Oak Wilt in Michigan
Michigan State University
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Zachary Clankenheim and Gerard Adams, Department of Plant Pathology, Michigan State University; Johan Bruhn, Department of Plant Pathology, University of Missouri
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Zachary Blankenheim and Gerard Adams
Dept. of Plant Pathology, Michigan State University
Johann Bruhn
Dept. of Plant Pathology, University of Missouri

Introduction

Oak wilt is a major disease of oaks (*Quercus* spp.) in Michigan. The fungus, *Ceratocystis fagacearum* causes the disease by invading the vascular system of the tree. The pathogenic (disease) fungus causes the leaves on the tree to wilt. Wilting is followed by rapid death of trees in the red oak family. In the white oak family, death is usually limited to one or more branches of a tree. Oak wilt in Michigan may infect red, black, scarlet and pin oaks in the red oak family as well as white, swamp, and bur oaks in the white oak family. The leaves of oaks are useful in identifying the family (Figure 1). Less common ornamentals such as English and shingle oak also may become diseased. The pathogenic fungus may infect the trees when an insect carries the fungus to a recent wound. Alternatively, the fungus may infect a healthy tree through the roots, if the roots are grafted onto roots of a nearby infected oak of the same species.

Symptoms on the Red Oak Family

The red oak family can be recognized by its leaves, which have sharply pointed tips (Figure 1). Leaves of red oaks infected with oak wilt begin to turn reddish-to-bronze in color at the edges. The leaves may wilt and curl, then fall to the ground, or they may turn dark brown and remain attached to the branches. Some leaves drop before wilting begins. These leaves are usually greenish and lie stiff and flat on the ground. Wilting generally occurs in July, beginning at the top of the tree and progressing uniformly downward (Figure 2).

Wilting occurs within a week in response to water stress and can be seen early in dry summers and later in wet summers. Sometimes infected trees will bud in the spring with stunted leaves, or not leaf-out at all. Many red oaks die after wilting. It is difficult to diagnose an oak dying of wilt in the fall because individual trees vary in the time of normal autumn leaf drop. However, healthy deciduous

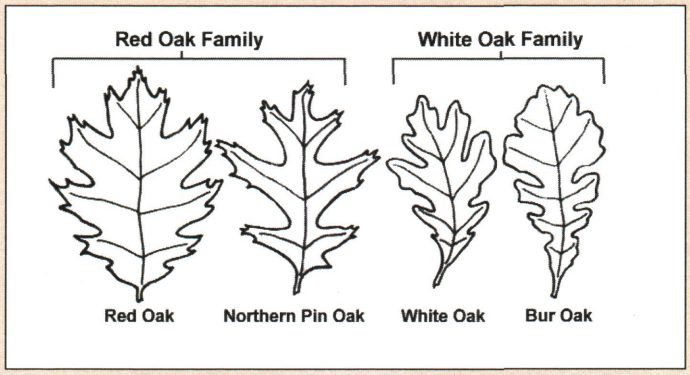


Figure 1
The red and white oak families can be differentiated by the characteristics of the leaves. In the red oak family, the leaves have sharply pointed tips. In the white oak family, the leaves have lobed margins without pointed tips.

Figure 2
In the foreground is a tree recently killed by oak wilt. Adjacent to it is an oak showing sudden wilting. Farther away are healthy oaks that may soon become infected with the pathogen via root grafts.

Figure 3 A, B
(A) Wilting leaves on trees infected with oak wilt appear bronze in color, wilted and curled. Leaves from infected trees generally fall and can be distinguished from leaves of healthy trees in autumn because the latter are not wilted and are red-to-brown in color. (B) These red oak leaves show wilt symptoms, which progress from the tip of the leaf downward.

leaves are generally red-to-brown and do not appear wilted when shed whereas leaves shed due to oak wilt generally appear bronze and wilted (Figure 3).

Wilting trees generally will have brownish streaking just beneath the bark on the sapwood, not in the phloem. With an axe cut a window in the bark of a wilting tree and look for streaking (Figure 4). The streaking is usually more apparent low on the trunk, near the ground. After the tree has died the newest ring of sapwood will stain uniformly brown; such trees will have a noticeable stale beer or sweet beechnut smell coming from the stained wood.

Figure 4
Brownish streaking usually is evident in the sapwood of an infected tree showing wilt symptoms when a window is cut into the bark near the ground.

During the year that the tree wilts and dies, the fungus produces special mat-like structures, called pressure pads. These pads form between the bark and wood, splitting the bark. They are covered with the spores of the fungus. Look for cracks in the bark and peel back the bark (Figure 5). Examine both the inner bark and the surface of the wood for gray-to-brown felt-like oval pads about 2 in. x 1 in. x 1/8 in. thick (Figure 6). Cracks can be located by sound by tapping a steel tool against the bark, sounding a hollow note. Often the pads can be found because squirrels are attracted to the pads and expose them by chewing away the bark just above the pads. The pads produce an odor of stale beer or sweet beechnut. The odor attracts insects. Insects that visit the pads can carry away numerous fungal spores. The spores may be transported to oak trees with new wounds, because the wounds often attract the same insects.

Figure 5
To determine whether a red oak has died from oak wilt, examine the bark for cracks and splitting. Remove the bark near cracks to examine the wood beneath for fungal pads.

Figure 6
The characteristic oval-shaped fungal pad occurring on the inner side of the bark and on the wood is diagnostic of oak wilt disease on red oak.

SYMPTOMS ON THE WHITE OAK FAMILY

The white oak family can be identified by the leaves, which have lobed margins without pointed tips (Figure 1). White oaks infected with oak wilt generally have leaves that become tan colored and necrotic (dead). Wilting begins from the tip and progresses through the length of the leaves; no distinct line is evident between the necrotic tissues and green tissues. Usually only a few of the branches on an infected white oak will wilt, and on these branches the leaves curl, remaining attached to the tree. Leaf symptoms generally are evident in July. Streaking in the new sapwood is less evident in the affected branch, and the fungal pads are rarely found as compared to red oak. However, in trees that have suffered repeated infection and recovery, some annual rings in the wood will be stained darkly as evidence of prior infection. Infected white oaks are difficult to diagnose. If a tree is suspected of having oak wilt, samples of wilting with leaves should be sent to the MSU Plant Diagnostic Clinic for confirmation by culturing of the fungus. White oak frequently has anthracnose in Michigan (see MSU Extension Bulletin E-1099). On anthracnose-infected trees, the curling leaves with angular areas of necrotic tissue are similar in appearance to leaves from oak-wilt infected trees. A distinct line is usually evident between green tissues and necrotic tissues in leaves of white oak infected with anthracnose (Figure 7B). However, anthracnose occurs in May while oak wilt is generally evident in July. In addition, white oak with anthracnose usually shows most of the disease symptoms on the lower branches whereas oak wilt begins more frequently in the uppermost branches of trees.

Figure 7 A, B
Early oak wilt symptoms on white oak can appear similar to anthracnose symptoms. Oak wilt symptoms generally occur in July while anthracnose occurs in May. In both diseases, curling leaves show green tissue and necrotic tissue. (A) Oak leaves with symptoms of oak wilt are often found in the upper crown. The leaves become tan and necrotic first at the tips, then down the length of the leaf. (B) Oak leaves with symptoms of anthracnose are often found in the lower crown. The leaves have necrotic spots of anthracnose that start from the inside and spread out toward the edges of the leaves.

OAK WILT OFTEN CONFUSED WITH OAK DECLINE

Often the decline and death of oak trees is misdiagnosed as oak wilt. A combination of harmful factors, collectively called 'oak decline,' may be contributing to the ill health of the oak trees. Some of the factors that stress oak trees include: drought, frost damage, wood-boring insects such as the two-lined chestnut borer, nutrient deficiencies, gypsy moth and other insect defoliation, pollution, construction damage, water logged soil, accumulation of soluble salts, root diseases such as *Armillaria* root rot and fungi that induce stem cankers.

Oak decline symptoms, while varied, often are similar to those of oak wilt. The lack of characteristic fungal pads on red oak is one possible sign of a problem other than oak wilt. Decline symptoms include: slow growth, misshapen leaves, chlorotic leaves, leaf scorch and branch dieback. Leaves on oaks with decline fall earlier in autumn than those on healthy oaks, whereas leaves on oaks with wilt die and remain attached throughout the winter. Symptoms of oak decline often take several years to develop after a stressful event, making it difficult to diagnose. Oak wilt symptoms develop within weeks. Unlike oak wilt that spreads from a central infection point, oak decline tends to be more random within well-defined areas.

LIFE HISTORY

The life cycle of the oak wilt fungus, *Ceratocystis fagacearum*, is interlocked with the life cycle of insects, primarily the picnic beetles (*Nitidulidae*, Figure 8). The common picnic beetle and other insects are attracted to the fungal pads formed on infected trees. In addition, these insects are attracted to wounds of any type on oak trees. When the insects visit the fungal pads they become covered with spores and carry the disease from infected trees to wounded trees. Firewood from an oak that died of oak wilt will often have fungal pads. Beetles will visit the firewood and transfer spores to nearby wounded oak trees.

When a spore-carrying picnic beetle feeds on a wounded oak, the fungal spores germinate and move into the water-conducting vessels, the xylem in the sapwood. At first, the fungus grows only in the outermost sapwood, in the newest growth ring. The tree, in an attempt to defend itself from infection, forms balloon-like plugs (tyloses) and gums in the water-conducting tissues to block the fungus. Unfortunately, these defensive responses block the movement of water from the roots to the foliage. This action combined with the formation of toxins by the fungus causes the affected trees to wilt. Wilting is followed by death of red oaks within two to six weeks. In white oak wilting may kill large branches but seldom kills the tree until several years of infection have occurred. White oaks are often capable of compartmentalizing the wilt fungus; therefore in the following spring new sapwood may be free from the previous year's infection.

Most red oak trees become infected with oak wilt through the roots. The fungus moves through the sapwood of a dying tree down the roots and into a nearby healthy tree's roots via root grafts (Figure 9). Root grafting is less common among oaks of the white oak family.

When the trees die, the fungus moves into all water-conducting vessels. At this time the sapwood turns brown and a fruity smell is evident, attracting picnic beetles. The fungus forms pads that produce pressure under the bark, splitting the bark directly above the pressure pad. Asexual spores form in mass on the exposed pads but the sexual spores are almost never seen in nature. Another species of *Ceratocystis*-like fungus, *Ophiostoma piceae*, does produce sexual fruiting bodies often on the pressure pad of the oak wilt pathogen. *Ophiostoma piceae* apparently parasitizes the pads of the oak wilt pathogen in nature and is thought to reduce spread of the fungus.

Pressure pads (fungal pads) form in abundance in Michigan on red oak, commonly a dozen pads may form per tree. Asexual spores of the pathogen also form on any wound on an infected tree. Most pads form in May but the time of pad formation varies with the time of tree death. When trees die in July, pads form about May the following year. If death occurs in May, pads generally form in August or September. Trees dying in September normally do not form pads. Pressure pads are produced for only one year after an infected tree dies. Fungal pads will form on branches as small as one inch in diameter, although generally they form on branches three inches, or larger, in diameter. In states south of Michigan, pad formation is rare because of unfavorably hot weather conditions. The most damaging time for pad formation to occur is in May when the picnic beetle vector populations are highest. During May, as many as four to five dozen picnic beetles may visit one pad on an infected oak.

Trees have been found to be more susceptible to infection in early June because it is easier to wound trees during spring when the bark is loose. Trees should be protected from wounding in the springtime; in Michigan, oak trees should not be pruned from April through the end of June.

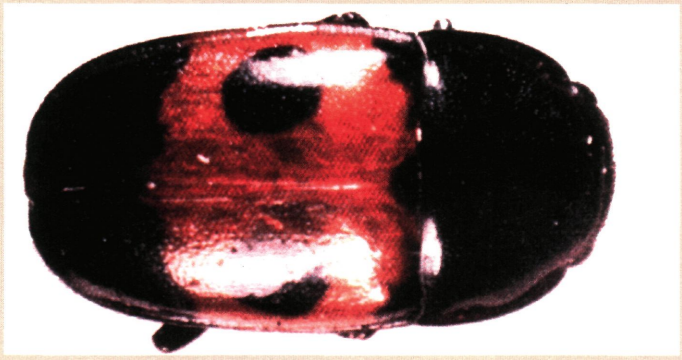


Figure 8
The common picnic beetle, in the Nitidulidae family, is the primary insect carrier of oak wilt disease.

Figure 9
The roots of oak trees often graft onto roots of nearby trees of the same species. These root grafts must be disrupted to prevent the spread of oak wilt disease from infected trees to healthy trees.

Don't prune from mid-April through June.

SAMPLE COLLECTION FOR LABORATORY IDENTIFICATION

Upon identifying symptoms of oak wilt on an oak tree it may be necessary to send samples to a diagnostic lab for more accurate diagnosis. It is important to select branches and leaves (based on the symptoms mentioned previously) that are only partially wilted, not already dead. Sample several different branches of at least one inch in diameter for any given oak tree. Package leaf and branch samples separately. Avoid sampling from April through June to reduce the risk of attracting insects to the wounds. Keep the samples cool, but not frozen, during the whole process of collection and shipping. Include background information with the samples—approximate age of the oak tree, any recent damage and the distance to other oak trees. Hand deliver or ship samples overnight in a disposable ice chest with ice packs, and time so that they do not arrive at the laboratory on the weekend.

PREVENTION

Preventing Infection by Insect Transmission

Oak trees are most easily wounded from April till late June when the bark is "slipping" and is easily loosened from the wood due to new stem growth. Research studies in the north central states have found that wounds made in early June are visited by the largest numbers of insects; and more trees wounded during this time period become infected by the spores carried by the insects. Wounds to the trunk are most susceptible to infection, including wounds from pruning of trunk sprouts. Avoid pruning, climbing with climbing irons, posting gates, clearing trees or other activities that could cause wounding of oaks from mid-April though June.

Wound Treatment

Pruning wounds should be treated with commercial pruning sealer within a day of pruning, and pruning of oaks should be done in the winter to avoid infection. The wound paint discourages visitation of the wounds by insects.

Construction

Most oak wilt infections are associated with human activity that has caused wounding and/or the transport of infested firewood. Construction and home building are common activities that indirectly lead to tree wounding and therefore are frequently associated with new infections. To avoid introduction of oak wilt to the construction site:

1) Delay construction until July.
2) Keep construction activities away from oaks by erecting a physical barrier or temporary fence around the tree. A suggested distance between the tree and the fence is approximately 10 feet, depending on tree size.
3) Remove oaks (that are planned for removal) either prior to mid-April or after June 30.

4) Communicate your concerns about the oaks to the builder.
5) Provide a can of tree paint, during the mid-April to July period, for immediate treatment of any anticipated oak wounding.

Control of Oak Wilt Disease

Control measures differ for oaks in the white or red group and also vary according to the quantity of red oaks near the infected tree. The approach used to control disease spread is different for an urban area than for a rural setting.

The primary means of controlling oak wilt is through sanitary removal of infected trees and their wood. Oaks killed by oak wilt should be condemned, cut down, and the wood removed before the following April. Precautions must be taken to sever any root connections with healthy oaks before cutting down the dead trees (see next column). Campgrounds and park lands with oaks should strictly ban the importation of oak firewood.

It is important to realize that white oaks can often recover from oak wilt, and transmission of the disease through root grafting (Figure 9) is less frequent among white oaks. While white oaks need not be removed unless they pose an immediate threat to other desirable oak trees, the dead branches should be pruned before the following April. If the infected white oak is within 30 feet of healthy white oaks, sever, if possible, root grafts at the 95 percent barrier line (see next column). Sever the root graft before cutting down the tree.

Removal and Handling of Infested Wood

Infected and dead red oaks should be cut down before April 1. Collect wood and branches down to one-inch diameter in size. Sell the wood in an oak free area, if possible. Alternatively, sell it to a sawmill or chipping facility, since lumber wood is not a source for infection. When cut into firewood, move it at least a mile away from any oak. Otherwise, stack and tarp the wood under heavy, clear plastic until the following August. The plastic heats up the wood and favors the growth of other fungi that can outcompete the oak wilt fungus for the substrate. Carefully seal the tarp by shoveling soil or putting rocks around the base to prevent insects from reaching the fungal pads. Debarking is also beneficial but can only be accomplished effectively on trees that have died in the spring when the bark is loose.

Preventing Infections by Root Graft Transmission

Before infected red oaks are cut down, root grafting to nearby oaks must be disrupted by mechanically severing them (Figure 10). Otherwise, spread of the fungus via root grafting will be accelerated between an infected stump and nearby healthy trees. No herbicides have been found to be effective in killing the roots of oaks adequately to serve as a means of preventing root graft spread.

Root grafts can be severed most easily with a vibratory plow (Figure 10), a trencher or backhoe. The vibratory plow is the quickest and most economical method since backfilling trenches is not required. Underground pipes and cables must first be located in urban settings. Vibratory plows are used in laying telephone cable and often a contract operator can be hired at an hourly rate to treat the affected oak area. The blade of the plow should be at least four feet; a five-foot blade is more efficient.

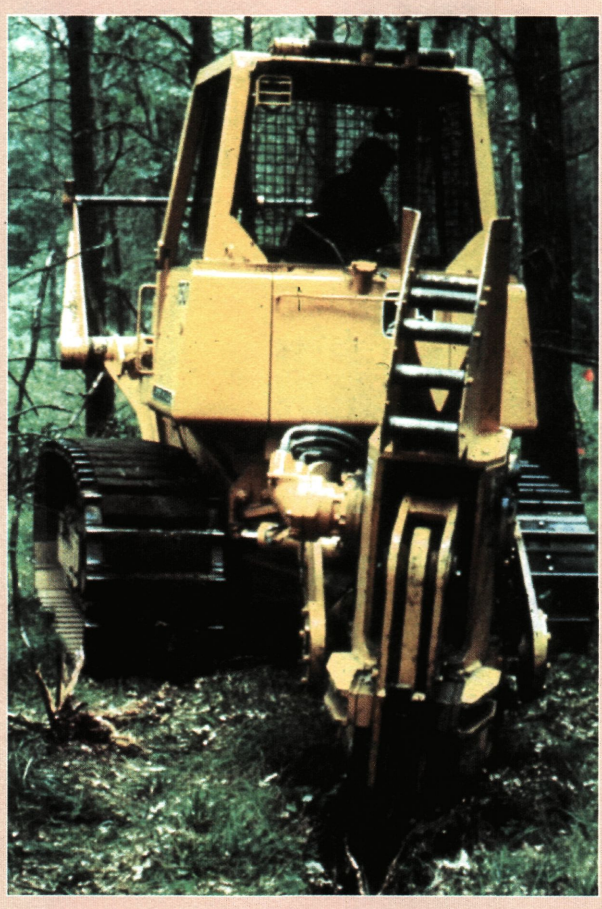


Figure 10
A vibratory plow with a 5-foot blade is most effective in severing root grafts between infected and healthy oak trees in locations where no underground pipes or cables are buried.

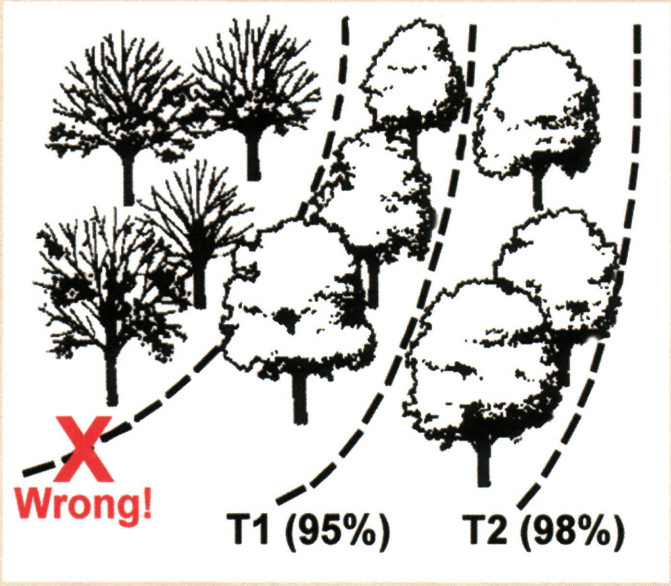


Figure 11
Sever roots along two lines encircling the trees. The placement of the T1 and T2 lines are based on distances calculated to provide a 95 percent and 98 percent probability that no future infections by root grafting will occur (see Table 1).

Two root-severing barriers are necessary for effective control of disease spread (Figure 11). The placement of the barriers is critical and should be constructed as suggested in Table 1. Place the first barrier at a distance where there is 95 percent probability that the trees outside the barrier will not show infection within a year. Place the second barrier at a distance where the probability is 98 percent.

Measure the infected tree (source tree) diameter at breast height (DBH), and then add the DBH of a nearby healthy tree. Using this combined DBH, refer to Table 1 for the appropriate distance to lay the 95 percent and 98 percent barrier lines. Do this for each healthy tree and map out the two encircling lines with white athletic field chalk to guide the plow operator. Oak wilt will not move across a road via roots, thus no barrier is needed adjacent to a road to prevent the spread.

Correct placement of barrier trench lines is essential! Proper placement of barrier trench lines is critical to isolate the spread of oak wilt within an area. Line 'X' in Figure 11 is placed in the wrong location. Most likely the disease has already spread to the healthy trees to the right side of line 'X'. Lines T1 and T2 are placed correctly. If these trench lines are dug deeply enough (4- to 5-feet deep), they should provide the 95 percent and 98 percent probability of no future spread of oak wilt via root grafts.

Several companies have developed injectable systemic fungicides for treatment of oak wilt. The success of the injection of fungicides is variable, it's best to seek the recommendation of a qualified Extension agent. Fungicides are best used as a preventive measure in uninfected trees. Check treated trees every one to two years for appearance of oak wilt symptoms. Therapeutic treatment of trees is somewhat effective for saving individual high value trees that show less than one-quarter wilting or crown loss from oak wilt. However systemic fungicides are not a proven barrier for stopping the spread of oak wilt. The optimal location for injecting fungicide into a tree is in the flare root area, which is the transitional zone between the trunk and root system. Injections require drilling small holes into the tree, so use

Table 1. Determining the distance of the two barrier lines from an infected tree. Distance in feet is listed below the soil type.

Size of Two Trees Combined	95% Barrier Line		98% Barrier Line	
	Soil Type		Soil Type	
Combined DBH*	Loamy soil	Sandy soil	Loamy soil	Sandy soil
Inches	feet	feet	feet	feet
2	3	4	4	5
4	6	8	8	10
6	9	12	12	15
8	12	16	16	20
10	15	19	20	26
12	19	23	24	31
14	22	27	29	36
16	25	31	33	41
18	28	35	37	46
20	31	39	41	51
22	34	43	45	56
24	37	47	49	61
26	40	50	53	66
28	43	54	57	72
30	46	58	61	77
32	49	62	65	82
34	53	66	69	87
36	56	70	73	92
38	59	74	77	97
40	62	78	81	102
42	65	82	85	107
44	68	85	89	112
46	71	89	94	117
48	74	93	98	123

Severing roots at the calculated distances will provide a barrier that gives a probability of 95 percent and a second probability of 98 percent that healthy trees outside the barrier will not become infected in a year. Measure the diameter at breast height (DBH) of the infected tree and add this to the diameter of a nearby healthy tree (combined DBH*). Refer to the table: opposite the combined DBH is the distance that should guide you in determining the barrier. The distance is measured from the center of the source tree to the center of the target tree.

Repeat this procedure with the other healthy trees surrounding each of the infected tree(s). When you have marked the two barrier lines that encircle the infected tree(s), sever the root grafts along these lines using a vibratory plow.

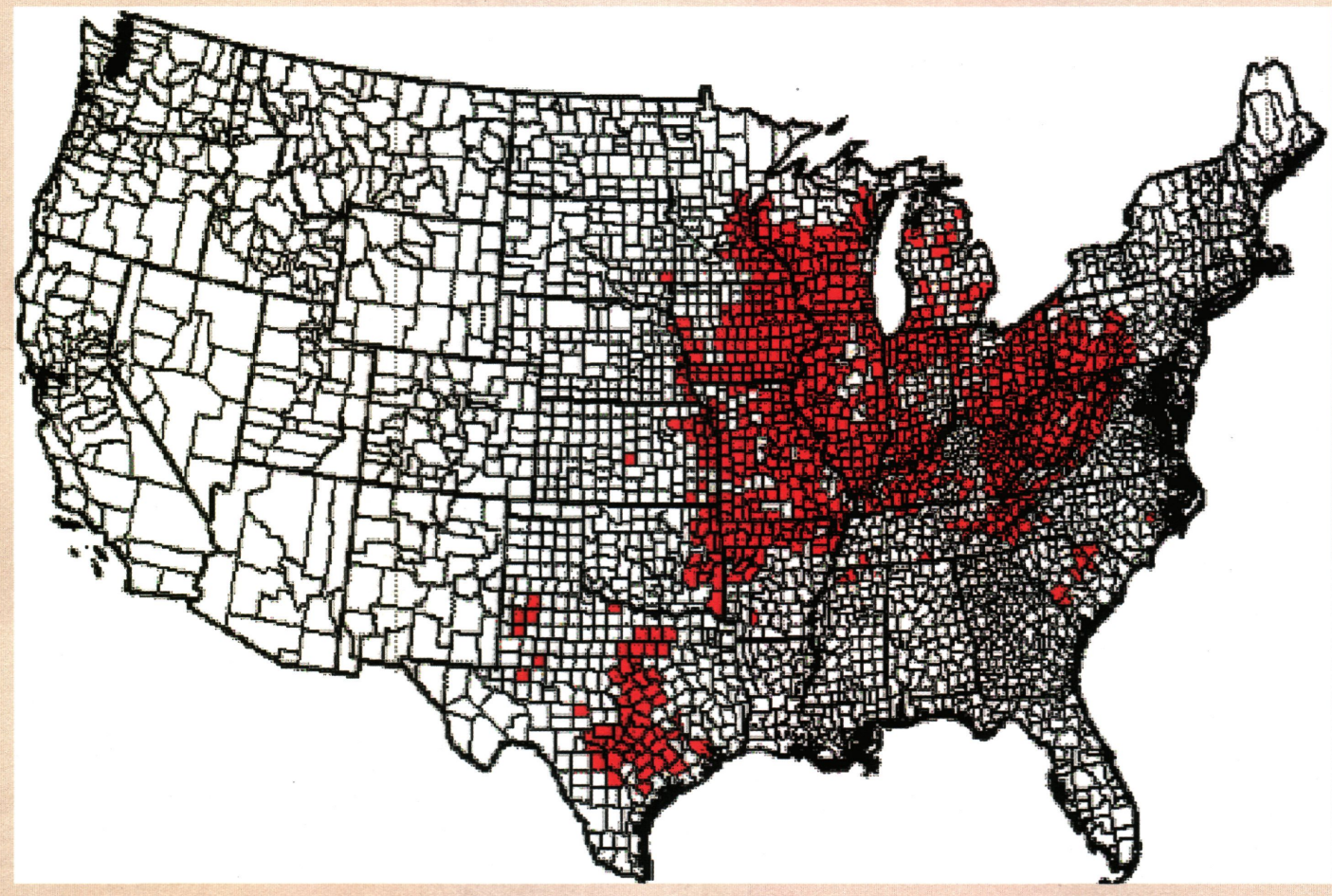
The calculated distances for placement of the 95 percent and 98 percent barriers are based on a sandy or sandy-loam soil type.

extreme caution when injecting trees, and do this only from July through the fall, never in the springtime. Wounding of the flare root area will heal more quickly than wounding of the trunk.

Table 1 is useful for estimating where to sever root grafts at distances between the infected trees and healthy trees. Severing at the calculated distances provides a barrier to transmission of the disease.

Check urban trees within the 95 percent barrier yearly and remove any oak trees showing a new infection as symptoms appear. Following erection of the barrier in a rural setting, cut down and remove immediately all red oaks inside the 95 percent root graft barrier.

Remember that trees within the inner barrier usually will become infected. Remove these trees to prevent regrowth of roots. Removing the healthy trees on the inner side of the inner barrier will prevent regrowth of roots across the barrier.



Distribution of oak wilt in the United States.

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