ROOT DISEASES OF DECIDUOUS FRUIT TREES

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INTRODUCTION

Wherever deciduous fruit trees are grown, losses from root troubles occur. In one place one disease will be the most important and in another region an entirely different disease will prevail. The root troubles affecting the pome fruits in the main are different from those affecting stone fruits. From the orchardists' point of view, root diseases may be very disconcerting, since they usually begin taking their heavy toll of trees about the time the orchard starts bearing. Before an orchardist sets out another tree in the spot where one has died he should know what caused the death of the tree. If it was poor drainage, remedial steps may be taken. If a parasitic root disease caused the tree to die, a replant will probably die also. Even though a definite remedy for a certain disease is not known, information about the nature of the disease may be valuable.

The object of this paper is to give a brief discussion of the present status of information on root diseases of deciduous fruit trees. The emphasis is here placed on the diseases rather than on the mycological aspects of the pathogens. Such a treatment will place the emphasis on the host and the effect of various environmental factors on its resistance and susceptibility. Root diseases of certain herbaceous and woody cultivated plants have been reviewed by Simmonds (46) and by Berkeley (3), while Garrett (21) has reviewed the relation of the pathogen to the soil environment and the influence of such environmental factors on the propagation and maintenance of the pathogens of a number of root diseases. Garrett (22) has recently given a still more comprehensive treatment of the root disease problem.

The writer has attempted, as well as may be, to make this discussion worldwide in its scope and application. However, he is most familiar with conditions in the eastern part of the United States where for 12 years he worked on root diseases of fruit

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trees, and for that reason it may be that the root diseases of this region will be more comprehensively treated than those of other regions.

In discussing the infectious diseases of pome and stone fruits, the more important ones will be treated first. Since many root troubles may be traced to physiological conditions, a brief discussion of the non-parasitic disorders and their possible relation to other root troubles will follow the section on parasitic diseases.

Many viruses, such as those causing phony peach, mosaic, yellows and peach rosette, may invade the roots, but since they do not produce symptoms in the root they will not be discussed in this paper; neither will root troubles resulting from improper use of chemicals for borer control be discussed.

Root troubles occurring in widely separated regions and on plants growing under very different environmental conditions have been studied by various workers who have attributed the particular types of trouble to one or another of a number of different things. Nematodes and woolly aphids often produce extensive root gall formation causing a serious devitalizing effect and therefore still further complicate the root disease problem. Many root troubles, however, can not be attributed to one single causal agent, as has often been done, but rather to a number of concomitant factors.

POME FRUITS

The principal root diseases of pome fruit trees occur on the apple, and these will be discussed first, followed by a mention of the root diseases of pear.

Apple

Black Root Rot. The most common and destructive parasitic root disease of apple trees is the black root rot (*Xylaria mali* Fromme). Most of the many species of the genus *Xylaria* are harmless saprophytes; a few are parasitic. A root disease of hibiscus (30) and root diseases of *Hevea* rubber trees (47) in the tropics have been reported as due to species of this genus. However, the black root rot (*Xylaria mali*) of the apple is the only root disease of importance occurring in the temperate zone that is known to be caused by a species of *Xylaria*. This disease is very restricted in its distribution. It occurs in the southeastern and south-central part of the United States, the region of its greatest prevalence extending from Maryland as far south as the apple is grown and west through Arkansas (10).

A tree affected with black root rot may show one or more rather definite characters which permit identification of the disease. Large finger-like fruiting bodies are frequently found at the base of diseased trees. These fruiting stromata are white at first, when an abundance of unicellular hyaline conidia are formed on them. Soon the fruiting bodies turn black, and by autumn mature ascospores have formed. A distinguishing character which is useful in the absence of fruiting bodies is the black charcoal-like stromatic coating on affected roots. The above-ground parts show secondary symptoms indicative of root trouble, but they are not distinctively different from those associated with other severe root disorders (18).

The disease spreads from root to root of an individual tree, and in three or four years a tree of bearing age may succumb to the disease. Although the disease is not highly contagious, each year a few more trees are affected so that eventually as many as 25% of the trees may have been removed from an orchard because of this disease.

Monthly inoculations over a period of several years gave an infection curve that made a rapid rise in June, reached its peak of 85% infection in July and then declined rapidly to nearly nothing in September (12). There is some evidence that this period of high infectibility in midsummer is associated with a period of low root activity of the host; that is, the curve of infection would be the inverse of the curve of root activity (12). Inoculation studies on nursery trees indicate that trees maltreated by severe summer pruning or by root pruning are more susceptible to *Xylaria* infection than are untreated checks. Field observations seem to support the hypothesis that trees growing under adverse conditions are more susceptible to infection than those growing under more nearly optimum conditions (10, 12).

Experiments are in progress to obtain more information as to whether or not replanting can be done safely where diseased trees have been removed, but the results have not been determined yet. According to the information now available it is not advisable to replant where trees that died of black root rot have been removed.

Searches for resistant stocks indicate that some stocks are more resistant than others, but a highly resistant stock has not yet been found (39, 20, 18, 19, 10, 13).

White Root Rot. A white root disease of apple and other trees has been described recently as occurring in the eastern and central parts of the United States (15). The fungus causing this disease (*Corticium galactinum* (Fr.) Burt) is widespread as a saprophyte both in this country and in other countries. Since the pathogen is so widespread and attacks such a wide variety of hosts, it may be that this disease is much more extensively distributed than is now known.

The most striking symptom is a thick weft of white mycelium covering the surface of affected roots. In the initial stages of infection the mycelium gradually kills the bark from the outside inwards and gradually advances to the cambium which it kills in spots. The living tissue surrounding these killed areas may begin to lay down walling-off tissue, but before much progress has been made the fungus usually kills farther. This process leaves bird's-eye-like or zonate spots on the wood surface of affected roots. If the bark is removed these zonate spots characteristic of white root rot are visible on the surface of the wood. In some cases, before the root is finally killed, bark and wood continue to grow around a spot where the cambium has been killed, thus giving a knotty and knarled aspect to affected roots. Finally the wood of affected roots is completely rotten and therefore very soft and lightweight. The fruiting of the pathogen is an inconspicuous hymenial layer, readily distinguishable from the white mycelium by its buff to ocherous color. The hymenial layer may be formed at any time in summer or autumn when conditions are favorable, but usually in autumn. It is formed on the surface of the soil at the base of the tree or in open pockets in the soil. Small unicellular hyaline basidiospores are produced in great abundance (15).

Trees of pre-bearing age are apparently less susceptible to white root rot than those of bearing age. In the unpublished experiments of the writer there are cases in which five-year-old apple trees were successfully inoculated one year and by the next year the lesions, which evidently did not involve the cambium, were completely healed over. Field observations indicate that bearing trees are more susceptible than those of pre-bearing age, a condition that Baines (2) found to obtain with *Phytophthora* collar disease of apple trees.

The writer has made numerous observations on the distribution of white root rot and has always found it attacking trees growing in new land which has been recently cleared or in land adjacent to woodland. This root disease, unlike black root rot, affects a large number of hosts such as dogwood (*Cornus florida* L.), blackberry (*Rubus alleghaniensis* Porter), holly (*Ilex opaca* Ait.) and a number of ornamental shrubs (15). Cases are known in which ornamental shrubs were planted on stumpy land and all the shrubs near the stumps were killed by this disease. The knowledge that the pathogen is so intimately associated with roots and stumps in the soil may be useful in choosing an orchard site or in combating the disease if it gets started in a planting of ornamental shrubs.

Phytophthora Root Rot. A serious collar disease of apple trees was until recently considered to be caused by the pear blight pathogen (*Erwinia amylovora* (Burr.) Winsl.) (33). It is now known that *Phytophthora cactorum* (Leb. and Cohn) Schroet. is the cause of collar blight (2). Some varieties are much more suceptible than others, Grimes Golden being especially susceptible. Formerly it was considered that this disease affected primarily the trunk. Within the past decade, however, a form of the disease has been reported that extends well down on the roots of apple trees (57). Some symptoms of affected roots show similarity to the collar blight type of the disease; namely, a water-soaked area when the disease is active, later followed by a crack or definite line of demarcation between the healthy and affected tissue. It is possible that *Phytophthora* is more prevalent as a root rot than is now known, because the pathogen is difficult to isolate and the disease is very similar to such environmental disturbances as winter injury, and therefore diagnosis may be uncertain. Further work is necessary to determine the prevalence of and the importance of *Phytophthora* as a root rot disease of apple trees.

Crown Gall. Since crown gall (*Agrobacterium tumefaciens* (E. F. Sm. and Town.) Conn) is concerned to a considerable extent with root tissue, it should be considered in this discussion of root diseases. The workers on crown gall have recognized two types of infectious formations, *viz.*, the gall type on the collar and roots (caused by *Agrobacterium tumefaciens* (E. F. Sm. and Town.) Conn) and the hairy-root form (caused by *Agrobacterium rhizogenes* (Riker *et al.*) Conn) which is characterized by excessive fibrous root productions (38, 43). In addition to these infectious malformations caused by specific pathogens there are two non-infectious malformations, *viz.*, non-infectious hairy root (42) and non-infectious overgrowths around graft wounds. Some varieties of apples are much more susceptible to graft-wound overgrowths than others (38, 40, 45).

Crown gall may affect a large number of fruit plants, but for convenience we will discuss it among the apple diseases. It is a more serious disease on nursery stock than in orchards. As many as 50% of nursery trees are sometimes discarded because of this trouble. Infection usually takes place at the wounds made in grafting and also at wounds made by the sharp edges of the endocarp of stone fruits (44) during emergence of the seedling.

Application of control methods has reduced nurserymen's losses in recent years. Control methods include disinfecting the seeds of stone fruits (44), disinfecting seedlings (40, 45), wrapping graft wounds to prevent infection (38), and acidifying the soil (41).

Rotation of crops has been recommended as a method of combating crown gall of roses in the nursery (29) and may be useful in fruit-tree nurseries.

Rosellinia. In Europe a white root rot of grape vines and also of various fruit and forest trees has been attributed to the fungus *Rosellinia necatrix* (Hartig) Berl. which belongs to the Tuberaceae or truffle family (32). This disease has been reported recently as a cause of serious losses of apple trees in California (53). In the case of *Rosellinia* root rot, in contrast to *Armillaria* root rot, there are no rhizomorphs. Roots affected with *Rosellinia* root rot are covered by profuse cottony mycelium which extends into the adjacent soil. Very little field work has been reported on the relation of environmental conditions to infection.

A serious root rot has been reported as occurring in New Zealand, where it attacks the apple and many other woody plants. The causal organism has been provisionally given as *Rosellinia radiciperda* Mass. (17). The disease occurs only in orchards planted on newly cleared land and on land where nursery trees have been grown. In this respect it is like the *Corticium* white root rot described above (15).

Rhizoctonia. A damping-off and also a collar disease affecting layers, shoots or young seedlings is caused by *Rhizoctonia solani* Kuehn. Although this pathogen primarily attacks herbaceous plants, it may cause serious losses of young and tender layer shoots of apple trees. A method of propagating own-rooted trees consists of bending and fastening down the young trees and covering them with soil. The shoots arising from the prostrate branches are very susceptible to attack by *Rhizoctonia.* This fungus may cause damping-off about the time of emergence, or it may cause a collar blight by producing numerous deep lesions below the soil line. Control methods consisting of numerous soil treatments were tried without results (16). Possibly a change in method of propagation will need to be employed in cases where the disease is serious.

Sclerotium rolfsii Sacc. This pathogen has recently been found to cause a collar blight on apple nursery trees (8, 55, 4). This disease is not always confined to nursery trees. The author has noted orchard trees as much as four years old affected by it. In midsummer a weft of white mycelium forms on the main stem of a tree at the ground level or lower. Soon the white mycelium disappears and brown sclerotia about the size of mustard seeds form on the soil and on the trunk about the collar. Since some cover crops are so much more susceptible than others to this disease, it is not unlikely that the character of the cover crop in the rotation in the nursery or even in a young orchard may affect the destructiveness of the disease. Certain legumes, particularly *Lespedeza stipulacea* Maxim., are especially susceptible (8). Recent experiments with this disease on sugar beets show as much as 65% reduction in infection by application of nitrogenous fertilizers (28).

Phymatotrichum. The cotton root-rot fungus, *Phymatotrichum omnivorum* (Shear) Dugg., may attack and kill apple trees when grown in regions where the disease abounds (49). Since the region of the cotton root-rot disease is outside the range for commercial apple culture, it does not seriously affect apple production.

Armillaria. Armillaria root rot has been reported as affecting apple trees in the western part of this country and in other countries (59, 7). In the eastern and central part of the United States it is not a serious apple root disease.

Clitocybe. A mushroom root rot (*Clitocybe tabescens* (Scop.

ex Fr.) Bres.) somewhat resembling *Armillaria* root rot has been reported on apple trees (37), but it is not known to be a serious disease on this host. A partial explanation may be that the region where the pathogen thrives is south of the region where the apple is extensively grown.

Pear

The regions in the eastern United States where pears are extensively grown are north of the region where root diseases of the apple are most prevalent. Scattered pear trees growing in home orchards near apple trees affected with black root rot have been examined frequently by the writer, but no black root rot or other parasitic root diseases were observed. Inoculation tests with *Xylaria mali* indicate that the pear is highly resistant to this root disease (10). The fact that the usual root diseases of the apple have not been reported in the literature as causing serious diseases on the pear is further evidence that the pear is probably much less susceptible to root diseases than the apple. Observations of the writer of pear trees growing in the commercial pear-growing districts of Oregon and Washington also indicate that the pear is less susceptible to environmental root disturbances than the apple.

Pear blight (*Erwinia amylovora* (Burr.) Winsl.) may occur on the roots as well as the tops and cause a serious root disease. A root form of blight infection usually is due to the spread of the pathogen downward in the trunk or sprouts and then into the roots, or rarely root infection may take place directly from the pathogen in the soil (51). The root form of this disease is confined largely to those regions of the West Coast of the United States where the temperature is warm enough for the organism to thrive. The remedial treatment for the root form of the disease involves the same method of cutting out cankers and disinfecting the wounds as is used in the control of the disease in the aboveground parts (51).

Crown gall attacks pear trees as well as other fruit trees. The discussion of this disease on the apple is also applicable to the pear.

A mushroom root rot (*Clitocybe tabescens* (Scop. ex Fr.) Bres.) has been reported as causing a root rot of pear trees (34) in Louisiana, but no other report of this pathogen's attacking the pear has been noted. *Armillaria* root rot (*Armillaria mellea* Vahl ex Fr.) attacks the pear (7), but it is not known to cause serious losses in the United States.

STONE FRUITS

The root disorders of the cherry are here briefly summarized separately from those of the peach and other stone fruits. They are mainly of a non-parasitic nature, and the general discussion of non-parasitic diseases applies to the cherry as well as to the apple and other tree fruits. Although the losses caused by root disturbances in the cherry are of frequent occurrence and often of great magnitude, there is very little literature on the subject.

Cherry

The cherry is very susceptible to adverse environmental conditions, especially those of the soil. This is particularly true of the sweet cherry. While the cherry is grown in a wide range of soil and climate, many of these conditions are not suited to optimum development. Perhaps because of this condition environmental root disturbances are especially prevalent on the cherry and can usually be traced to unfavorable conditions resulting from hardpan, seepage or poor drainage. *Armillaria* frequently invades roots that have been thus affected.

Peach and Other Stone Fruits

Most of the literature dealing with root rots of stone fruits is concerned with peaches. For the present discussion of root troubles the peach will be taken as representative of a group of stone fruits which includes also plums, apricots and almonds.

Armillaria Root Rot. The main parasitic root disease of stone fruits is the *Armillaria* root rot (*Armillaria mellea* Vahl ex Fr.). The fungus causing this disease is very widespread as a saprophyte, occurring on stumps in woods throughout this country and in other countries. In the western part of the United States it causes severe injury to peach and other stone fruits and occurs on a wide variety of woody plants as well as on some herbaceous ones (27). In other parts of this country losses are very slight from this disease (11). In certain localities, however, where there is considerable loss from root troubles, *Armillaria* root rot is present and may seem to be causing considerable loss, but other complicating factors are also operating, so that it is difficult to determine to what extent this root rot organism is a primary cause or is merely attacking already moribund roots (11). Losses from this disease are reported from South Africa and other countries (56).

An important diagnostic character is the presence of string-like rhizomorphs or black root-like growths over the surface of affected roots, hence the name "shoestring root rot". Another diagnostic character is the formation of white or cream-colored fan-shaped sheets of fungus filaments in the outer layer of the root and collar region. Clumps of tan-colored mushrooms may appear in late summer or early fall on the diseased roots or at the collar of diseased trees and serve as another identification character (27).

The extensive literature on this disease has been listed and discussed by Reitsma (35).

Probably much light would be thrown on the nature of this disease if one could correlate its distribution with the ecology of the host and of the pathogen. Although the pathogen is worldwide in its distribution, there are relatively few regions, such as semi-arid regions of the Pacific Coast of America and in South Africa and Australia, where it is reported to be a serious disease.

One of the limiting factors in the distribution of *Armillaria* root rot may be soil temperature. Inoculation experiments of peach and apricot seedlings in California showed moderate infection at 10° C. and severe infection at 17°–24° C., while the greatest root growth of the peach was at 10° C. and of the apricot at 17° C. (5). Further studies may demonstrate that the regions where *Armillaria* causes a serious root rot are regions of high soil temperatures.

From the nature of the case any remedial treatment is difficult and expensive. Thomas of the University of California (54) has successfully used a soil treatment with carbon bisulphide.

Phymatotrichum omnivorum (Shear) Dugg., the pathogen of the cotton root rot, may affect the peach and other stone fruits (49), but the region of its prevalence is not where peach trees are grown extensively.

Corticium galactinum (Fr.) Burt, causing white root rot, may affect peach and other stone fruit trees (15), but it is not now known to cause a serious orchard disease.

Agrobacterium tumefaciens (E. F. Sm. and Town.) Conn, causing crown gall, may seriously affect the roots of nursery trees by producing galls on the roots (40, 41, 44, 45). If trees having galls are culled out at planting time there is usually very little of the disease in a mature orchard. Crown gall is reported to be a serious orchard disease of almond and peach trees in certain parts of California, and in those regions it may be the limiting factor in almond production. A method of successfully killing galls on living trees has been devised (1). (See crown gall under apple root diseases.) Also preliminary investigations with penicillin in the treatment of galls on living *Bryophyllum* plants indicate further possibilities from local applications to kill the crown gall pathogen in the galls (6).

NON-PARASITIC DISEASES

It often requires considerable investigation to determine whether a certain fungus is growing as a saprophyte on a dying root or as the causative agent. Root troubles are further confused by the resemblance of a wide variety of environmental and physiological disturbances to those caused by some pathogenic organisms. Many times conditions are unfavorable for proper functioning of the host plant, and some pathogenic or saprophytic organisms growing on such weakened hosts may seem to cause trouble but in reality are largely secondary. A knowledge of these non-parasitic disturbances is requisite for a correct understanding of root troubles. The important causes of non-parasitic root diseases of fruit trees arranged roughly in the order of their importance are winter injury, poor soil aeration, drought, shallow soil, high water table and incompatibility of stock and scion.

Winter Injury. The place where root and top meet, usually spoken of as the collar, is very important from the standpoint of root diseases. This region is the last to mature in the fall, often not before cold weather (48). Root tissue is much more susceptible to cold injury than top tissue (31). Inadequate snow covering at the collar of a tree when low temperatures prevail may result in winter injury to the collar and shallow roots.

For many years collar injuries to apple trees have been known and have been the subject of investigation (23, 24, 50). This type of trouble may be observed on apple trees growing in a wide range of ecological conditions, as in the mountains of North Carolina, Virginia, Pennsylvania and New York, and in the semi-arid regions of Colorado, Utah, Washington and British Columbia. The environmental conditions in these places are widely divergent, and the complex conditions resulting in collar injury are undoubtedly very different. Accordingly the trouble has been attributed to many causes. In the irrigated and semi-arid regions it has been attributed to alkaline irrigation water, to arsenical injury (25), to excessive nitrate (26) and to winter injury (31). In the more humid regions pear blight was considered important in causing a collar disease (33).

Welsh (57), working in British Columbia, has recently shown that *Phytophthora cactorum* causes collar and root injury. This information that *Phytophthora* may cause at least one type of collar disease has thrown some light on the confusion about the cause of collar rots. However, further study is necessary to learn to what extent collar injuries are due to *Phytophthora*. Since the symptoms of *Phytophthora* and of pear blight may be quite similar to each other and since *Phytophthora* is now known to cause a disease of the below-ground parts of apple trees, perhaps some of the trouble previously attributed to pear blight and possibly other causes will be found in reality to be caused by *Phytophthora*.

Undoubtedly winter injury is one of the important factors contributing to this type of disturbance (23, 24, 50, 31). There are many factors entering into the winter injury complex other than low temperature. The physiological status of the tree is just as important as the weather. It is not possible to state a definite temperature which causes winter injury. Autumn temperatures are often so mild that trees continue to grow late in the season. A sudden drop in temperature after this mild weather may cause serious collar injury. Similarly in the spring freezing temperatures after dormancy has broken may cause serious collar injuries. In regions of low rainfall inadequate moisture at the advent of cold weather may be a contributing factor to collar winter injury.

Cold injury at the collar may be localized and thus completely kill a spot of relatively small area. On the other hand, the injury may be generalized and therefore the vigor and vitality of the whole tree be affected. Killed or weakened tissue may become a good court of entrance for parasitic or weakly parasitic fungi. Many times it is difficult to determine whether some fungus is incidental to winter injury or is the primary cause of the disturbance.

Winter injury may be intimately associated with a number of nutritional and environmental disturbances. Any devitalizing tendency may cause a tree to be more susceptible to winter injury than normally. A tree growing in waterlogged soil or weakened by overbearing is more susceptible to winter injury than it otherwise would be.

Poor aeration may be associated directly or indirectly with many types of root injury. The possibility of poor aeration should always be considered in diagnosing root disorders. Serious root trouble can often be corrected by providing adequate drainage.

Shallow soil, hardpan and high water table are related conditions which are directly or indirectly responsible for many root troubles that may be classed as drought injury.

Incompatibility of stock and scion may possibly be responsible for some obscure root disturbances where the cause of the trouble is not readily determined. Poor growth and loss of apple trees have been reported where Siberian crab was used as stock (58). Unpublished work of Guy E. Yerkes at the Plant Industry Station at Beltsville, Maryland, records a case where Stayman Winesap, Wealthy, and other varieties died within two years when worked on a certain clonal stock (Spy 227) of Northern Spy origin.

GENERAL DISCUSSION AND REMEDIAL MEASURES

Many root troubles of fruit trees are very obscure and imperfectly understood. The progress of a disease on tree roots can be learned only by digging. Since they require much time, effort and special tools, observations on roots can not conveniently be made in conjunction with other routine disease studies. Frequent observations during the year are necessary to learn the nature of a root disease; but such observations complicate the problem, since disturbance of the roots and soil to make them may create abnormal conditions.

In any study of root diseases the physiology of the host must be taken into consideration. Vigorous trees not only are less likely to develop the non-parasitic disturbances mentioned above, but they are also more resistant to parasitic diseases than are trees in unsuitable soil or suffering from improper orchard practices.

A number of remedial treatments for root rots on fruit trees as well as on other plants have been proposed, but most of them are not now in use. Some of the remedial measures that have been proposed for root rots of other hosts than fruit trees, if they had merit *per se,* could probably be adapted to fruit trees. But many of these recommendations are impractical and others are based on little or no experimental work.

Remedial treatments for root troubles are of necessity very restricted, and often they may be so slightly effective as to be impractical.

Soil disinfection will probably prove useful in certain special conditions. It is not only expensive and laborious but it has the added disadvantage when used against a disease of a perennial plant, such as a fruit tree, that if it is effective in killing a fungus parasite it will probably kill the living host plant and may even kill adjacent non-infected plants. Soil disinfection with carbon bisulphide has been successfully used in California as a means of eradicating *Armillaria* from an infested area in an orchard (54).

Fertilizing with the usual mineral fertilizer elements alone or in combination with heavy applications of stable manure was not effective in preventing infection from artificial inoculation with *Xylaria mali.* However, these tests did not include the factors of prolonged viability of natural inoculum and persistence of the disease in nature (14). Infection of *Sclerotium* on sugar beets, however, has been greatly reduced by application of nitrogenous fertilizers (28).

The field of resistant understocks has not been explored as much as it should be. Searches have been made for an apple stock that would be resistant to black root rot, and the results show that various stocks have differences in resistance, but a highly resistant one has not yet been found (20, 13, 18). Many of the possibilities in this fertile field are still unexplored. There is always the possibility that a more compatible rootstock or one better suited to some even slightly adverse soil condition will prove to be more resistant to root diseases.

Changing the soil reaction probably has very definite limitations in combating such soil organisms as *Corticium* and *Xylaria* and other pathogens that live in the roots of the host plant and thrive in the soil so long as there are roots of some host plant on which they can feed. However, the widely distributed soil organism causing crown gall does not thrive in an acid soil, and changing the soil reaction sufficiently for it to be unfavorable to the crown gall organism may be a mode of attack on crown gall in the fruit tree nursery (41).

A method of combating crown gall when it becomes established on orchard trees is the local application of a chemical to the gall. This unique type of control is applicable only to such a localized pathogen and even there it has its limitations (1).

Sanitary measures, such as hauling instead of dragging from the orchard trees that have been removed because of root disease, should be effective in preventing the spread of the pathogen of parasitic diseases such as black root rot and white root rot.

Locating the orchard on land free from stumps rather than on stumpy new land should be a useful precaution against starting an epidemic of such a disease as white root rot.

Possibly the most important application of the work that has been done on root troubles lies in the field of prevention. Most of the root troubles of fruit trees are more serious when the host plant is at a disadvantage. It is, therefore, important that the orchard be located in a region to which the particular fruit plant is adapted, and also that the site, topography and fertility of the soil be favorable so that the minimum of unfavorable environmental influences will prevail. Many of the most serious root troubles discussed in this paper are troubles of old or at least mature trees. When good culture and favorable environment are provided, a uniform stand of thrifty trees will result and profitable crops will probably be produced before these root troubles begin taking a heavy toll of trees. When such favorable conditions are provided, the orchard will probably be more profitable while it is producing and not become unprofitable because of root rot so soon as an orchard growing under less favorable conditions.

The trend of study of this group of difficult-to-control diseases will probably be more and more in the direction of learning the rôle of adverse environment in producing non-parasitic disturbances and also the effect of various environmental conditions on susceptibility and resistance to parasitic root disturbances. Probably in many cases specific recommendations for control can not be made, but an intimate knowledge of the disease in relation to all factors of environment may prove to be very important in preventing root troubles.

LITERATURE CITED

1. Ark, P. A. Chemical eradication of crown gall on almond trees. Phytopathology 31: 956–957. 1941.
2. Baines, R. C. Phytophthora trunk canker or collar rot of apple trees. Jour. Agr. Res. 59: 159–184. 1939.
3. Berkeley, G. H. Root rots of certain non-cereal crops. Bot. Rev. 10: 67–123. 1944.
4. Birmingham, W. A. Another fungus attacking apple stocks. Agr. Gaz. New South Wales 64: 58–60. 1933.
5. Bliss, D. E. Relation of soil temperature to Armillaria root rot in California. Phytopathology [Abs.] 31: 3, 1941.
6. Brown, J. G., and Boyle, Alice M. Penicillin treatment of Crown Gall. Science 100: 528. 1944.
7. Carne, W. M. Root rot of fruit trees due to *Armillaria mellea*. West Austral. Dept. Agr. Jour. 2d ser. 3: 429–432. 1926.
8. Cooley, J. S. *Sclerotium rolfsii* as a disease of nursery apple trees. Phytopathology 26: 1081–1083. 1936.
9. ———. Susceptibility of crop plants and weeds to *Sclerotium rolfsii*. Phytopathology 28: 594–595. 1938.
10. ———. Factors affecting distribution and severity of black root rot of apple trees. Jour. Agr. Res. 65: 299–311. 1942.
11. ———. Armillaria root rot of fruit trees in eastern United States. Phytopathology 33: 812–817. 1943.
12. ———. Some host parasite relations in the black root rot of apple trees. Jour. Agr. Res. 69: 449–458. 1944.
13. ———. Susceptibility to black root rot of apple trees having various root and top combinations. Phytopathology 35: 142–143. 1945.
14. ———. The effect of manure and of commercial fertilizer on susceptibility of young apple trees to black root rot. Phytopathology 35: 207–209. 1945.
15. ——— and Davidson, Ross W. A white root rot of apple trees caused by *Corticium galactinum*. Phytopathology 30: 139–148. 1940.
16. ——— and Lincoln, B. F. A disease of apple grafts and layers caused by a Rhizoctonia. Phytopathology 33: 255–257. 1943.
17. Cunningham, H. H. Fungous diseases of fruit trees in New Zealand. 1925.
18. Fromme, F. D. The black root rot disease of the apple. Va. Agr. Exp. Sta., Tech. Bul. 34: 52. 1928.
19. ——— and Thomas, H. E. Black root rot of the apple. Jour. Agr. Res. 10: 163–174. 1917.
20. ——— and Schneiderhan, F. J. Studies on black root rot of apple. Phytopathology 28: 483–490. 1938.
21. Garrett, S. D. Soil conditions and the root infecting fungi. Biol. Rev. 13: 158–184. 1938.
22. ———. Root disease fungi. 1944.
23. Grossenbacher, J. G. Crown-rot, arsenical poisoning and winter-injury. N. Y. (Geneva) State Agr. Exp. Sta., Tech. Bul. 12: 369–411. 1909.
24. ———. Crown-rot of fruit trees. Field Studies N. Y. (Geneva) State Agr. Exp. Sta., Tech. Bul. 23: 1–59. 1912.
25. Headen, W. P. Arsenical poisoning of fruit trees. Colo. Agr. Exp. Sta., Bul. 157: 1–56. 1910.

26. ———. The fixation of nitrogen in some Colorado soils. Colo. Agr. Exp. Sta., Bul. 178: 1–96. 1910.
27. HENDRICKSON, A. H. Oak fungus in orchard trees. Calif. Agr. Exp. Sta., Cir. 289: 1–13. 1925.
28. LEACH, L. D. AND DAVEY, A. E. Reducing southern *Sclerotium* rot of sugar beets with nitrogenous fertilizers. Jour. Agr. Res. **64**: 1–18. 1942.
29. LYLE, E. W. Effect of crop rotation on crown gall and root knot in East Texas. Experiment with roses. So. Florist & Nurseryman 52(8): 7–22. 1941.
30. LYON, H. L. An hibiscus disease. Hawaii Planters' Rec. **13**: 361–367. 1915.
31. MAGNESS, J. R. Collar rot of apple trees. Wash. Agr. Exp. Sta., Bul. 236: 1–19. 1929.
32. NATTRASS, R. M. The white root rot of fruit trees caused by *Rosellinia necatrix* (Hart.) Berl. Bristol Univ., Agr. & Hort. Res. Sta., Ann. Rpt. **1926**: 66–72. 1926.
33. ORTON, C. R. AND ADAMS, J. F. Collar blight and related forms of fire blight. Pa. Agr. Exp. Sta., Bul. 136: 1–23. 1915.
34. PLAKIDAS, A. G. Infection with pure cultures of *Clitocybe tabescens*. Phytopathology **31**: 93–95. 1941.
35. REITSMA, J. Studien über *Armillaria mellea*. Phytopath. Ztschr. **5**: 461–522. 1932.
36. RHOADS, A. S. Root rot of the grape vine in Mo. caused by *Clitocybe tabescens* (Scop.) Bres. Jour. Agr. Res. 341–364. 1925.
37. ———. Clitocybe root rot of woody plants in Florida. Citrus Ind. **13**(5): 11, 14. 1932.
38. RIKER, A. J. *et al.* Hairy root, crown gall, and other malformations at the unions of piece-root grafted apple trees and their control. Jour. Agr. Res. **48**: 913–939. 1934.
39. SCHNEIDERHAN, J. F. Root stocks in relation to the black root rot *Xylaria mali* of apple trees. Am. Pomol. Soc., Proc. **52**: 63–66. 1936.
40. SEIGLER, E. A. Crown gall problem still confronts the trade. Am. Nurseryman **55**(3): 66. 1932.
41. ———. Relations between crown gall and pH of the soil. Phytopathology **28**: 858–859. 1938.
42. ———. Noninfectious hairy root. Am. Nurseryman **71**(3): 7. 1940.
43. ——— AND PIPER, R. B. Pathogenesis in the woolly-knot type of crown gall. Jour. Agr. Res. **43**: 985–1002. 1931.
44. ——— AND BOWMAN, J. J. Crown gall of peach in the nursery. Phytopathology **30**: 417–426. 1940.
45. ——— AND ———. Crown gall on budded fruit trees. Am. Nurseryman **75**(3): 7–9. 1942.
46. SIMMONDS, P. M. Root rots of cereals. Bot. Rev. **7**: 308–332. 1941.
47. STEINMANN, A. Diseases and pests of *Hevea brasiliensis* in Netherland Indies. 1927.
48. SWARBRICK, T. Studies in the physiology of fruit trees. 1. The seasonal starch content and cambial activity in one- to five-year-old apple branches. Jour. Pom. & Hort. Sci. **6**: 137–156. 1927.
49. TAUBENHAUS, J. J. AND EZEKIEL, W. N. Cotton root rot and its control. Texas Agr. Exp. Sta., Bul. 423: 1–39. 1931.
50. THOMAS, H. EARL. Root and crown injury of apple trees. N. Y. (Cornell) Agr. Exp. Sta., Bul. 448: 1–9. 1926.
51. ——— AND ARK, P. A. Fire blight of pears and related plants. Calif. Agr. Exp. Sta. Bul. 586: 1–43. 1934.

52. ———— AND MACDANIELS, L. M. Freezing of roots and crowns of apple trees. N. Y. (Cornell) Agr. Exp. Sta. Bul. 556: 1–23. 1933.
53. THOMAS, HAROLD E., HANSEN, H. N. AND THOMAS, H. EARL. Dematophora root rot. Phytopathology [Abst.] 24: 1145. 1944.
54. ———— AND LAWYER, L. O. The use of carbon bisulphide in the control of Armillaria root rot. Phytopathology [Abst.] 29: 827–828. 1939.
55. TURNER, T. W. Pathogenicity of *Sclerotium rolfsii* for young apple trees. Phytopathology [Abst.] 26: 111. 1936.
56. WALLACE, G. B. *Armillaria mellea* in East Africa. East African Agr. Jour. 1: 182–192. 1935.
57. WELSH, M. F. Studies of crown rot of apple trees. Canad. Jour. Res. 20: 457–490. 1942.
58. YERKES, G. E. AND SUDDS, R. H. Influence of the stock on the performance of certain apple varieties. Am. Soc. Hort. Sci., Proc. **36**: 116–120. 1938.
59. ZELLER, S. M. Observations on infections of apple and spruce roots by *Armillaria* (Vahl). Phytopathology **16**: 479–484. 1926.