable. The tubers from diseased plants produce diseased progeny as a general rule. This affords a means of distinguishing from genuine leaf-roll those temporary conditions which give rise to a similar appearance of the plants. All those who are best acquainted with the trouble agree as to the results of planting diseased seed stock, though there are different explanations therefor.

This point is one of capital importance in the control of the disease and of great interest in its bearing on the nature of the disease. It will be further discussed on another page.

CHEMICAL COMPOSITION OF LEAF-ROLL POTATOES.

It was early suggested by Sorauer that the leaf-roll potatoes exhibited a more active oxidase reaction than the healthy ones. This was determined by Grüss and later more thoroughly by Doby (1911, 1912), who proved that leaf-roll potato tubers gave a higher reaction with respect to oxidase, peroxidase, and tyrosinase; also that they had a slightly higher ash content and less starch and protein.

The full significance of these results is not yet understood. It would seem that katabolism is more rapid in the diseased plants, yet the biochemist could hardly determine by analysis which of the samples given him were healthy and which diseased.

We hope that more light will be shed on this subject through the early publication of the work of Dr. H. H. Bunzel, of the Bureau of Plant Industry, who in 1912 and again in 1913 has made a study of the leaf-roll material at Houlton, Me., using a method and apparatus designed to give more accurate results than any previously available. (Bunzel, 1912.)

NECROSIS OF PHLOEM STRANDS.

It has recently been pointed out by Quanjer (1913) that the physiological and structural viewpoint has been neglected by investigators of leaf-roll and that the small attention given has been principally devoted to the xylem, in the search for fungi, rather than to the phloem.

This author finds that the phloem strands of leaf-roll plants are shrunken and the walls thickened and lignified, resulting in such a disorganized condition that the translocation of elaborated food materials from the leaves to the tubers for storage is prevented or interfered with.

This shrinkage of the phloem strands can be detected before external signs of leaf-roll appear, but it is not present in false leaf-roll due to mechanical injury, wet soil, bacteria, overfertilizing with kainit, etc., nor in the curly-dwarf disease. It is discoverable first after the young shoot from a diseased tuber has broken through the ground and formed several leaves. Each new branch is in the beginning healthy, but the diseased condition soon manifests itself. It can be traced upward, as the plant grows, to the tips of mature diseased shoots, and even to the petioles and midribs of the leaves and to the flower stems, but not on lateral leaf veins. The same pathological condition can be traced downward in the underground portion of the stem to the mother tuber, but it rarely appears in the stolons and never in the young tubers.

This shrinkage of the phloem affords an explanation of many of the results of leaf-roll, including the thickened stems and formation of aerial tubers, which takes place when the products of photosynthesis can not be translocated. It may be connected with the "endurance of the mother tuber" and with the higher percentage of nitrogen in the latter, since these compounds can not move so freely in the shrunken phloem. The reduction of growth and the lessened yield are attributable to the same cause. The rolling of the leaves is a natural reaction of the plant to a stem injury or stoppage.

The observations of Quanjer led him to the conclusion that leaf-roll is hereditary and not parasitic and that the presence of fungous mycelium, bacteria, tyloses, and vascular discoloration are not characteristic symptoms of the disease.

It is left undetermined how this phloem shrinkage is brought about. It has not yet been produced experimentally, nor have remedial measures been found, but the need is emphasized, as pointed out by Sorauer (1913), for more experimental work, under controlled conditions, on the influence of the several natural environmental factors on the potato plant.

NONCOMMUNICABILITY OF LEAF-ROLL.

That leaf-roll is not communicable from diseased to healthy plants is the conclusion to be drawn from all available evidence. Appel, Werth, and Schlumberger (1910) report grafting a great number of diseased sprouts on healthy ones and vice versa. These were put in the greenhouse and union took place. The scions gradually died, however, after the plants were brought into the open air. During

POTATO LEAF-ROLL. TYPICAL ROLLING OF THE UPPER LEAVES OF A GERMAN VARIETY. (AFTER APPEL.)

FIG. 1.—LEAF-ROLL IN SEEDLING POTATO NO. 16518, ALEXANDER NO. 1 RED × KEEPER. WASHINGTON, D. C., AUGUST, 1912.

FIG. 2.—POTATO LEAF-ROLL, SHOWING ITS EFFECT ON TUBER FORMATION. STOLONS THICKENED AND PRODUCING NUMEROUS SMALL TUBERS ONLY. MITCHELL, NEBR., SEPTEMBER, 1911. (PHOTOGRAPHED BY FRITZ KNORR.)

FIG. 1.—POTATO LEAF-ROLL FROM COLORADO. PLANT WITH THICKENED STEMS AND AERIAL TUBERS, ALTHOUGH THE STEM IS SOUND.

FIG. 2.—POTATO LEAF-ROLL FROM COLORADO, SHOWING THE TENDENCY OF THE TUBERS TO CLUSTER AT THE BASE OF THE STEM.

FIG. 1.—POTATO CURLY-DWARF. ADVANCED GERMAN TYPE. (AFTER APPEL.)

FIG. 2.—POTATO CURLY-DWARF, SHOWING DWARFING, REDUCTION OF FOLIAGE, AND ABSENCE OF TUBERS. HOULTON, ME., AUGUST 12, 1912.

the four weeks during which they were under observation there was no apparent influence of the diseased part on the healthy. Similar experiments were performed by Schander (1912) with substantially the same results.

The evidence in the seedling collection of this bureau is also strongly negative. Certain varieties with clearly marked leaf-roll have stood surrounded by healthy varieties without any indication of the spread of the disease.

RELATION OF FUNGI TO LEAF-ROLL.

The first investigations of leaf-roll made by Appel in 1905 led him to believe that it was due to a Fusarium similar to that described by Smith and Swingle. Mycelium was found in the vascular bundles of diseased plants, and cultures were derived from the stem ends of tubers. The species of Fusarium was not determined with certainty, for at that time the identification of Fusaria by morphological characters was not possible. The findings of Appel were verified by many other workers, and for a time leaf-roll was generally attributed to a Fusarium. Some good authorities are even now strongly inclined to this theory (Köck and Kornauth, 1912).

It has, however, been abundantly proved that in many cases of leaf-roll no fungus is present, and that these include the most advanced stages of the disease. The theory has been advanced by Appel that these fungus-free cases represent the second stage of a disease, the first stage having been due to Fusarium infection, and the weakness caused by the fungus transmitted to the progeny. This hypothesis has not been supported by the observed facts. It is greatly weakened by the results of the writer's seedling studies, which show the earliest typical stages of leaf-roll to be fungus free and by the fact that no inheritable leaf-roll follows *Fusarium oxysporum* infections in America. The subject has been somewhat obscured by the mass of polemic discussion, but it is now quite generally admitted that the presence of fungous mycelium is not a characteristic of leaf-roll.

The number of cases in Europe where mycelium has been found in diseased plants is so great that some explanation is required. In the opinion of the writer, the Fusaria that have been found in connection with leaf-roll in Europe are of nonparasitic types which have invaded diseased or weakened tissues. Where mycelium is reported in the bundles, and especially where it is found up to the tips of the stems, the first inference must be *Verticillium albo-atrum*, whose hyphæ, though thinner, may easily be mistaken for that of Fusarium. Mixed infection with Verticillium may account for most of the present confusion. This fungus is widespread in Europe, while it is now quite definitely established by Dr. Wollenweber that the *Fusarium*

oxysporum of Smith and Swingle is different from any European species yet known.

Leaf-roll diseased plants in America have been free from fungous infection in so far as the writer's observation goes, except for certain cases in Colorado, which were plainly mixed infections with *Fusarium oxysporum*, and here many other plants in the same field were fungus free. The external appearance of leaf-roll and wilt present many differences already given in detail.

Other fungi than Fusarium have also been reported in connection with leaf-roll, but for the most part without verification, e. g., *Solanella rosea* (Vanha, 1910), Phoma, Bacteria, etc. (Stoermer, 1910). The burden of proof is now on those who attribute leaf-roll to fungi to identify their organism through pure culture and reproduce the disease by inoculation. For a more extended summary of this phase of the subject, see Krause (1912).

LEAF SPOTTING IN RELATION TO LEAF-ROLL.

The occurrence of spots or flecks on potato leaves is not an invariable symptom of leaf-roll, but is often observed in connection with it, particularly in the severer types of leaf-roll. The spots observed by the writer were small, dark-brown flecks in the tissues of the terminal leaves, generally between the veins. They have also been found on plants not attacked by leaf-roll. These spots are apparently free from fungi and are believed to be due to physiological causes. Frank (1897) connected these spots with several types of what he termed "Kräuselkrankheit," but Appel is undoubtedly correct in pointing out that there is no connection between the spots and the curly-dwarf or the leaf-roll.

OTHER LEAF-ROLLS.

Typical leaf-roll must be differentiated from several similar appearances, due to other causes, as follows:

(*a*) Temporary leaf-roll due to water-logged soil. There are not infrequent cases in poorly drained land or in seasons of excessive precipitation when the potato plants suffering from lack of soil aeration show this by a rolling of the leaves. This can, however, be distinguished from the true leaf-roll, as the symptom disappears when the cause is removed, while true leaf-roll is inherited. The plants, moreover, do not undergo the same color changes. (Appel and Schlumberger, 1911.)

(*b*) A leaf-roll condition, usually of temporary duration, may be induced by heat or drought, or by the use of excessive quantities of fertilizer, especially potash (Quanjer, 1913). In such cases the rolling may be more marked on the lower leaves.

(*c*) Blackleg (*Bacillus phytophthorus*) produces an upward rolling of the leaves, with a yellow color. The later stages of this disease may at first glance exactly simulate leaf-roll, but as blackleg is invariably associated with a blackening and shriveling of the base of the stem the two can not be confused after the plants in question have been pulled up.

(*d*) Curly-dwarf is perhaps an allied malady, but differs in that there is a pronounced shortening of the stem and branches, a crinkling or downward curling of

the leaves, and normal color and turgidity. This is further described and illustrated on page 37.

(*e*) Wilt of both the Fusarium and Verticillium types may at certain stages bear a slight outward resemblance to leaf-roll, but they are distinguishable by the occurrence of the causal fungi, by the discoloration of the wood vessels of the lower stem, and by the brown stain in the stem end of the tubers. These wilts cause the rapid death of the plants attacked, or at the least an abnormally early maturity, while leaf-roll plants live nearly as long as healthy ones.

(*f*) Rhizoctonia stem-blight, as it occurs in Colorado and other Western States, may in one stage be easily confused at first sight with leaf-roll. (See under "Rosette," p. 40.) The leaf-roll symptom may, in fact, be induced by stem injuries of various kinds, but the disturbance is fundamentally different from true leaf-roll in that it is not transmissible. Heribert-Nilsson (1913) has described such a leaf-roll, due to hypocotyl injury by an insect, *Agrotis segetum*.

In Germany, leaf-roll was formerly included under the collective term "Kräuselkrankheit," which is now being restricted to curly-dwarf. Appel also separates a "bacterial ring disease," which has not yet been thoroughly worked out, and which can not at present be identified with any American malady. (Appel and Kreitz, 1907.) A new disease, to be described as "streak," also enters to some extent into the complex situation in America.

There is little likelihood of confusion with tip-burn, as this disease is already so well known. The illustration, Plate XIV, shows the characteristic browning and curling of the margins of the leaflets due to excessive transpiration during hot, dry weather. Tip-burn is comparatively much less prevalent in the cooler climate of Europe than in the United States, but it was observed by the writer in typical form in Dresden during the hot, dry summer of 1911.

LEAF-ROLL IN EUROPE.

The leaf-roll disease of potatoes first came into public notice in Europe in 1905, when a small epidemic occurred in Westphalia and other points in Germany. Appel found it in the same year in Denmark. It is his opinion that it had also prevailed many years before but had been forgotten or confused with other troubles under the collective term "Kräuselkrankheit." In 1907 a more general outbreak occurred in Germany, and much alarm was expressed (Arnim-Schlagenthin, 1908). The disease was reported on all sides. In Austria the Government appointed a special commission to investigate the disease. The experiments thus begun are still in progress. Up to date four reports have been published: (1) Dafert, 1911; (2) Köck and Kornauth, 1911; (3) Reitmair, 1912; (4) Köck and Kornauth, 1912. In these the reader will find recorded many data which are only briefly mentioned here.

Among other investigations begun then or a little later, and in addition to those of Appel and his assistants at the Kaiserliche Biologische Anstalt für Land- und Forstwirtschaft at Dahlem, Berlin,

from whom so much has already been drawn, the ones deserving of special mention are those of Dr. Schander, in the Kaiser Wilhelms Institut für Landwirtschaft in Bromberg and of Dr. Spieckermann in Muenster. So many others have written on this subject that it is possible only to refer to the extensive bibliographies of Appel and Schlumberger, 1911, of Köck and Kornauth, 1911 and 1912 (Mitteilungen des Komitees zum Studium der Blattrollkrankheit, Nos. 2 and 5), and of Himmelbaur, 1912.

GEOGRAPHIC DISTRIBUTION OF LEAF-ROLL.

Much is lacking in the knowledge of the exact distribution of the leaf-roll diseases, but it begins to appear that it is now, or soon will be, a factor in potato culture wherever this crop is grown. Its occurrence is certain in Germany, Austria-Hungary, Switzerland, the Netherlands, Denmark, and Sweden, as well as in the United States. It is probably in Norway, Russia, Bulgaria, and Roumania. That it has not been reported in France, Belgium, and England may be because of lack of sufficient observation. The somewhat limited observations of the writer in these countries in 1911 failed to disclose any true leaf-roll. The disease reported under that name from Ireland is the Verticillium wilt.

In Germany the leaf-roll has been most widespread and injurious in the west, e. g., in Westphalia and the Rhine provinces, though since its first outbreak in 1905 the introduction of healthy seed stock from other districts is reported to have restricted its spread. Leaf-roll has been observed in nearly all parts of Germany, but in most cases only scattered fields suffered.

In Austria, also, the disease seems to be present in nearly all districts, including Hungary, though not always to a destructive degree.

OCCURRENCE OF LEAF-ROLL IN THE UNITED STATES.

Two developments of leaf-roll in this country have been studied by the writer. One was in a collection of seedlings grown by Prof. William Stuart, of the Bureau of Plant Industry, and the other was a destructive outbreak in eastern Colorado and western Nebraska during 1911 and 1912. The leaf-roll in the seedling collection, while not of direct economic importance, afforded an opportunity to diagnose the trouble and differentiate it from others and also suggested a probable solution of the problem of control.

The western outbreak was, on the other hand, the cause of immense losses and brought the leaf-roll problem, for the first time, to the forefront in this country. That it will continue to be an important economic factor in American potato production is indicated by its discovery in two new localities in 1913. The writer found a field of Irish Cobbler near Onley, Va., with well-marked leaf-roll characterized by rolled leaves with a reddish tinge and stunted growth. The

source of this seed was thought to be Maine. Dr. I. E. Melhus found another field in northern Maine with 100 per cent leaf-roll, a noteworthy occurrence when the extremely vigorous and healthy condition of the potatoes in that district is considered.

As stress will be laid, later in this bulletin, on the development of leaf-roll in seedling varieties, in connection with the problem of controlling this disease, it will be well to describe the collection which formed the basis of the writer's studies.

HISTORY OF THE SEEDLING COLLECTION.

In 1904 Prof. L. R. Jones, then botanist of the Vermont experiment station, was sent to Europe by the Bureau of Plant Industry to search for potato varieties resistant to late-blight, *Phytophthora infestans*. He brought back about 100 varieties, which were placed on trial at several points, including the Vermont experiment station at Burlington, where Prof. Stuart began crossing the European sorts with each other and with American varieties. Notable success was achieved in 1909 in securing seed from a large number of crosses; about 25,000 seedlings were raised the following season, propagated that year in Washington, the following year in New York, and in 1912 in both New York and Maine.

It had been observed by Prof. Stuart that some of his seedling varieties from earlier crosses exhibited sudden loss of vigor. Occasional numbers which had in the beginning showed promise would produce only weak or abnormal progeny.

DISEASE PHENOMENA IN THE SEEDLINGS.

Such was the condition found by the writer in the breeding fields in Maine and New York in 1912. These fields consisted of 10 and 16 acres, respectively, and contained over 10,000 seedlings of known parentage, 5 hills of each sort.

As might be expected, these seedling potatoes showed every degree of variation in plant characters, color and size of leaves, habit of growth, etc., but in addition many showed distinct evidence of a diseased condition, and indeed of quite distinct types of disease, which are herein described as leaf-roll, curly-dwarf, and "streak."

It is noteworthy that in neither field was there any trace of Fusarium wilt, nor of Verticillium wilt, blackleg, or mosaic disease, although the latter three were common in adjoining fields. This is a very important fact, since it strongly supports the argument that these are distinct diseases. The reason for the nonoccurrence of these troubles is that the seedling varieties, since their origin from seed, had been grown from selected tubers, and no stronger proof is needed that such diseases may be controlled in commercial seed growing by the tuber-unit selection method, applied, if need be, to a seed plat of limited area, from which the main crop is propagated.

The sharp differentiation between healthy and diseased varieties in adjacent rows, and other field evidence, indicates that the leaf-roll and curly-dwarf are manifestations of physiological weakness and associated with decline or loss of vigor of the strain. That certain varieties show a greater tendency to such degeneration phenomena is evident, and the still more marked development of these troubles on certain seedlings emphasizes their relation to the varietal problem. That many other seedlings in the same field exhibited unusual health and vigor seems convincing evidence that in this seed selection and breeding the way lies open for the complete solution of this problem of leaf-roll control.

Of 59 of these diseased seedlings selected at random as typical examples in 1912, 29 were affected with leaf-roll and 30 with curly-dwarf; and of 22 selected in 1913, 7 had leaf-roll and 15 had curly-dwarf. The parentage of these is indicated in Table I, for its bearing on the question that will be asked as to whether certain combinations of varieties have a tendency to produce leaf-rolled or curly-dwarfed offspring.

TABLE I.—*Parentage of diseased seedlings.*

Parent varieties.	Number diseased with—		Parent varieties.	Number diseased with—	
	Leaf-roll.	Curly-dwarf.		Leaf-roll.	Curly-dwarf.
Geheimrat Theil × Keeper	2	2	Apollo × Silverskin	1	.....
Sophie × Keeper	11	3	Gem of Aroostook × Round Pinkeye	1	5
President Krüger × Keeper	1	1	Daisy × Keeper	.....	1
Delaware × Keeper	.....	2	Early Eureka × Keeper	.....	1
Norcross × Keeper	1	.....	Holborn Abundance × Irish Seedling	3	5
Gem of Aroostook × Keeper	7	4	Alexander's No. 1 Red × Irene	.....	3
Alexander's No. 1 Red × Keeper	1	4	Manly × Irene	3	.....
Round Pinkeye × Keeper	.....	2	Garnet Chili × Silverskin	.....	2
Irish Cobbler × Keeper	.....	1	Irish Cobbler × Irish Seedling	.....	1
Green Mountain × Keeper	.....	2	Apollo × Irish Seedling	.....	1
Keeper × Round Pinkeye	.....	1			
Keeper × Silverskin	.....	3			
Sophie × Irish Seedling	4	.....			
Delaware × Round Pinkeye	1	1	Total	36	45

A much more detailed analysis of the characteristics of these varieties and their seedlings is really required to answer this question. It is clear, however, that some varieties, like Keeper, are poor parents. A large number of successful crosses with Keeper were secured by Prof. Stuart because it produced an abundance of pollen, but the offspring of these have been so unsatisfactory on account of their tendency to curly-dwarf and leaf-roll that the variety will not be used again for crossing.

From different crosses having the same varieties as parents there have come seedlings, some of which were leaf-rolled and some curly-dwarfed. No. 16472, illustrated in Plate IV, figure 1, is a perfect type of leaf-roll in a cross between Alexander's No. 1 Red and Keeper, while No. 16503, shown in Plate XI, figure 1, is an equally

good type of curly-dwarf in another cross between the same parents. No cases are recorded where both leaf-roll and curly-dwarf were found in the same seedling number, but there are several instances where diseased and healthy plants occur in the same row. The results of 1913 are more striking in their proof of the hereditary nature of leaf-roll and curly-dwarf. This field contained 20 hills of each variety, planted with 10 tubers, each cut in half, and the two halves of each seed potato dropped in adjoining hills. As a general rule, all the 20 hills were uniformly diseased, as shown in Plate VI, illustrating No. 2171, one of the best types of leaf-roll in the collection. Two plants from this row are shown in a closer view in Plate V. Compare also Plate XII, showing the uniform affection by curly-dwarf of Nos. 821 and 822, which are hybrids between Sophie and Keeper.

In several cases in 1913 only a portion of a variety was affected, but with few exceptions the two hills originating from one tuber behaved alike. Row No. 1763, for instance, had two hills with leaf-roll, then four normal, then two leaf-rolled. Row No. 1613 had the first pair of hills normal, the second and third leaf-rolled, the fourth and fifth pairs normal, and all the remainder leaf-rolled. Other examples of similar inheritance of curly-dwarf are cited on page 38.

WESTERN OUTBREAK OF LEAF-ROLL.

For many years there has been an important center for potato production in Weld County in northern Colorado, known as the Greeley district. More recently a considerable acreage of potatoes has been grown on the North Platte River in western Nebraska.

Since the average rainfall at Greeley is not large, all potatoes must be grown under irrigation. The potatoes generally receive sufficient rain in the spring to keep them growing until July, when irrigation is begun and repeated as needed. Rotations of crops have been generally practiced. A common one is, alfalfa two or three years, potatoes, beets, and grain. The methods of culture have been considered good, and large yields were secured for years. It has been estimated that 35,000 to 40,000 acres are annually planted to potatoes in the Greeley district. The total yield per year was stated by Bennett (1907) to be 9,000 to 14,000 carloads, or 4,000,000 to 6,000,000 bushels. This crop has been the greatest factor in promoting the prosperity of this section. The leading varieties have been Pearl, Rural New Yorker, and Early Ohio.

Some difficulties had been experienced from diseases of potatoes previous to 1910. The greatest stress had been laid on the Rhizoctonia stem-blight, a trouble which assumes a peculiar form in this western country. (See under "Rosette," p. 40.) Potato culture has been, in fact, restricted to the lighter soils, the physical condition of

which is further improved by plowing under alfalfa just before planting potatoes, and by the practice of extremely deep cultivation with special implements.

Scab of the tubers has not been uncommon, and in some seasons there has been a late summer occurrence of early blight, but the most important disease has been perhaps the Fusarium wilt (*Fusarium oxysporum*). This fungus was widely prevalent throughout the district, and its effect on the crop could be observed with especial clearness in fields where potatoes had been grown for two or three consecutive years. Stem-end browning is common in Greeley potatoes, but the loss from Fusarium dry-rot has not been large. Crop rotation kept the loss from wilt down to a point where the disease caused little concern, though it is possible that a longer rotation would have been better.

These details concerning the prevalence in Colorado of Rhizoctonia and Fusarium have been given at this point because they were at first charged with the losses due to leaf-roll.

During the season of 1911 there was an outbreak of a potato disease which practically destroyed the crop in northern Colorado and western Nebraska. The shipments from the Greeley district fell from an expected 7,000 to 200 cars. The average yield of the 3,190 acres in the Mitchell (Nebr.) district was only 14 bushels per acre that year, as compared with 103 in 1909, 39 in 1910, and 102 in 1912. The cause of this extraordinary falling off in yield was the leaf-roll disease, though it was at first locally thought to be Fusarium and Rhizoctonia combined with the effect of the very dry and unfavorable weather of spring and early summer. It was predicted that with normal weather conditions and some improvements in cultural practices the disease would not be likely to recur (Corbett, 1912). In 1912, however, very favorable conditions for growing crops prevailed. There was an abundance of moisture in the soil in the spring and favorable temperatures throughout the season. Nevertheless, the disease again prevailed, nearly as severely as before. The shipments from Greeley were about 700 cars, with half the normal acreage. The Scottsbluff section came through with better results; for, although the leaf-roll appeared in June and threatened a repetition of the 1911 experience, there was a revival of the crop, after some midsummer rains, and a fair yield.

It now seems indisputable that the Colorado and Nebraska disease is the same type of leaf-roll observed in the Maine and New York seedlings and that this is the trouble called "Blattrollkrankheit" by the Germans. There have been variations in the symptoms observed, but it appears that this is also the case in different parts of Germany or between different varieties there. The American trouble exhibits the rolling, the yellow color, and all the important characters de-

FIG. 1.—POTATO CURLY-DWARF. A DISEASED AND A HEALTHY PLANT OF THE SAME VARIETY, SEEDLING NO. 16503, ALEXANDER NO. 1 RED × KEEPER. HOULTON, ME., 1912.

FIG. 2.—POTATO CURLY-DWARF. AN ADVANCED CASE BETWEEN TWO NEARLY NORMAL HILLS. NO. 13372, HOLBORN ABUNDANCE × IRISH SEEDLING. COMPARE PLATE XIII, FIGURE 1, WHICH SHOWS THE YIELD FROM THESE HILLS. HOULTON, ME., 1913.

POTATO CURLY-DWARF, SHOWING ITS TRANSMISSION THROUGH SEED TUBERS AND VARIETAL SUSCEPTIBILITY AND RESISTANCE IN SOPHIE × KEEPER HYBRIDS NOS. 821 AND 822 (IN THE CENTER), ALL DISEASED, AND NOS. 820 AND 823 (ON THE RIGHT AND LEFT, RESPECTIVELY), UNIFORMLY HEALTHY. HOULTON, ME., AUGUST, 1912.

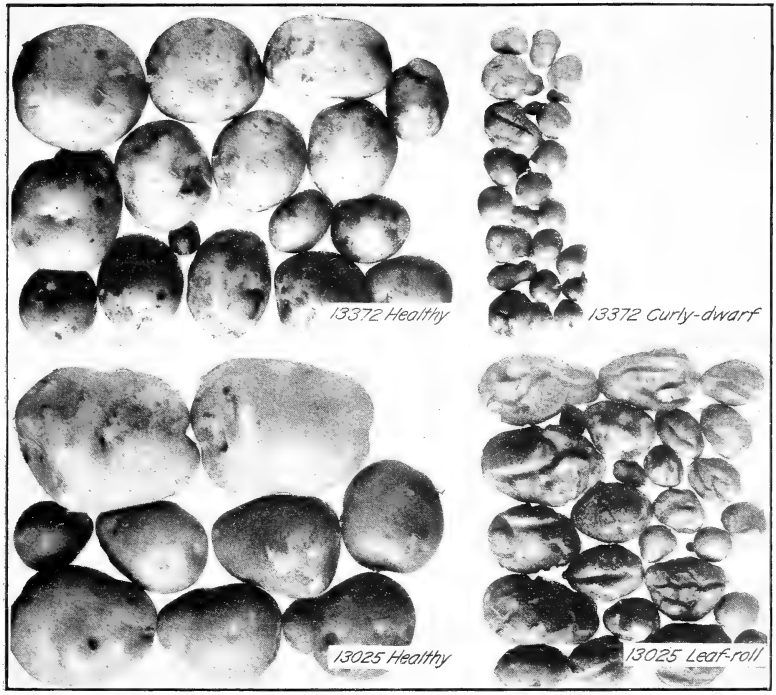


FIG. 1.—POTATO LEAF-ROLL (BELOW) AND CURLY-DWARF (ABOVE), SHOWING THE YIELD OF HEALTHY AND DISEASED HILLS OF THE SAME VARIETY. HOULTON, ME., SEPTEMBER, 1913.

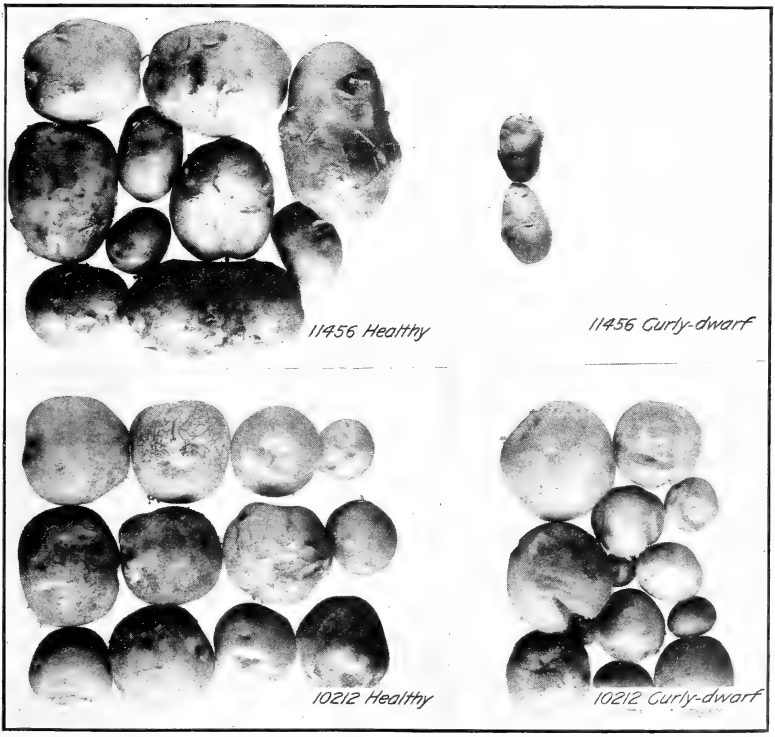
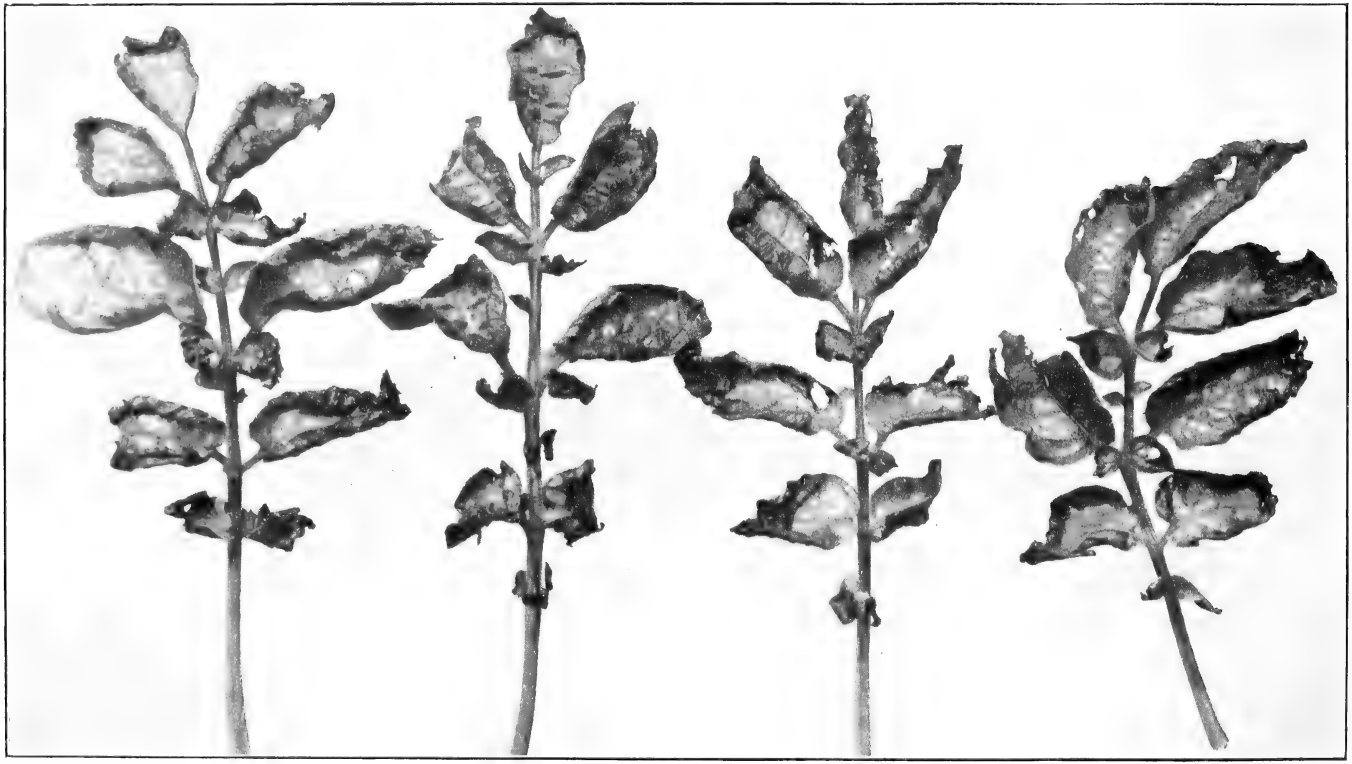


FIG. 2.—POTATO CURLY-DWARF. COMPARISON OF THE YIELD OF HEALTHY AND DISEASED HILLS OF THE SAME VARIETIES. HOULTON, ME., SEPTEMBER, 1913.



POTATO TIP-BURN, A HOT-WEATHER REACTION OF POTATOES GROWN IN MIDSUMMER AT WASHINGTON, D. C. (FOR COMPARISON WITH LEAF-ROLL.)

scribed, and the effect on the plant is the same, though possibly in the western cases there have been more pronounced abnormalities in stolon and tuber formation than are described in the German literature. These effects are illustrated in Plate VIII, figure 2, and Plate IX, figure 2, which show the numerous stolons, often thick and white, bearing many small tubers, frequently strung along like beads. The few tubers which attain any size are generally clustered around the base of the stem, as in Plate IX, figure 2, This clustering is characteristic of leaf-roll. Kornauth and Reitmair (1909) say: "The stolons are greatly shortened. Many times the tubers are attached directly to the stem."

AERIAL TUBERS.

Aerial tubers are very frequent, and there is often a thickening of the upper stem and leaf petioles which seems to be another result of the plant's efforts to store starch above ground. (Pl. IX, fig. 1.) This is a distinct phenomenon from the formation of aerial tubers due to lesions on the stem caused by Rhizoctonia, for the leaf-roll cases show no trace of fungous injury. Neither of these characters is constant, however. Mr. Fritz Knorr informs us that "in 1911 the greater percentage of the plants took on this stoloniferous character and a smaller portion developed the aerial tubers; this year (1912) the reverse was the case. We had but few of the stoloniferous plants and very many of the aerial tubers."

These are reactions of the plant to the abnormal physiological conditions accompanying the leaf-roll, which are in turn influenced more or less by moisture and food supply and by weather factors. It is easy to understand how aerial tubers are produced by the fungus Rhizoctonia, which causes lesions on the stem near the soil line and thus prevents the translocation of starch from leaves to tubers, for we can produce the same result by a mechanical injury, i. e., "girdling" the stem or by rooting a cutting from a potato shoot in such a manner that no node is covered by soil and stolons can not, in consequence, be formed.

In those leaf-roll diseased plants which form aerial tubers there are no below-ground fungus lesions, and some other force, such as the phloem shrinkage described by Quanjer, must be acting to hinder the storing of starch in the tubers.

There is evidence, as mentioned in the paragraph on the relation of enzyms to leaf-roll, which suggests that there may be unusual katabolic activities going on in the diseased plants, which would consume the carbohydrates formed in photosynthesis, leaving little or none to be laid by in the tubers during the period of leaf-roll prevalence. If, at a later date, under the influence of favorable weather, for example, an excess of starch was again formed in the

leaves, but some physiological defect prevented its prompt translocation to the below-ground tubers, it would be laid up in thickened branches and aerial tubers.

An interesting and important line of study in pathological physiology presents itself in the determination of the ways in which leaf-roll potatoes differ from healthy ones. Doubtless a better knowledge of the nature of leaf-roll will lead to a determination of its cause. Up to the present but little more has been done than to diagnose leaf-roll more accurately and separate it from other maladies with which it has been confused.

CAUSE OF LEAF-ROLL.

The hypotheses as to the cause of leaf-roll are numerous but exceedingly varied. They have indeed only one point in common—that all are as yet unproved. It has been argued by one that leaf-roll results from the use of unripe tubers for seed; by another, that it is due to the employment of matured tubers for seed; while a third believes that seed from prematurely ripened plants is a cause of leaf-roll. The disease is attributed by some to a lack of mineral elements in the soil, while others advance evidence that it is caused or aggravated by an oversupply of these same mineral elements. Poor cultural methods, lack of seed selection, and varietal degeneration are other suggested causes. The struggle between those who believe leaf-roll due to fungi and those who think it nonparasitic is nearly fought out, with the victory apparently in sight for the latter. Many signs now point to the plant breeder as the one who will finally triumph over this malady.

The present-day opinions on the cause of leaf-roll may be briefly reviewed. (Appel and Schlumberger, 1911.)

The relation of fungi to leaf-roll has already been briefly summarized. Much more on this point will be found in the writings of Himmelbaur, of Köck and Kornauth, and of Appel and Schlumberger. (See "Bibliography," pp. 44–48.)

On the question of using mature or immature seed, Hiltner (1905) is the leading advocate of the stand that the immature seed stock gives an abnormal growth. On later evidence, he limits this to those potatoes which are prematurely ripened by drought or other untoward circumstances. Against this is to be balanced the very extensive use, with good results, of immature tubers for planting. In Scotland, particularly, this is held to be the best practice. Hiltner (Appel and Schlumberger, 1911) further holds leaf-roll to be the result of excessive applications of fertilizer of unbalanced composition at the wrong time. He considers that the concentrated salts, especially potash salts, enter the roots and cause a disturbance in nutrition. Through the presence of these salts in the vessels, the water in them is prevented from rising. He thinks that these salts also favor the

entrance of fungi into the vessels. In this connection it may be noted that no fertilizers are used in Colorado, but that, according to Headden (1910), an abnormally large amount of nitrogen is present in these soils.

Experimental evidence on the effect of fertilizers is brought forward by Osterspek (Appel and Schlumberger, 1911), who comes to the following conclusions:

(1) The leaf-roll occurred most severely where no fertilizer was used.

(2) The second degree of severity was where the potash salts were left out.

(3) The absence of phosphoric acid favored the leaf-roll to a lesser degree, though still perceptibly.

(4) The use of a complete fertilizer, with nitrate of soda, superphosphate, and potash salts, tends to reduce the prevalence of leaf-roll.

(5) A second application of nitrate of soda after stable manure or after a complete commercial fertilizer reduced the leaf-roll.

Many practical growers have attributed leaf-roll to defective cultural conditions, poor soil, etc. Störmer (1911) also subscribes to this view: "Through such means as the selection of the smallest potatoes for seed stock, poor preparation of the soil, excessive applications of commercial fertilizers, heating of the potatoes in the silo, etc., a degeneration of the stock may be brought about and with this the leaf-roll." However, he has not yet exact proof of this. He believes that a hereditary leaf-roll may be caused by soil influence, "that one and the same potato may degenerate or remain healthy, according to the place where grown." He reports having succeeded in bringing up the vigor of a weak stock by growing it in one year on a poor, sandy soil. This leads us to the consideration of the problem from the varietal viewpoint.

VARIETAL SUSCEPTIBILITY AND RESISTANCE TO LEAF-ROLL.

The first appearance of leaf-roll in Germany was on the variety Magnum Bonum and was considered as an evidence of varietal deterioration (Schultz [Soest], 1905). Magnum Bonum is one of the older varieties. It has also been one of the most popular and, since its introduction from England, has become one of the most widely cultivated potatoes in Germany and Austria. It has everywhere proved the most susceptible to leaf-roll, but those who take this to be proof of the general "running out" of the variety have to meet several counter arguments. Healthy stocks of Magnum Bonum are still to be found. The leaf-roll attacks many other varieties, and it occurs even on plants grown from seed.

As to the relative susceptibility or resistance of American varieties there are almost no data. The Pearl, in the West, seems more liable to the trouble and may have to give way, like the Magnum Bonum. In Germany, however, extensive records are already kept by the German Potato-Culture Station (Von Eckenbrecher, 1912) and others.

It is not thought worth while to reproduce here the tables and summaries of these variety tests. The varieties grown in Europe are almost entirely different from those grown in the United States, and repeated experiences have shown that few of them will thrive here if introduced. In general, the indications are that varietal differences in susceptibility to leaf-roll do exist, but that the tests need to be carried on longer before any conclusions are drawn respecting given varieties. It seems certain that leaf-roll is not a result of "running out" of varieties through old age, for many quite recently originated strains are affected. More striking still is its occurrence in seedlings, which has been observed by several workers.

There have been unusual opportunities to study the occurrence of leaf-roll in the Stuart collection of 10,000 seedlings, where perhaps the most striking feature was that the leaf-roll was confined to certain numbers. The five hills of a kind would be uniformly affected, while those on either side were perfectly healthy. Clearly, the disease is not due entirely to soil or climatic influences, and certainly there was no indication of fungous infection. The marked contrast between diseased and healthy rows is well shown in Plate VI, in which the left-hand row is a hybrid (No. 2171) between Sophie and Keeper, the healthy row on the right being from the same cross (No. 2165).

An interesting suggestion is put forward by Hedlund (1910), that leaf-roll is a pathological, adaptative mutation, and, further, that since acquired characters are not inherited the leaf-roll character must be latent in normal potatoes.

CONTROL OF LEAF-ROLL.

No measure offers more hope of success in controlling leaf-roll than the use of better seed stocks. Three means may be used to bring this about: First and simplest, the importation of seed potatoes from districts where the disease is unknown. This affords relief but may not greatly raise the standard of quality. Second, hill selection, to pick out from weak varieties strains that will withstand the disease. This has been done already by Von Lochow (1910), who took several types from the variety Professor Wohltmann and bred them in pure lines. The result was that certain of these pure strains showed susceptibility to leaf-roll, while others remained entirely or nearly free from it. Third, new varieties may be bred from seed. This, while requiring the most time, may be the best means for meeting the requirements where whole districts are attacked, as in the Colorado outbreak. That such good varieties can be produced one can hardly doubt after seeing the departmental collection of over 10,000 seedlings with its infinite variety of disease-resistant qualities.

It is the prevailing opinion of European investigators that leaf-roll is inherited—i. e., that the tubers from diseased hills will produce diseased progeny. Cases are cited where the first crop after the

appearance of the disease was normal, but later harvests fell to nothing. No reliable results are available in this country. Conflicting reports come from farmers in the Greeley section; but, as no pathologist accustomed to the diagnosis of leaf-roll saw either crop, the relative amount of disease in home-grown and outside seed remains unknown.

It seems a wise precaution to use only selected seed from such sources as Minnesota and Wisconsin for planting next year where leaf-roll occurred last season. It may be that the disease will not appear on crops from home seed, but the chances are that it will.

The introduction of new and more vigorous varieties affords a still more hopeful means of ultimately controlling the situation. The problem of finding the best source of seed is the most important one now confronting potato growers in the region affected by these troubles. What is needed are selected stocks, true to name, with vigor unimpaired and free from disease. The present difficulty is that it is almost impossible to find such potatoes in large quantities. Where growers have made experiments with outside seed they have, as a rule, made their purchases in the open market or from middlemen who have filled their orders with uninspected stocks, for which reason no conclusions can be drawn from any experiments to date.

There is fortunately a movement to organize among potato growers in the principal Northern States, and this is backed by their State experiment stations in a way that should in time make a supply of reliable seed available.

It would be well to follow the example of Germany, where a system of official inspection is being inaugurated, through which growers and purchasers may be assured that the crop from a given estate is free from leaf-roll. Such a certificate can be granted only after an inspection of the growing crop. The importance of such an inspection in midsummer by a representative of the purchaser or by an official expert can not be overstated. It is entirely impossible to determine the vigor and freedom from leaf-roll of a stock of potatoes after harvest.

The practical phases of such a system of seed inspection and certification will be discussed more fully in a later publication.

CURLY-DWARF.

Under the name "curly-dwarf" there is to be differentiated from the leaf-roll a peculiar disorder, characterized by a dwarfed development of the potato plant, accompanied by a pronounced curling and wrinkling of the foliage, which has been compared to Scotch kale and Savoy cabbage. It is known in Germany as "Kräuselkrankheit." The accompanying illustrations from photographs (Pls. X and XI) show the typical appearance of this disease more clearly than the printed description.

The stem and its branches, the leaf petioles, and even the midribs and veins of the leaves all tend to be shortened in many cases to a very marked extent, and particularly in the upper nodes of the plant, so that the foliage is thickly clustered. The diminished growth of the leaf veins, in proportion to the parenchyma, results in a bullate, wrinkled leaf, often strongly curled downward. There seems also to be a tendency to form more secondary branches than is normal, and as these remain short and have curly leaves the compactness of the plants is more striking. The stems are also very brittle.

COLOR OF THE FOLIAGE.

The color of the foliage in curly-dwarf is typically a normal green, except that in very severe or advanced cases there is a lighter green or yellow color sometimes accompanied by brown or reddish flecks in the leaves where the tissues are dying. Typical curly-dwarf is readily distinguished from leaf-roll by the wrinkled or downward curling of the leaves, the normal color of the foliage, and the firmness of the leaves, which do not lack turgidity.

The tuber yield of curly-dwarf plants is greatly curtailed. Severe cases have no tubers, and many such have been observed. In others a few small potatoes are formed. This difference in productivity is strikingly shown in the photograph reproduced in Plate XIII, figure 2, of the yield from curly-dwarf hills compared with adjoining healthy hills.

The nature and cause of this disease remain unknown. No evidence of fungi or other parasites have been found. There is neither browning nor mycelium in stems and tubers, but the curly-dwarf is transmitted through the seed. The hereditary nature of the trouble is attested by the German authorities, and it has been observed by the writer in the case of some hill selections made by Prof. Stuart in 1911 and planted in the Arlington greenhouses that winter. The tubers from diseased hills all developed into curly-dwarf plants, while those from healthy hills remained normal. Equally good evidence of the transmission of this diseased condition through the tubers was afforded by the Stuart seedling collection of 1913, which, as described under leaf-roll, was planted in 2-hill tuber units. No. 4033 had 4 pairs of curly-dwarf and 5 pairs of healthy hills in the following order: Two normal hills, 2 curly-dwarf, 2 normal, 2 curly-dwarf, 2 normal, 2 curly-dwarf, 2 normal, 4 curly-dwarf, 2 normal. No. 13016 had the first two hills normal, the next two curly-dwarf. No. 13372 had 4 normal hills, then 4 curly-dwarf, 1 normal, 1 curly-dwarf, and 2 normal. No. 14637 had hills Nos. 1 and 2 normal, and 3 and 4 curly-dwarf; and these examples might be multiplied many times. The few exceptions where single hills developed the disease may be due to an error in dropping the seed or to planting a small tuber whole.

OCCURRENCE AND DISTRIBUTION.

In Europe curly-dwarf is apparently not sufficiently common to have any economic significance. The literature on this subject must, however, be interpreted with an understanding of the confusion of terms among the older authors, who often used the word "Kräuselkrankheit" as a collective term for curly-dwarf, leaf-roll, bacterial ring disease, and still others (Appel and Schlumberger, 1911; Frank, 1897; Kühn, 1859). Evidence is also found in the old English literature that a varietal deterioration called "curl" was frequent even in the nineteenth century (Dickson, 1814; Shirreff, 1814; Townley, 1847; Foster, 1905). It is impossible to know whether this trouble was leaf-roll or curly-dwarf; but the thought suggests itself that there have been periods, or cycles, of decline in potato varieties, followed by the rejuvenation due to introduction of new sorts. It may be that such a period of decline is now beginning, as manifested by the appearance of leaf-roll and similar troubles in the principal potato countries during recent years.

In the United States it is probable that curly-dwarf plays a large rôle in the deterioration of potatoes. It is commonly met with in New England and New York fields, though not always recognized, as the larger plants overshadow and conceal the weaklings. The writer has sought this type of deterioration in potato fields in many States from Maine to California, and has found it to be not infrequent in occurrence, but that its presence in the average field is limited to scattered plants, usually less than 2 per cent. Field-to-field inspection in important potato districts has, however, resulted in the discovery of some fields where a larger percentage, even half or more of the plants, showed curly-dwarf. Some of these fields showed weakness in other ways, through failures to germinate, blackleg, mosaic disease, and general lack of vigor.

In another instance a strain of potatoes was being grown by a progressive, careful farmer, who had adopted the hill-selection method to increase vigor and productiveness, yet a considerable proportion went down with curly-dwarf in 1913, three years after the selection ceased. The 1912 crop was normal in appearance but was subjected to severe drought. This is of interest in connection with the belief that prevails in some quarters that dry years induce this type of trouble. The same grower shipped a portion of his 1912 crop to a southern State for the early spring planting, and much curly-dwarf appeared in the fields of the purchaser.

It seems evident that this is a physiological disorder, resulting in a permanent deterioration of the stock. It may develop at any time as a result of conditions not yet fully understood, and the vigor of the affected strain apparently can not be restored.

This is a problem in varietal decline that should receive earnest consideration. The prevalence of such weak plants should be ascertained in any stock intended for propagation, and measures undertaken to provide disease-free seed potatoes in sufficient quantity to meet all demands.

There are all grades of the condition above described, from pronounced types of curly-dwarf to those approaching normal vigor. It will furthermore be apparent that this is a difference inherent in the varieties or strains under observation. Schander has described a related condition as the "Barbarossa disease," so named because it is characteristic of the German variety Barbarossa. In every potato field are found some weaklings, or plants which are merely small, without any curled leaves or dwarfed stems, and without the fungous lesions described under "Rosette." The extent to which these small plants represent a permanent deterioration in the vigor of the stock, and thus a condition related to the curly-dwarf, is a problem not yet settled. Certainly such weaklings should be eliminated when improved seed is desired.

CONTROL OF CURLY-DWARF.

Since potatoes from diseased hills can not be restored to vigor, all such should be rejected for planting. The occurrence of any considerable number in a field may be taken as evidence of a general decline, requiring that the entire stock be given up and new seed substituted.

It has already been demonstrated by Prof. Stuart that we have in the method of tuber selection outlined by Webber (1908) a means by which all diseased potatoes may be eliminated from a stock, since when all tubers are cut into four pieces and these planted in adjacent hills all those which show inherited weakness may be eliminated and only the strongest and most productive selected.

ROSETTE.

Phases of leaf-roll and curly-dwarf marked by dwarfed growth and the formation of aerial tubers have been described. These symptoms may, however, result from another cause—the stem lesions due to Rhizoctonia, and no attempt to differentiate potato troubles can be successful which does not take into consideration the varied effects of this fungus. It must be recognized that Rhizoctonia appears to be a more active parasite in America than in Europe and to play a greater rôle in the Western States than in the Eastern.

Since this article is written primarily to effect a diagnosis of potato troubles, it will not be necessary to review the facts already well known to pathologists relative to the occurrence of Rhizoctonia on its various hosts or to discuss the relationship and parasitism of the several known strains. This subject is being fully reinvestigated

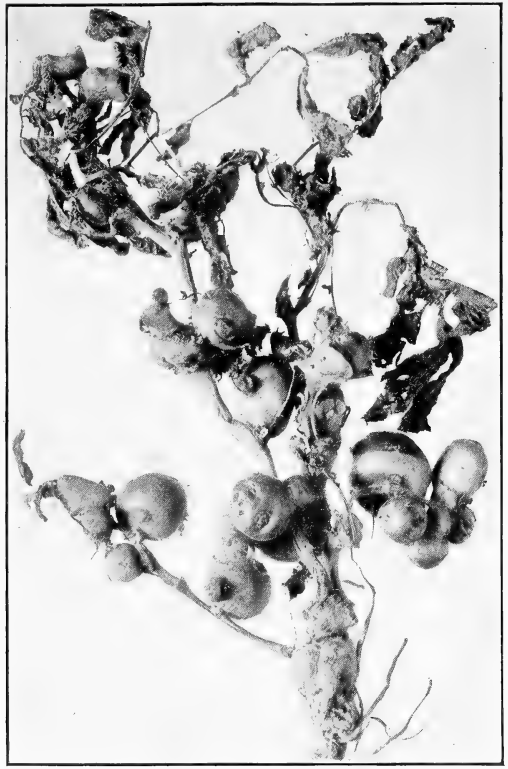


FIG. 1.—RHIZOCTONIA EFFECT ON POTATO, SHOWING AERIAL TUBERS DUE TO LESIONS AT THE BASE OF THE STEM. LA CONNER, WASH., SEPTEMBER, 1909.

FIG. 2.—RHIZOCTONIA LESIONS AT THE BASE OF STEMS, OFTEN PRODUCING THE ROSETTE EFFECT ON THE FOLIAGE. (PHOTOGRAPHED BY H. B. SHAW, JEROME, IDAHO, 1913.)

FIG. 1.—POTATO MOSAIC DISEASE. EUREKA VARIETY IN ARLINGTON GREENHOUSE, 1913.

FIG. 2.—HEALTHY EUREKA POTATO PLANT. (FOR COMPARISON WITH FIGURE 1.)

by Dr. H. A. Edson, of the Bureau of Plant Industry. It is, however, important to mention that types of potato disease are not infrequently encountered which simulate in one character or another the leaf-roll, the curly-dwarf, and sometimes blackleg, but which is believed to be associated with Rhizoctonia, although it must be admitted that the proof is somewhat scanty.

This fungus is almost ubiquitous on potato tubers in its sclerotial form; small black mycelial masses superficially attached to the epidermis without evidence of parasitism may be found on tubers from every State. In other cases a russet scab or cracking is attributed to the same fungus, and lesions are formed on the underground stem and stolons. The fruiting stage, *Corticium vagum solani* Burt (*Hypochnus solani* Prill), is formed on the green stem above ground and is merely a superficial nonparasitic layer over healthy tissues.

The reaction of the potato plant to Rhizoctonia infection depends upon the part attacked. If this be the stolons, the young tubers are cut off, and this process, taking place in the heavy irrigated soils of the West, is held by Rolfs (1902, 1904) to be the cause of that type of potato failures in which large overgrown vines produce few or only small tubers. If the lesions encircle and girdle the main stem near the soil line, the result will be the formation of numerous aerial tubers (Pl. XV, fig. 1) formed as a result of the destruction of the phloem and the prevention of carbohydrate translocation. The same result would follow mechanical girdling. This type of injury sometimes results in a leaf-roll that is hard to distinguish from the genuine leaf-roll until the plant is pulled and the stem injury noted. Such plants were conspicuous in the Red River Valley in Minnesota in 1913. There may have been a complication with blackleg there, but there was no leaf-roll. In the San Luis Valley of Colorado, also, the Rhizoctonia injury is reported by Edson and Wollenweber to take a form strongly simulating leaf-roll.

Rhizoctonia lesions on the young hypocotyl, such as are figured in Plate XV, figure 2, cause a dwarfed growth described by Selby as rosette. The condition figured by him closely approaches curly-dwarf, and the question is well worth raising in the case of stunted plants bearing Rhizoctonia lesions whether their vigor had not been impaired prior to infection.

One can pass through potato fields in Ohio and Wisconsin, for example, and on pulling the small, weak, or rosette plants find many, but usually not all, with these stem lesions. So far as the writer knows, no one has planted the tubers from such hills to learn whether the weakness is transmissible. The case for Rhizoctonia is weakened, however, when one finds the stem lesion on vigorous, outwardly healthy hills as well as on the rosette examples. The subject clearly needs further investigation.

MOSAIC.

The potato mosaic is an abnormal condition of the foliage characterized by a spotted or mottled appearance of the leaves, portions of which are lighter green in color and with thinner, less perfectly developed parenchyma than the normal. In the later stages, brown flecks of dead tissues may appear. These light-green areas vary considerably in size in different cases, from definite patches of 5, 10, or 20 millimeters, with fairly distinct demarcation between diseased and healthy tissues, to an indefinite punctate type where a thin yellow-green spot of leaf tissue merges gradually into the apparently normal. The latter has been the more common on potatoes in the writer's observations to date, while the former is more frequent in the mosaic diseases of tobacco, tomato, and other plants. Reference to Plate XVI, figure 1 will make these points clearer than pages of text. There are phases of mosaic where it might be inferred that the plants under observation were of varieties having naturally irregular, curled, or wrinkled foliage, were it not for the contrast with the healthy plants alongside. (Pl. XVI, fig. 2.)

Cases of potato mosaic have been observed with the abnormal leaf areas so large and so clearly marked as to suggest variegations, such as are familiar among ornamental plants. True variegations occur somewhat rarely in potato foliage, but the writer has seen one variety all the plants of which had variegated green and yellow-white leaves. This sort, appropriately named the "Harlequin," was grown in 1911 in a variety test on the experimental grounds of the Landwirtschaftliches Institut at Goettingen, Germany. As might be expected, it was lacking in vigor as compared with the other varieties.

The effect of mosaic on the growth and development of potato plants is quite marked. Most conspicuous is the irregular, distorted, or wrinkled foliage. This effect is manifestly due to the imperfect development of the diseased portions of the leaf parenchyma. The plants are also smaller, except in the mildest cases. The effect on the yield was tested by harvesting 80 mosaic hills and 80 healthy hills of the Green Mountain variety, on September 10, 1913. The yield of the diseased plants was 94.4 pounds; and of the healthy, 120.8 pounds, a difference of 22 per cent.

Typical potato mosaic can not be confounded with typical curly-dwarf. The former is marked by abnormalities in the leaf parenchyma while the especial characteristic of the latter is the restricted development of the vascular elements. There do occur, however, some intergrading forms that present puzzles that will doubtless be cleared up later when both diseases have been more fully studied.

No references to potato mosaic have been found in the literature. It was first observed by the writer in 1911 in a field at Giessen, Germany, where it was not uncommon, especially on some varieties.

In 1912, it was exceedingly prevalent in some fields of Green Mountain in Aroostook County, Me. The number of plants affected varied from 1 per cent up to practically 100 per cent. Some fields of several acres were seen where hardly a normal plant could be found. The disease was present again in 1913 in the same district, always on the Green Mountain variety. Mosaic has not been found in the potato districts of Wisconsin, Minnesota, Colorado, or other Western States, though an extended survey of these States was made in 1912 and 1913.

There is evidently much difference in varietal susceptibility. Hundreds of fields were examined in Maine where the Green Mountain variety was growing side by side with Irish Cobbler, but practically no mosaic was observed in the latter, whereas it was very common in the former. There appears to exist also a corresponding difference in the tendency of strains or stocks of the same variety toward mosaic. Different fields of the Green Mountain variety showed from none to 100 per cent of diseased plants. An experiment in the Arlington greenhouses further demonstrated this point, though undertaken for another purpose—the control of silver scurf. Two greenhouse beds were planted with the variety Eureka, using seed from two sources. One lot showed 46 mosaic and 31 healthy plants, eliminating doubtful cases, or 59.7 per cent diseased. The second lot had 100 per cent free from mosaic. Portions of the first lot had been treated with formalin, corrosive sublimate, and heat, with control lots untreated. These treatments did not appreciably affect the proportions of mosaic which developed.

That mosaic is transmitted through the tubers is thought to be not improbable. An experiment to test this was carried out in Maine during the past season with somewhat inconclusive results. Tubers from mosaic hills marked in 1912 were planted in hill-unit rows, with controls. The progeny were in part mosaic and in part of a doubtful character, smaller and less vigorous than the controls, but with less clearly marked mosaic than the parent hills. On account of some confusion of the labels, it is thought best to repeat the test before drawing conclusions.

The cause of potato mosaic is unknown, nor have experiments been made to determine whether, like the mosaic of tobacco, it is communicable from plant to plant. Allard (1912) has shown that the tobacco mosaic can not be transferred from tobacco to potato by inoculation. The exact nature and relationship of potato mosaic to other similar troubles remains to be worked out. In this article, which is primarily diagnostic, it is aimed to point out that such a disease exists and that it may become a factor in the problem of varietal deterioration of such importance as to require consideration when selecting or inspecting seed stocks for certification or purchase.

BIBLIOGRAPHY.

ALLARD, H. A.

1912. The mosaic disease of tobacco. Science, n. s., v. 36, no. 938, p. 875–876.

1914. The mosaic disease of tobacco. United States Department of Agriculture, Bulletin No. 40, 33 p., 7 pl.

APPEL, OTTO.

1906. Neuere Untersuchungen über Kartoffel- und Tomatenerkrankungen. Jahresbericht, Vereinigung der Vertreter der Angewandten Botanik, Jahrg. 3, 1904/5, p. 130–132, fig. 1.

1907. Die Blattrollkrankheit der Kartoffel. Kaiserliche Biologische Anstalt für Land- und Forstwirtschaft [Germany], Flugblatt No. 42, 4 p., 2 fig.

1909. Die Blattrollkrankheit der Kartoffel. Kaiserliche Biologische Anstalt für Land- und Forstwirtschaft [Germany], Flugblatt, Aufl. 3, No. 42, 4 p., 2 fig.

1911. Die Schwarzbeinigkeit und die Bakterien-Knollenfäule der Kartoffel. Kaiserliche Biologische Anstalt für Land- und Forstwirtschaft [Germany], Flugblatt, Aufl. 4, No. 28, 4 p., 4 fig.

——— and KREITZ, WILHELM.

1907. Der derzeitige Stand unserer Kenntnisse von den Kartoffelkrankheiten und ihrer Bekämpfung. Berlin. 31 p., 18 fig. (Mitteilungen, Kaiserliche Biologische Anstalt für Land- und Forstwirtschaft [Germany], Heft 5.)

1908. Die hauptsächlichsten Kartoffelkrankheiten. Illustrierte Landwirtschaftliche Zeitung, Jahrg. 28, No. 17, p. 150–151, fig. 7–8 (colored plate).

——— and SCHLUMBERGER, OTTO.

1911. Die Blattrollkrankheit und unsere Kartoffelernten. Berlin, 102 p., illus., 3 pl. (Arbeiten, Deutsche Landwirtschafts-Gesellschaft, Heft 190.)

——— WERTH, EMIL, and SCHLUMBERGER, OTTO.

1910. Zur Kenntnis der Kartoffelpflanze. Mitteilungen, Kaiserliche Biologische Anstalt für Land- und Forstwirtschaft [Germany], Heft 10, p. 12–14.

——— and WOLLENWEBER, H. W.

1910. Grundlagen einer Monographie der Gattung *Fusarium* (Link). Arbeiten, Kaiserliche Biologische Anstalt für Land- und Forstwirtschaft [Germany], Bd. 8, Heft 1, p. 1–207, 12 fig., 3 pl.

ARNIM-SCHLAGENTHIN, GRAF.

1908. Europas Kartoffelbau in Gefahr. Fühlings Landwirtschaftliche Zeitung, Jahrg. 57, Heft 3, p. 102–107.

BENNETT, E. R.

1907. The Colorado potato industry. Colorado Agricultural Experiment Station, Bulletin 117, 23 p., 6 pl.

BEOBACHTUNGEN und Untersuchungen über die Blattrollkrankheit der Kartoffeln in [1908.] Westfalen. Veröffentlichungen, Landwirtschaftskammer für die Provinz Westfalen, Heft 8, 35 p.

Reprinted from Jahresbericht, Landwirtschaftliche Versuchsstation, Münster, 1908, p. 52–84.

BOHUTINSKY, G.

1909. Beiträge zur Erforschung der Blattrollkrankheit. Monatshefte für Landwirtschaft, Jahrg. 2, Heft 4, p. 118–130, 4 fig. Also in Zeitschrift für das Landwirtschaftliche Versuchswesen in Oesterreich, Jahrg. 13, Heft 7, p. 607–633, 3 fig., 1910.

BUNZEL, H. H.

1912. The measurement of the oxidase content of plant juices. U. S. Department of Agriculture, Bureau of Plant Industry, Bulletin 238, 40 p., 9 fig., 2 pl.

CLINTON, G. P.

1895. Fungous diseases of the potato. Illinois Agricultural Experiment Station, Bulletin 40, p. 139.

CORBETT, L. C.
1912. Suggestions to potato growers on irrigated lands. U. S. Department of Agriculture, Bureau of Plant Industry, Circular 90, 6 p.

CRICHTON, DANIEL.
1814. Experiments and observations on the potato. Memoirs, Caledonian Horticultural Society, v. 1, p. 438-441. For extract see Stephens, Henry. The Book of the Farm . . . v. 2, New York, 1847, p. 203.

DAFERT, F. W.
1911. Bericht über staatliche Massnahmen anlässlich des Auftretens und der Verbreitung der Blattrollkrankheit der Kartoffel in den Jahren 1908 bis 1910. (Mitteilungen des Komitees zum Studium der Blattrollkrankheit der Kartoffel, No. 1.) Zeitschrift für das Landwirtschaftliche Versuchswesen in Oesterreich, Jahrg. 14, Heft 5, p. 757–758. Also reprinted with Mitteilungen No. 2.

DICKSON, THOMAS.
1814. Observations on the disease in the potato generally called the curl; pointing out the most probable method of preventing it; with an account of the results of a few experiments made on the subject. Memoirs, Caledonian Horticultural Society, v. 1, p. 49–59. For short abstract see Stephens, Henry. Book of the Farm . . . v. 2, New York, 1847, p. 203.

DOBY, G.
1911–1912. Biochemische Untersuchungen über die Blattrollkrankheit der Kartoffel. Zeitschrift für Pflanzenkrankheiten, Bd. 21, Heft 1/2, p. 10–17; Heft 6, p. 321–336; Bd. 22, Heft 4, p. 204–211; Heft 7, p. 401–403.

ECKENBRECHER, C. von.
1906–1912. Bericht über die Anbauversuche der Deutschen Kartoffel-Kultur-Station im Jahre 1905–1911. Zeitschrift für Spiritusindustrie, Ergänzungshefte.

FLUGBLATT über die Blattrollkrankheit. (Mitteilungen des Komitees zum Studium
1911. der Blattrollkrankheit der Kartoffel, No. 3.) Zeitschrift für das Landwirtschaftliche Versuchswesen in Oesterreich, Jahrg. 14, Heft 7, p. 911–915, 1 fig., 1 pl. Also reprinted.

FOSTER, C.
1905. "Curl" and its cure. National Potato Society, Annual Report, p. 25–29.

FRANK, A. B.
1897. Die Staudenkrankheiten der Kartoffelpflanze oder die Kräuselkrankheit und verwandte Lauberkrankungen. In his Kampfbuch gegen die Schädlinge unserer Feldfrüchte. Berlin, p. 217–222, pl. 14, fig. 2–4, pl. 15, fig. 1.

HEADDEN, W. P.
1910. Fixation of nitrogen in some Colorado soils. Colorado Agricultural Experiment Station, Bulletin 155, 48 p., 8 fig.

HEDLUND, T.
1910. Några iakttagelser öfver bladrullsjuka hospotatis. Tidskrift för Landtmän, bd. 31, p. 512–515, 532–541. Abstract in Centralblatt für Bakteriologie, [etc.], Abt. 2, Bd. 31, No. 11/15, p. 331. (Original not seen.)

HERIBERT-NILSSON, N.
1913. Potatisförädling och potatisbedömning. 31 p., illus. Reprinted from W. Weibulls Arsbok, 8.

HILTNER, L.
1905. Zur Frage des Abbaues der Kartoffeln. Praktische Blätter für Pflanzenbau und Pflanzenschutz, Jahrg. 8 ([n. R.] Jahrg. 3), Heft 12, p. 133–140, 1 fig.

HIMMELBAUR, WOLFGANG.

1912. Die Fusariumblattrollkrankheit der Kartoffel. Oesterreichisch-Ungarische Zeitschrift für Zuckerindustrie und Landwirtschaft, Jahrg. 41, Heft 5, p. 716–744, 13 fig.; Heft 6, p. 944–976, fig. 14–25.

IRISH, J. P., jr.

1913. The work of the Delta Experiment Farm in 1912. U. S. Department of Agriculture, Bureau of Plant Industry, Circular 127, p. 3–13, 1 fig.

JAMIESON, CLARA O., and WOLLENWEBER, H. W.

1912. An external dry rot of potato tubers caused by Fusarium trichothecioides, Wollenw. Journal, Washington Academy of Sciences, v. 2, no. 6, p. 146–152.

JONES, L. R., GIDDINGS, N. J., and LUTMAN, B. F.

1912. Investigations of the potato fungus Phytophthora infestans. U. S. Department of Agriculture, Bureau of Plant Industry, Bulletin 245, 100 p., 10 fig., 10 pl.

KÖCK, G., and KORNAUTH, K.

1911. Studien über die Ursache der Blattrollkrankheit der Kartoffel und über die Möglichkeit der Uebertragung dieser Krankheit durch das Saatgut und den Boden. (Mitteilungen des Komitees zum Studium der Blattrollkrankheit der Kartoffel, No. 2.) Zeitschrift für das Landwirtschaftliche Versuchswesen in Oesterreich, Jahrg. 14, Heft 5, p. 759–805. Also reprinted with Mitteilungen No. 1.

——— ———, and BROŽ, O.

1912. Bericht über die von der k. k. Pflanzenschutzstation im Jahre 1911 durchgeführten Versuche zum Studium der Blattrollkrankheit der Kartoffel. (Mitteilungen des Komitees zum Studium der Blattrollkrankheit der Kartoffel, No. 5.) Zeitschrift für das Landwirtschaftliche Versuchswesen in Oesterreich, Jahrg. 15, Heft 3, p. 179–247, 1 fig.

KORNAUTH, K., and REITMAR, O.

1909. Die Blattrollkrankheit der Kartoffel und ihr Auftreten in Oesterreich. Monatshefte für Landwirtschaft, Jahrg. 2, Heft 3, p. 79–90. Also reprinted.

1909. Studien über die Blattrollkrankheit der Kartoffel. Mit besonderer Berücksichtigung ihres Auftretens und ihrer Verbreitung 1908 in Oesterreich. Zeitschrift für das Landwirtschaftliche Versuchswesen in Oesterreich, Jahrg. 3, Heft 3, p. 97–125. Also reprinted.

KRAUSE, FRITZ.

1912. Ueber das Auftreten von Pilzen in Kartoffeln. Mitteilungen, Kaiser Wilhelms Institut für Landwirtschaft, Bromberg, Bd. 5, Heft 2, p. 143–170, fig. 2–7.

KÜHN, J. G.

1859. Die Krankheiten der Kulturgewächse, ihre Ursachen und ihre Verhütung. Aufl. 2, Berlin, p. 200.

LOCHOW, F. von.

1910. Prüfung auf Leistung bei der Kartoffelzüchtung. Illustrierte Landwirtschaftliche Zeitung, Jahrg. 30, No. 16, p. 135–136, illus.

LOUNSBURY, C. P.

1909. Plant and fruit import regulations. Report, Government Entomologist, [Cape of Good Hope], 1908, p. 58–60.

1910. Internal plant and fruit regulations. Report, Government Entomologist, [Cape of Good Hope], 1909, p. 84.

MANNS, T. F.

1911. Fusarium blight (wilt) and dry rot of the potato. Preliminary studies and field experiments. Ohio Agricultural Experiment Station, Bulletin 229, p. 299–337, illus.

ORTON, W. A.
1902–1907. Plant diseases in the United States in 1901–1906. U. S. Department of Agriculture, Yearbook, 1901, p. 668–672; 1902, p. 714–719; 1903, p. 550–555; 1904, p. 581–586; 1905, p. 602–611; 1906, p. 409–508.
1909. Potato diseases in San Joaquin county, California. U. S. Department of Agriculture, Bureau of Plant Industry, Circular 23, 14 p.
1913. Potato leaf-roll. U. S. Department of Agriculture, Bureau of Plant Industry, Circular 109, p. 7–10.
1913. Potato-tuber diseases. U. S. Department of Agriculture, Farmers' Bulletin 544, 16 p., 16 fig.
1913. Powdery dry-rot of the potato. U. S. Department of Agriculture, Bureau of Plant Industry, Circular 110, p. 13–15.

PETHYBRIDGE, G. H.
1910. Potato diseases in Ireland. Department of Agriculture and Technical Instruction, Ireland, Journal, v. 10, no. 2, p. 241–256, 8 fig.
1911. Leaf roll and "curl." Department of Agriculture and Technical Instruction, Ireland, Journal, v. 11, no. 3, p. 447–449.
1912. "Curl" and "leaf-roll." Department of Agriculture and Technical Instruction, Ireland, Journal, v. 12, no. 2, p. 354–356, fig. 3–4.

QUANJER, H. M.
1913. Die Nekrose des Phloëms der Kartoffelpflanze, die Ursache der Blattrollkrankheit. Mededeelingen, Rijks Hoogere Land-, Tuin- en Boschbouwschool, [Wageningen], deel 6, afl. 2, p. 41–80, pl. 2–9.

REINKE, JOHANNES, and BERTHOLD, G.
1879. Die Zersetzung der Kartoffel durch Pilze. Berlin. 100 p., 9 pl. (Untersuchungen, Botanisches Laboratorium, Universität Göttingen, Heft 1.)

REITMAIR, O.
1912. Biologische Studien über die Blattrollkrankheit der Kartoffel. (Mitteilungen des Komitees zum Studium der Blattrollkrankheit der Kartoffel, No. 4.) Zeitschrift für das Landwirtschaftliche Versuchswesen in Oesterreich, Jahrg. 15, Heft 1, p. 1–106.

REMY, TH., and SCHNEIDER, G.
1909. Beobachtungen über das Auftreten der Blattrollkrankheit. Fühlings Landwirtschaftliche Zeitung, Jahrg. 58, Heft 6, p. 201–219.

ROLFS, F. M.
1902. Potato failures. A preliminary report. Colorado Agricultural Experiment Station, Bulletin 70, 19 p., 12 pl.
1904. Potato failures. A second report. Colorado Agricultural Experiment Station, Bulletin 91, 33 p., 5 pl.

SCHANDER, RICHARD.
[1911.] Versuche mit Stecklingen, Veredelungen usw. Mitteilungen, Kaiser Wilhelms Institut für Landwirtschaft, Bromberg, Bd. 4, Heft 1, p. 57–58.
1912. Beiträge zur Kultur der Kartoffel. Mitteilungen, Kaiser Wilhelms Institut für Landwirtschaft, Bromberg, Bd. 5, Heft 2, p. 136–143, fig. 1.

SCHULTZ, G. (Soest.)
1905. Entartung der Magnum bonum—Kartoffel? Deutsche Landwirtschaftliche Presse, Jahrg. 32, No. 91, p. 760, fig. 872–875.

SELBY, A. D.
1903. A rosette disease of potatoes, attributed to the sterile fungus Rhizoctonia. Ohio Agricultural Experiment Station, Bulletin 139, p. 53–66, 5 fig.
1903. Studies in potato rosette. II. Ohio Agricultural Experiment Station, Bulletin 145, p. 15–28, 4 fig.

SHIRREFF, JOHN.
1814. On the curled disorder in potatoes. Memoirs, Caledonian Horticultural Society, v. 1, p. 60–64.

SMITH, ERWIN F.
1896. A bacterial disease of the tomato, eggplant, and Irish potato. (*Bacillus solanacearum* n. sp.) U. S. Department of Agriculture, Division of Vegetable Physiology and Pathology, Bulletin 12, 26 p., 2 pl.

——— and SWINGLE, D. B.
1904. The dry rot of potatoes due to Fusarium oxysporum. U. S. Department of Agriculture, Bureau of Plant Industry, Bulletin 55, 64 p., 8 pl.

[SORAUER, PAUL.]
1913. Die neueren Untersuchungen von Quanjer über die Ursache der Blattrollkrankheit der Kartoffel und der Sorauer'sche Standpunkt. Zeitschrift für Pflanzenkrankheiten, Bd. 23, Heft 4, p. 244–253. Also reprinted.

SPIECKERMANN, A.
1911. Beiträge zur Kenntnis der Bakterienring- und Blattrollkrankheiten der Kartoffelpflanze. Jahresbericht, Vereinigung für Angewandte Botanik, Jahrg. 8, 1910, p. 1–19.

STEWART, F. C.
1896. Potato diseases on Long Island in the season of 1895. New York State Agricultural Experiment Station, Bulletin 101, p. 83–86.
1897. Another stem-blight of potatoes. New York State Agricultural Experiment Station, 15th Annual Report, 1896, p. 509–510.
1898. The communicability of potato stem-blight. New York State Agricultural Experiment Station, 16th Annual Report, 1897, p. 421–423.

STÖRMER, K.
1910. Die Blattrollkrankheit der Kartoffeln. Illustrierte Landwirtschaftliche Zeitung, Jahrg. 30, No. 60, p. 565–566.
1911. Abbau und Wiederauffrischung von Kartoffelsorten durch Bodeneinflüsse. Illustrierte Landwirtschaftliche Zeitung, Jahrg. 51, No. 19, p. 177–179.

TOWNLEY, JOHN.
1847. The limited duration of varieties of the potato, and the progressive deterioration of the plant as a species, proved by a consideration of the curl, dry-rot, and other diseases. In his The Diseases, Regeneration, & Culture of the Potato . . . London, p. 67–85.

VANHA, J. V.
1910. Die Kräusel- oder Rollkrankheit der Kartoffel, ihre Ursache und Bekämpfung. Monatshefte für Landwirtschaft, Jahrg. 3, Heft 9, p. 268–276, 2 fig. Also reprinted.

VOLKART, A.
1908. Pflanzenschutz. Die Schweiz. Samenuntersuchungs- und Versuchsanstalt, Zurich, Jahresbericht 30, p. 32–34. Reprinted from Landwirtschaftliches Jahrbuch der Schweiz, Jahrg. 22.

WEBBER, H. J.
1908. Plant breeding for farmers. New York Cornell Agricultural Experiment Station, Bulletin 251, p. 291–332, fig. 135–144.

WOLLENWEBER, H. W.
1911. Untersuchungen über die natürliche Verbreitung der Fusarien an der Kartoffel. Mitteilungen, Kaiserliche Biologische Anstalt für Land- und Forstwirtschaft, [Germany], Heft 11, p. 20–23.
1913. Pilzparasitäre Welkekrankheiten der Kulturpflanzen. Berichte, Deutsche Botanische Gesellschaft, Bd. 31, Heft 1, p. 17–34. Also reprinted.
1913. Studies on the Fusarium problem. Phytopathology, v. 3, no. 1, p. 24–50, fig. 1, pl. 5.

○