UNIVERSITY OF MISSOURI . COLLEGE OF AGRICULTURE
AGRICULTURAL EXPERIMENT STATION
COLUMBIA, MISSOURI
M. F. MILLER, *Director*

CIRCULAR 305 Columbia, Missouri AUGUST, 1945

Phloem Necrosis, a Destructive Disease of the American Elm

C. M. TUCKER[1]

INTRODUCTION

The American elm (*Ulmus americana*) is the most highly prized tree for home and street plantings in most communities in Missouri. Its habit of growth makes the species particularly desirable for street plantings. The upright branches form a high arch which does not interfere with traffic, and the foliage of moderate density permits the passage of sufficient light to encourage the growth of grasses. The American elm is native in Missouri, occurring along water courses in all sections of the State. City plantings, formerly, were often made by transplanting small elms from the woods. In recent years plantings of nursery trees of the improved vase and moline types, both varieties of the American elm, have been made so extensively that, in certain localities, approximately 90 per cent of the street trees are American elms.

The elm has considerable value as a source of lumber, but its wide use for ornament and shade gives it a much greater intangible value that cannot be expressed in monetary terms. It is adapted to a wide variety of soil types and terrains. It is drought-resistant, and in the past, has been relatively free from serious diseases that might destroy it.

The appearance of a disease which threatens the species has caused great concern among home owners, nurserymen and city

[1]The writer has drawn freely on the publications of Roger U. Swingle, Pathologist, Bureau of Plant Industry, in charge of investigations on phloem necrosis at the Columbus, Ohio, laboratory.

officials. This interest resulted in an appropriation, in 1945, by Congress, of funds to expand investigations on the control of the disease. Under a cooperative arrangement between the Bureau of Entomology and Plant Quarantine, the Bureau of Plant Industry, the University of Missouri, and the Parks Department of Kansas City, Missouri, experimental work was initiated in the Kansas City area in July, 1945.

DISTRIBUTION AND HOSTS

Phloem necrosis is known to occur in the following states: West Virginia, Kentucky, Tennessee, Mississippi, Ohio, Indiana, Illinois, Missouri, Kansas, Arkansas[2], Oklahoma[2], Iowa[2] and Nebraska[2]. (Fig. 1.) It has not been reported from other parts of the world. The area in which the disease occurs is bounded on the north, roughly, by the fortieth parallel of latitude. Peoria,

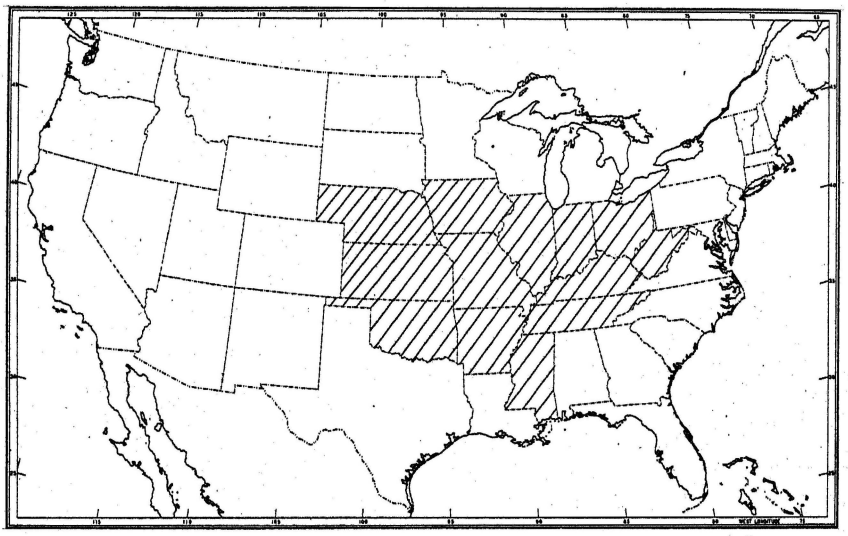

Fig. 1. Phloem necrosis of the American elm occurs in the states indicated. The disease is known to occur only in the United States.

Ilinois, and southwestern Iowa, somewhat north of this parallel, are the northernmost areas of known infection. In Missouri, only the two northern tiers of counties lie north of the fortieth parallel and the entire State is well within the danger zone.

[2]Phloem necrosis was identified in Oklahoma and Arkansas by Howard W. Larsh, Associate Professor of Botany, University of Oklahoma, and reported in his letter of July 14, 1945, to T. W. Bretz. It was observed in Iowa and Nebraska on September 7, 1945, by T. W. Bretz.

Phloem necrosis has been observed[3] in the following Missouri counties: Andrew, Atchison, Barton, Buchanan, Caldwell, Cape Girardeau, Clay, Clinton, Cole, Franklin, Holt, Jackson, Jasper, Lafayette, Linn, Livingston, Newton, Pike, Platte, Ray, Saline,

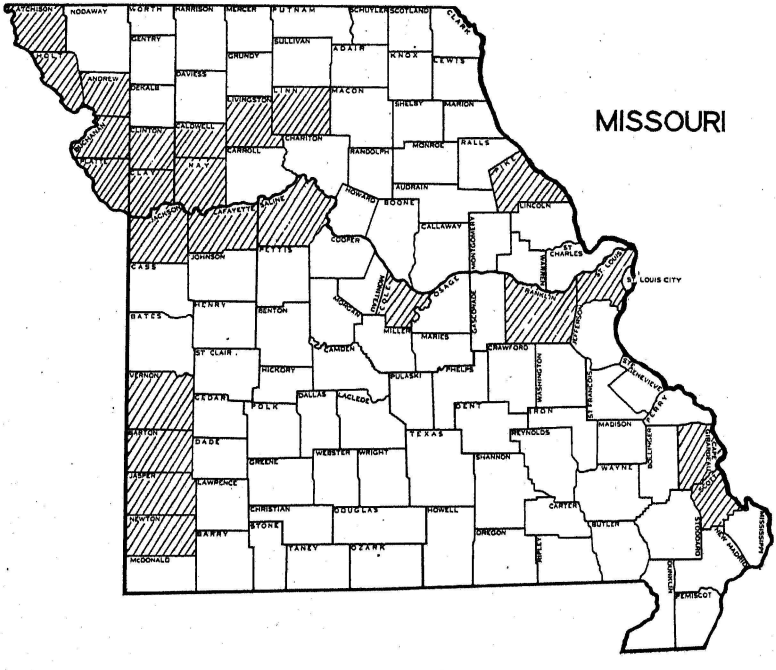

Fig. 2.—Phloem necrosis has been reported in 24 Missouri counties. The entire State is within the danger zone. and more extensive surveys will probably reveal the occurrence of the disease in other counties.

Scott, St. Louis, and Vernon. (Fig. 2.) It is probable that more extensive survey work will reveal its presence in other areas. The disease is already widely prevalent in several counties along the Missouri river and in the southeast and southwest. There seems little reason to doubt that the area of infection will increase steadily, and possibly, rapidly, in extent.

The American elm, including the varieties vase, moline and holly leaf, are susceptible to phloem necrosis. The three other species of elm native in Missouri are the rock elm (*Ulmus*

[3]Surveys to determine the prevalence of phloem necrosis in Missouri have been made by T. W. Bretz, Bureau of Plant Industry, and by J. A. Denning, State Entomologist, and members of his staff.

Thomasi), the slippery elm (*U. fulva*) and the winged elm (*U. alata*). The rock and slippery elms are resistant and the disease has not been observed in them. Definite information regarding the susceptiblity of the winged elm is not yet available.

The introduced species, the English elm (*U. campestris*) and the Siberian (Chinese) elm, (*U. pumila*) are resistant. The latter has been planted extensively. It is a less desirable species than the American elm, but its value may be enhanced by its resistance to phloem necrosis in areas where the disease is destructive.

HISTORICAL

Phloem necrosis was only recently identified as a virus disease. However, it is probable that the disease was responsible for an epidemic dying of elms in Kentucky, southern Indiana and southern Illinois as early as 1880. Although the nature of the disease was not determined at that time the descriptions of the diseased trees resemble trees affected by elm phloem necrosis sufficiently to suggest the probability that the disease has been active in those areas for many years.

The disease was first observed in Ohio in 1918, and has since spread widely over the state, causing very extensive dying of elms in Dayton and Columbus. In each city there are streets, formerly arched over by large elms, where only an occasional living tree now remains. Phloem necrosis was identified in Kansas in 1944, where Topeka is the most western known location of diseased trees.

In Missouri the first positive identification of the disease was made in 1939 by Roger U. Swingle, who observed it in southeastern Missouri. The occurrence, in 1944, of numerous dead trees in the immediate vicinity of dying trees in St. Louis and Kansas City indicates that the disease was certainly present in those cities in previous years, perhaps as early as 1940. Prior to 1944 only a few trees are known to have died, but in 1944 an extensive epidemic developed in Kansas City and St. Louis. It is estimated that from 3,000 to 4,000 elms were killed in the two cities.

CAUSE AND SYMPTOMS

Phloem necrosis is caused by a virus, an ultramicroscopic disease-causing agent. Virus diseases of plants are, in general, transmitted by insects from diseased to healthy plants. Viruses causing diseases of the type of phloem necrosis are usually trans-

mitted by insects of the leaf hopper group. In the case of phloem necrosis the insect species responsible for transmission has not yet been determined. Extensive investigations on this phase of the disease are under way at the Columbus, Ohio, laboratory of the U. S. Department of Agriculture.

The disease is not transmitted by ordinary contact between diseased and healthy trees. Attempts to transmit the disease by injections of sap from diseased trees, by planting healthy trees in soil mixed with bark and wood from diseased trees, and other attempts at mechanical transmission were not successful.

Transmission of the disease was secured by budding or grafting infected tissue on healthy trees. Transmission occurred, however, only when a union developed between the infected graft or bud and the stock. When the bud or graft died before the union developed transmission of the disease did not occur.

The development of symptoms of phloem necrosis in trees inoculated by budding may require from 6 months to 3 years. The long incubation period indicates the necessity for continuing experimental work on the control of the disease over a period of several years, since an unpredictable number of trees in the experimental plots may have acquired the virus before the control experiments were begun.

In nature, it is probable that the virus is transmitted by a sucking insect, possibly a leaf hopper, and also by the natural root grafting that frequently occurs between roots of adjacent trees. In narrow curb areas along streets where trees are planted at short intervals, and root growth is principally in 2 directions, there is increased probability of natural root grafting between intermingled roots of adjacent trees. In such locations observations indicate that phloem necrosis often spreads rapidly, killing one tree after another, in sequence, as it progresses from the original diseased tree. (Fig. 3.)

On large American elms the earliest noticeable symptom of phloem necrosis is usually a slight wilting, causing the leaves to hang more nearly vertical, and a slight upward cupping or rolling of the leaves, which makes the leaves appear narrower and exposes more of the dull green lower leaf surface. These leaf symptoms cause the tree to appear somewhat dull green in color and give the impression of sparse foliage. (Fig. 4.) Very soon, or simultaneously, occasional scattered leaves turn yellow and fall. The leaf symptoms sometimes occur on a single large branch first, but more frequently the yellowing leaves are distributed fairly uniformly over the entire tree. A fairly constant

symptom is the early partial defoliation of the terminal, current season growth of small branches. This is especially noticeable in the extreme top of the tree, and is illustrated clearly by the central tree in Fig. 4. At this stage small sprouts on the trunk or large branches near the crotch may have yellowing or dead, brown leaves.

Following the occurrence of the early symptoms yellowing and falling of the leaves occur at a more rapid rate, and the foliage becomes thinner and thinner until defoliation is complete or only a few dead leaves remain attached to the twigs. (Fig. 5.) When the initial symptoms develop in midsummer or earlier the course of the disease is usually short, and defoliation and death often occur within a few weeks. Some trees under observation in Missouri that appeared to be normal in the autumn of 1944 began to develop leaf symptoms in June, 1945. A month later they could be detected at a considerable distance by their sparse, yellow foliage. The period of appearance of symptoms may be affected by weather conditions and vary somewhat from year to year. New cases continue to appear during July, August, September, and October. Trees that develop early symptoms in late September or October may survive the winter and produce a weak, or occasionally, a fairly normal leaf growth in the spring. During May or June the leaves on such trees begin yellowing and falling.

Small trees attacked by the disease may exhibit only yellowing, falling leaves as early symptoms. Small trees and those of medium size sometimes die very quickly after the appearance of the first symptoms, and, instead of turning yellow and falling, the leaves may turn brown, dry, and remain attached to the twigs.

Symptoms similar to the leaf symptoms caused by phloem necrosis may result from a number of causes, and the disease cannot be identified with certainty by the behavior of the leaves alone. The most constant and dependable diagnostic character is a discoloration of the inner surface of the bark. A thin layer of the bark (phloem) in contact with the wood becomes lemon yellow in color in early stages, soon darkening to the color of butterscotch (Figs. 6 and 7). This discoloration and destruction of the current season growth of bark, or phloem, accounts for the name, *phloem necrosis,* that has acquired general use. The yellow or butterscotch discoloration appears first near the base of the trunk and in the large buttress roots, and it is in this region that a cut should be made through the bark with a chisel

Fig. 3. Phloem necrosis of elm. Of the 12 fifteen to twenty year-old trees only one is normal. The first dying elms in this area were noted in 1940. The majority of the dead trees developed symptoms during the summer of 1944. St. Louis, Missouri. Oct. 3, 1944.

Fig. 4. Phloem necrosis of elm. Left, healthy elm; center, infected elm showing typical symptoms, partial defoliation, particularly on current year's growth, and some yellowing; right, tree that developed symptoms and died in summer of 1944. St. Louis, Missouri. Oct. 3, 1944.

Fig. 5. Phloem necrosis of elm. Leaves at upper left brown and dead but firmly attached. This frequently occurs when trees die very quickly. St. Louis, Missouri. Oct. 3, 1944.

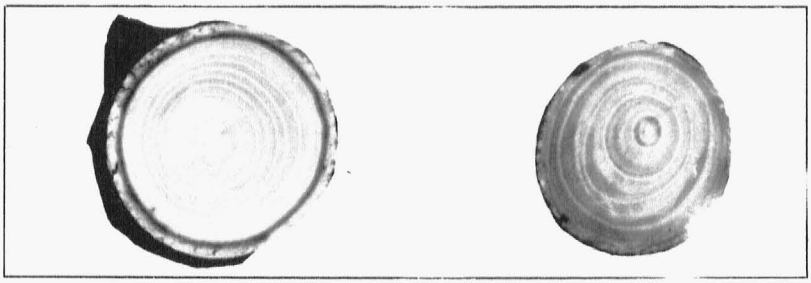

Fig. 6. Phloem necrosis of elm. Left, cross section of stem from a diseased tree showing browning of inner region of phloem. Right, section of healthy stem.

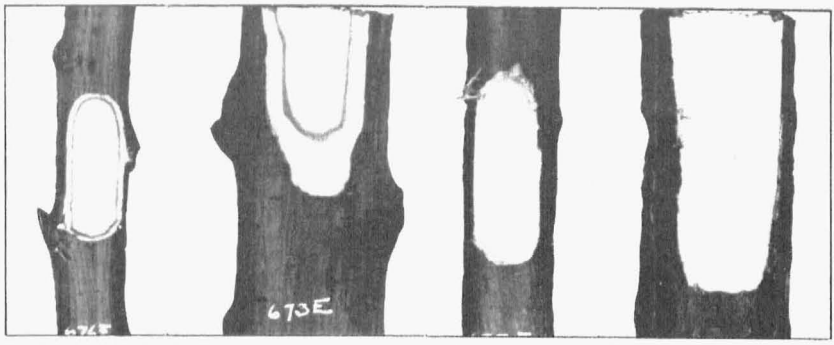

Fig. 7. Phloem necrosis of elm. Left, infected stems. Right, healthy stems. The brown discoloration of the inner layer of bark (the portion in contact with the wood) is characteristic of the disease.

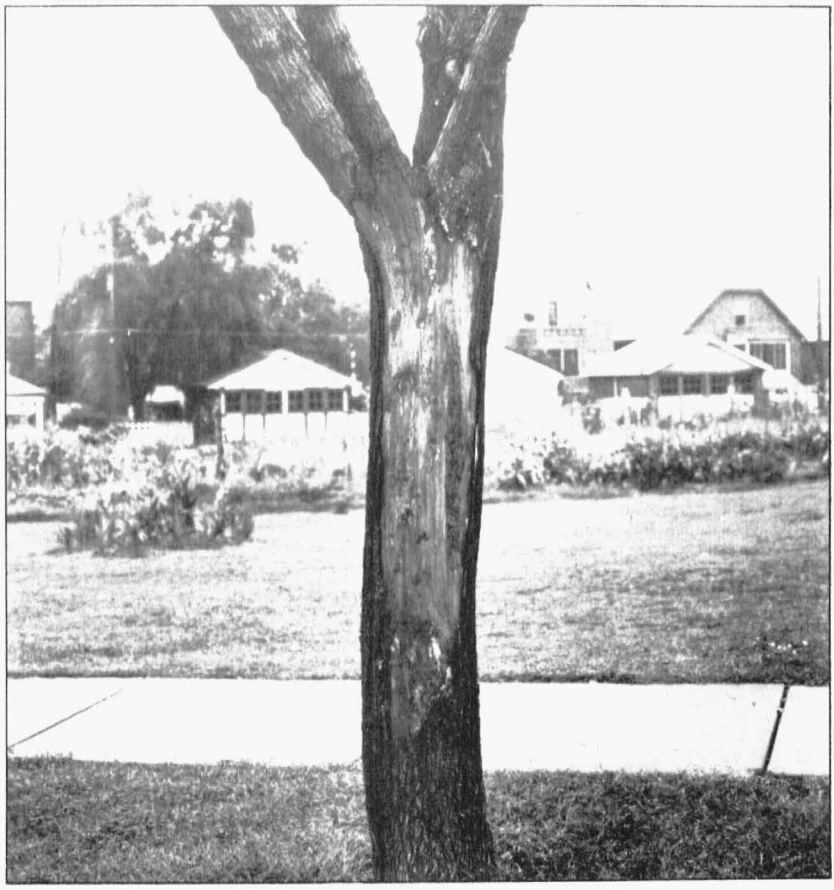

Fig. 8. Phloem necrosis of elm. The destruction of the current year's phloem results in early loosening and sloughing of the bark on dead trees. St. Louis, Missouri. Oct. 3, 1944.

or hatchet, and a short length of bark peeled away from the wood. In a normal tree the inner surface of the bark is white when the cut is made; normal bark becomes brown in color after a few minutes exposure to the air, and this browning should not be confused with the yellow to butterscotch color in trees affected by elm phloem necrosis.

The leaf symptoms, wilting, yellowing and defoliation, cannot be depended upon for the identification of phloem necrosis. Similar symptoms often develop as the result of drought, die-back, insect injury, parasitic root fungi, girdling, and excessive water in low areas. Some of these adverse factors can be corrected and the trees restored to a healthy condition. It is necessary to examine suspected trees for the occurrence of the discolored layer of inner bark (Figs. 6 and 7) and the characteristic odor of wintergreen, which constitute positive evidence of phloem necrosis. The disease cannot be identified on trees that have been dead for some time, since the bark has then become brown and dead throughout and the characteristic thin layer of discolored tissue cannot be seen.

Another valuable character for the identification of phloem necrosis is the development of a distinct odor of wintergreen in the thin layer of discolored inner bark. The odor is especially marked in tissue in the yellow or light brown stages of infection, but is less distinct in dark brown tissue in later stages. Since the bark itself often has an odor that may obscure the wintergreen odor, it is helpful to peel off a strip of the discolored inner bark and place it in a small vial or hold it in the closed hand for a few minutes, after which the wintergreen odor is usually detectable. Analyses have shown that oil of wintergreen is actually present in the discolored tissue. So far as is known this chemical never occurs in normal elms or in elms affected by diseases other than phloem necrosis.

The destruction of the inner bark results in a loosening of the bark as infected trees die. The dead, drying bark pulls away from the wood of the trunk and falls off in slabs soon after the death of the tree. (Fig. 8.)

Infected trees do not recover. Death of the entire tree always occurs within a period of a few weeks, or, in some late autumn cases, a few months after disease symptoms become apparent.

The root system is the region of most extensive destruction in diseased trees. The fibrous roots are destroyed first, and when the leaf symptoms develop there are few functional roots re-

maining. The death of the roots prevents recovery under any circumstances. Sprouts do not develop on stumps remaining after infected trees are felled.

Phloem necrosis usually spreads rapidly but its spread is not progressive and uniform, involving all elms in the path of invasion. In most instances the development of epidemics is first noted in towns and cities, where "pockets" of infection involving, at first, only a few trees, appear in scattered locations, often separated by distances of several miles. As the epidemic develops the "pockets" become more numerous and increase in size until the entire area is covered. The disease usually appears first in large trees, but eventually elms of all ages become infected. However, in at least two communities in Missouri the first cases of the disease were identified several miles from a town, in small seedling elms with trunks approximately one inch in diameter, growing in brushy fence rows along the roadside.

In some areas in Ohio, where the disease has been present several years, 90 per cent of the elms have been killed. In Dayton and Columbus the disease has destroyed many elms, while in some neighboring cities the disease has not become epidemic. It is apparent that the spread of phloem necrosis may occur in long jumps, and it is probable that it will appear, sooner or later, throughout the general area involved (Fig. 1).

The progress of an epidemic may fluctuate greatly from year to year. After the disease has attained epidemic proportions, causing the death of many trees in a single season, it may subside somewhat over a period of a few years. The killing of trees continues but on a greatly reduced scale. This period of relatively small losses may be followed by a flare-up resulting in the death of many more trees than in any previous season. Throughout the affected region 1944 was a year of very heavy losses, some cities reporting the death of 10,000 to 20,000 elms during that summer. The causes of the sporadic outbreaks are not known. It seems probable that they may be correlated with seasons of unusual abundance of the insect that transmits the virus.

CONTROL

There are no control measures of proved value for the protection of elms from phloem necrosis. There is no evidence that any of the known methods of plant disease control or prevention are effective in preventing spread of the disease.

It seems certain that an infected tree may serve as an infection center from which the virus can be transmitted by insects to healthy trees. Since infected trees invariably die, it is advisable to remove these danger centers as soon as it is certain that they are infected. The cost and difficulty of removing a tree at this time is not greater than removing it a few weeks or months later, and its early removal *may* prevent the loss of other trees. An extensive experiment is under way at Marietta, Ohio, where a few cases of the disease have appeared, to determine the value of eradication of diseased elms as early as the disease can be diagnosed. The eradication work is being carried on throughout the city and in a zone one mile wide surrounding it. The experiment has not continued long enough to justify conclusions.

It is hoped that the local officials in Missouri communities will be watchful for the appearance of the disease, and act quickly to eliminate infected trees. Although there can be no assurance that the early destruction of diseased trees will prove effective, nothing will be lost by the removal of dying trees while they are yet reservoirs of the virus from which the disease may be transmitted. There is a possibility that their early removal may greatly reduce the rate of spread of the disease.

Attempts to control phloem necrosis by protecting trees from the insect that transmits the virus have been hampered by lack of information regarding the identity of the insect and the period during which it may be expected to feed on the elm. Furthermore, insects of the types which transmit viruses have, in the past, proved controllable only by insecticides of the contact type. With the availability of new insecticides with a high residual toxic value the protection of valuable trees by a few spray applications during the summer may prove feasible. Investigations on the use of one of these insecticides were begun in Kansas City in 1945. Continuation of the work for several years probably will be necessary before conclusions can be drawn regarding its value.

In view of the behavior of the disease in other areas there is little basis for optimism regarding the future of the American elms now growing, although some communities may remain free from the disease for an unpredictable number of years.

The development of varieties of the American elm resistant to phloem necrosis appears a distinct possibility. In Kentucky, the disease has long been present and has killed most of the elms; however, there are yet scattered old elms that have survived and

remained healthy. The virus and its vector are yet present, since susceptible elms transplanted in recent years were observed dying in 1944. The U. S. Department of Agriculture, at its Columbus laboratory has found that young trees propagated from certain of the old disease-free Kentucky elms are resistant to phloem necrosis. Repeated attempts to inoculate them have failed to transmit the disease.

Until resistant strains of the American elm are available it is inadvisable to make new plantings of this species. The danger of loss is great enough to justify the substitution of oaks, maples or other species for the elm. The vase and moline elms are varieties of the American elm and are very susceptible to phloem necrosis. Other elms are resistant and may be substituted for the susceptible species. Replacement of dead elms with susceptible American elms is deplorable, since there is little likelihood that the young elms will long escape infection in a locality where the virus occurs.

The shipment of American elms from nurseries near which infected trees have appeared provides a possible means of introduction of phloem necrosis into new areas. Trees in very early stages of infection cannot be detected; they may survive transplanting for a year or two and serve as focal points of new outbreaks.

In some areas unscrupulous persons have claimed to be able to "cure" infected trees, usually at high cost to the home owner. These claims have proved false and the materials used, while usually harmless, have proved worthless for the control of phloem necrosis.

In cases of doubt regarding the occurrence of phloem necrosis in suspected trees assistance may be obtained from the county agricultural extension agent.

SUMMARY

Phloem necrosis, a destructive virus disease of the American elm, is widely distributed in several middle western states. The disease occurred in epidemic form in some areas in Missouri in 1944 and 1945, and has been observed in 24 counties. It occurs in all the principal geographic areas of the State.

The American elm, including the varieties vase, moline and holly leaf, are susceptible to phloem necrosis. Other species of elm, including the rock, slippery, English and Siberian (Chinese) elms, are resistant.

The virus is probably transmitted from diseased to healthy trees by a leaf-feeding insect of the sucking type, and by the natural root grafting that often occurs between roots of adjacent trees.

Diseased elms may be identified by the yellowing, falling leaves, and with more certainty by the development of a yellow to butterscotch discoloration of a thin layer of inner bark in contact with the wood, particularly near the base of the trunk and in the buttress roots. A characteristic odor of wintergreen is detectable in the discolored layer of bark tissue.

Infected elms invariably die within a short period. They should be removed as early as possible after the disease is identified to prevent the spread of the disease by insects.

Experiments on the control of phloem necrosis by eradication of infected trees and by the use of insecticides are under way, but the long incubation period of the disease will make necessary several years of observation before conclusions can be drawn regarding their effectiveness.

Until strains of the American elm resistant to phloem necrosis are available it is advisable to substitute other trees for home, park, and street plantings in Missouri.

Nursery elms from areas in which the disease occurs may introduce the disease into new locations, and serve as centers of spread.

The county agricultural extension agent will assist in diagnosing phloem necrosis, and should be called upon in doubtful cases. Leaf symptoms similar to those caused by the virus may result from other causes.