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report on
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PINE WILT DISEASE

Pine wilt is a recently recognized problem of pines in the United States. The disease is caused by the pinewood nematode, *Bursaphelenchus xylophilus*, which is closely related to the well-known foliar nematodes of the genus *Aphelenchoides*. Like its relatives, *B. xylophilus* is parasitic primarily in above-ground tissues of higher plants but can reproduce on many species of fungi as well. Unlike all other nematodes that cause plant diseases in the United States, the pinewood nematode is transmitted from plant to plant by an insect vector.

Figure 1. Foliar symptoms of pine wilt. Brown needles are retained through the winter.

Before the recognition of pine wilt disease in the late 1970's, the occasional rapid death of scattered pines had been attributed to a variety of causes, including insect attack, fungal infection, rodent injury, adverse soil conditions, weather stress, and lightning. Many of these casualties are now thought to have resulted from pinewood nematode infection.

Figure 2. Wilt-killed pine stands out prominently among healthy pines, as green needles rapidly turn to brown, but remain on tree throughout the winter.

HISTORY

Pine wilt is known to occur only in certain east Asian countries and the United States. At present, pine wilt is most important in Japan, where it has caused serious losses in the red and black pine forests for over forty years. Entire stands of pines have been killed in the space of two to three years.

Originally given the name *B. lignicolus* in Japan, the pinewood nematode in that country is now known to be the same species as *B. xylophilus*, described in 1934 from a dead longleaf pine in Louisiana. In the interim years, the nematode was presumed to feed only on fungi in dead pines. It is considered native to North America and probably was introduced into Japan at least seventy years ago in wood dunnage or lumber from the United States.

Although *B. xylophilus* was identified in this country many years ago, pine wilt disease was not recognized until early 1979 in Missouri, Since then, the pinewood nematode has been found in almost

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Figure 2. Young Scotch pine - single terminal winter flag (arrow) containing nematodes.

all states east of the Rocky Mountains and in California. The nematode was first reported in Canada in 1983. Despite this wide distribution, no evidence exists that the disease has been spreading rapidly in most areas where it occurs. It is usually found only sporadically and primarily in southern and introduced pine species.

Unlike other areas of the country, Illinois has experienced a dramatic increase in the incidence of pine wilt since its first detection in late 1979 in the southern part of the state. The nematode has been found in dead pines in 76 of the 102 counties in Illinois and is probably present wherever there are substantial numbers of pines. Pine wilt disease is now occurring in epidemic proportions in some areas of the state, and has become the most destructive malady ever to afflict pines in Illinois. The reason for the rapid rise in incidence is unclear, but it appears to be associated with an increase in populations of more susceptible species in areas of the country that originally had few native stands of conifers. It is also associated with the age of these pines and in populations of the insect vector. A general weakening of pines by drought stress and severe winters in the 1970's and 80's and, more recently, the rising number of wilt-killed pines have provided the vectors with a greatly improved breeding habitat.

HOSTS

Virtually all species of pine grown east of the Rocky Mountains are known hosts of the pinewood nematode. The species differs widely, however, in their susceptibility to pine wilt. Fortunately, native American pines are relatively resistant. Thus, pine wilt does not appear to be as serious a threat to pine forests in this country as it is to those in Japan, where the native pines are highly susceptible. The disease does not occur in conifers other than pines, although the nematode has been found occasionally in white and blue spruce, balsam fir, eastern and European larch, and Atlas and deodar cedar.

Pine wilt in Illinois is most common in the Scotch pine. The disease progresses most rapidly and once the nematode becomes established in the wood, the tree is doomed. Because of the high susceptibility of Scotch pine, windbreak, landscape, and Christmas tree plantings of this species are seriously threatened throughout the state. The etiology of pine wilt in other species of pines planted in Illinois is not well understood. The incidence is much less common in the moderately susceptible Austrian, red and jack pines, infrequent in mugo and loblolly pines, and extremely rare in white pine. The disease is essentially limited to trees over ten years of age, when the pines become more attractive to the insect vectors.

SYMPTOMS

The most prominent symptom of pine wilt is the sudden decline and death of the entire tree within a few weeks or months after the first sign of disease. Symptom development is most rapid and uniform over the tree during the warmest months of the year–when the needles seemingly die all at once– and in young to middle-aged trees. The foliage of the infected tree passes from the normal, healthy green through four stages of discoloration. The needles first turn light grayish green. By this time, resin no longer flows from the wood and the tree is already dead. The overall color of the tree then proceeds to a yellowish green as chlorophyll begins to disappear from needles, then to a yellowish brown as the remaining chlorophyll is lost, and finally to a total brown (Figure 1). Longer and softer-needled species of pines

show an obvious wilt of needles over the entire tree, as if its source of moisture has been suddenly cut off. Because death is so rapid, the tree retains its brown needles for a long period of time, often up to a year. Thus, wilt-killed pines stand out prominently among healthy neighboring pines (Figure 2).

Most mortalities occur from late summer to late fall. Toward the end of this period, symptom development slows and becomes less uniform over the tree. Some infected trees survive the winter, usually with one or more dead branches (flags) that stand out against healthy portions of the tree (Figure 3). The flags are usually located in the upper crown but can occur anywhere in the tree. Up to 50 percent of the crown of a live tree may be flagged. Pruning out these branches seldom eliminates the disease because the nematode usually has already reached the trunk.

Younger trees with winter flags inevitably die during the spring, the second peak period of annual mortality. Spring mortalities frequently show interrupted candle growth, wilting of young candles, and the color changes first in second- and third-year needles. On Austrian pine, the nematode-induced branch flagging can be confused with branch dieback caused by the fungi *Sphaeropsis (Diplodia) pinea*, particularly when the dieback is rapid after prolonged wet weather. Dieback from the fungus disease usually progresses from the base of the crown upwards and rarely kills its host.

Figure 4. Old Scotch pine - healthy, uninfected right limb; dead, infected left limb. Top portion of infected limb advanced to needle-shed stage; probable area of nematode into crown.

Large, old Scotch pines with widely separated limbs frequently die from the upper crown downward or limb by limb, particularly if only one limb was initially infected (Figure 4). Because of the distance that the nematode population must move from the point of introduction to the trunk, total death of these trees may take up to a year from the time the first flag branch becomes obvious. More resistant species of pines may survive for a year or more with localized infections. These nematode-weakened trees may eventually succumb to attack by secondary pests or pathogens.

In Scotch and Austrian pines that die during the late summer-fall period, the nematode usually can be found throughout the wood of the tree crown once the symptoms become apparent. The nematode is rare in twigs because of rapid drying of the tissues and is absent from needles and cones. Other species of pine and Scotch and Austrian pines that die in the spring frequently have only spotty infections in the wood, necessitating extensive sampling to detect the nematode.

DISEASE CYCLE

The pine wilt disease cycle is highly complex, involving at least four different organisms (Figure 5). Infection of healthy pines results from a unique relationship between *B. xylophilous* and a sawyer beetle in the genus *Monochamus*. Bluestain fungi *Ceratocystis* spp, which rapidly invade the wood of dead weakened pines, also are intimately involved in the disease cycle as an alternate food source for the nematode. A similar pathogen-vector-fungus relationship is known to occur in Japan.

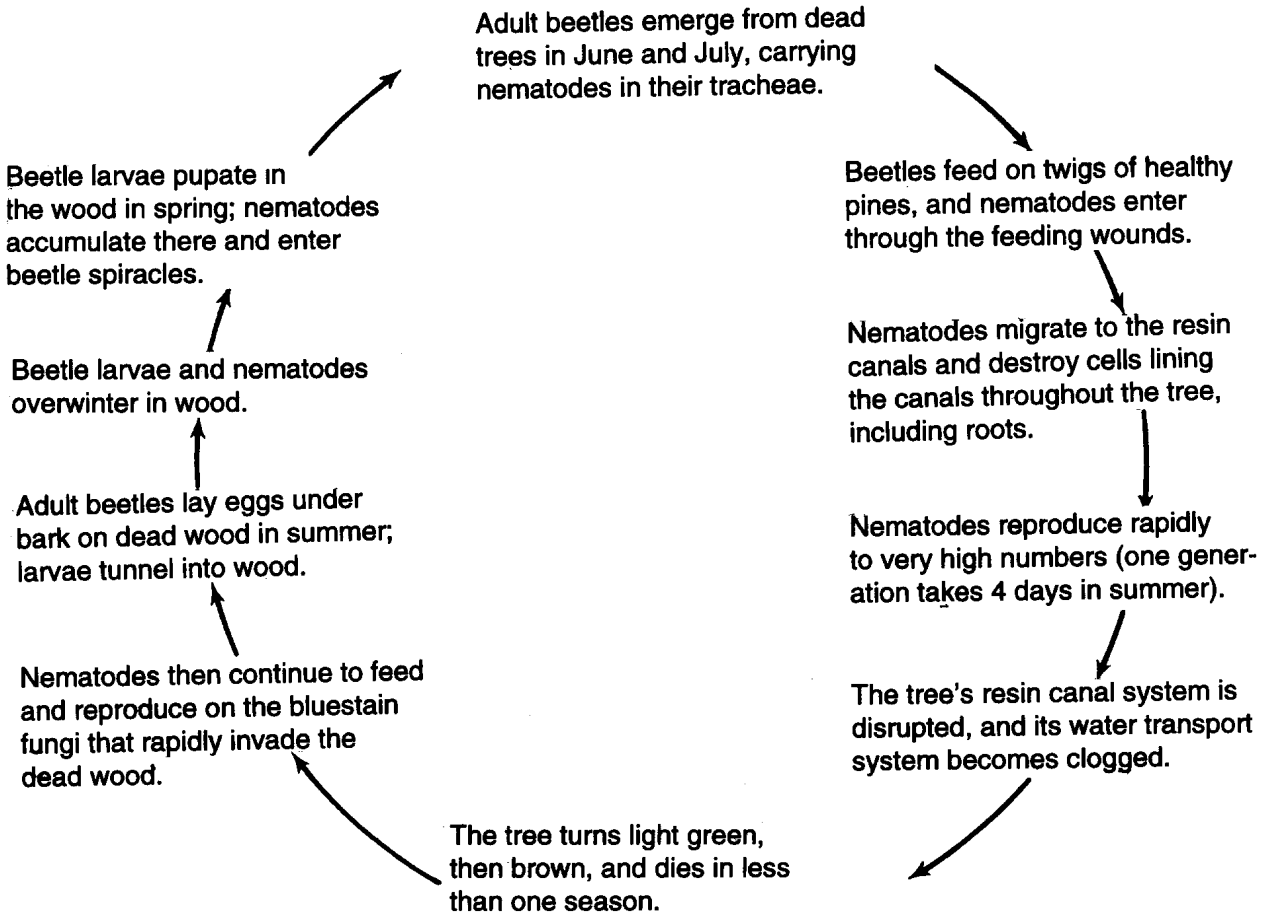

Figure 5. Disease cycle of pine wilt.

The sawyer beetles (Figure 6), also known as long-horned beetles because of their very long antennae, are themselves economic pests in the timber industry because the larvae burrow into the wood of recently felled trees, thereby lowering the quality of the wood. Female pine sawyer beetles lay their eggs under the bark of dead or dying pines, mostly during the summer. Legless, grublike, white larvae with small brown heads hatch within one to two weeks and feed beneath the bark until about half grown. The larvae then tunnel deeply into the wood, where they chew angled, elliptical entrance holes. They over-winter in the tunnels and pupate in the spring. Characteristic coarse frass deposited during feeding can be seen under the loosened bark of trunks and branches. When fully grown, the larvae are 3/4 to 1 ½ inches in length. Adult beetles emerge from late spring to late summer, producing uniformly round exit holes, 1/4 inch in diameter, in the bark of the tree. Generally, there is one generation a year, but two generations can occur in the southern United States. The adult beetles of the various species of pine sawyers range in length from 3/4 to 1 ½ inches and in color from gray to brown to black. Their bodies are usually mottled with small, light-colored patches. The antennae of the male can be over four times the length of its body.

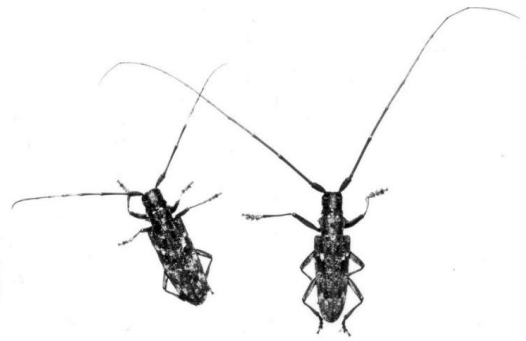

Figure 6. Female (left) and male Carolina pine sawyer beetles.

Dead pines infected with *B. xylophilus* harbor untold millions of pinewood nematodes, most of which are in a specialized, nonfeeding, third juvenile stage, called the dispersal stage, by

Figure 7. Sawyer beetle and its maturation feeding wound on pine twig, site of transmission of pinewood nematode.

the time the sawyer beetle larva is ready to pupate. The dispersal-stage nematodes accumulate around the pupation chamber and molt to more specialized, nonfeeding fourth-stage juveniles, called dauerlarvae. The dauerlarvae then infect the adult beetle as it emerges from its pupal shell and hardens its external skeleton in the chamber. The nematodes enter the beetle through its spiracles, or breathing pores, and mass within its tracheae, or breathing tubes. The beetle then chews its way out of the wood, carrying large numbers of nematodes in a quiescent state in its respiratory system.

Soon after emergence from the dead wood, the beetle flies to a live pine and feeds on the branches (its maturation feeding), usually first- and second-year wood of twigs (Figure 7). Under favorable temperature and moisture conditions, the dauerlarvae emerge from the beetle spiracles and enter the tree through the feeding wounds in the branches. A single beetle probably can transmit nematodes to get more than one branch in the same or different tree. The nematodes migrate to the resin canals of the pine and molt to adults, which are about 1/20 inch in length (Figure 8). The adults begin to feed on the thin-walled cells lining the canals. The adults mate and females begin laying eggs in the resin canals. The juvenile nematode molts once within the eggs, hatches as a second-stage juvenile, and passes through two additional feeding stages before a final molt to the adult stage. This normal life cycle without production of dispersal and dauerlarva stages then continues, building up the nematode population in the tree. The pinewood nematode has the shortest life cycle of any plant-parasitic nematode, resulting in a population explosion within highly susceptible pines. One generation is completed in four days when the nematode is cultured on fungi in its optimum temperature range of 25° to 30°C (77° to 86°F).

Figure 8. Adult male pinewood nematode - 1/30 of an inch.

During the warm summer months, the nematodes reproduce rapidly to very high numbers. They spread throughout the resin canal system of susceptible pines, into the trunk and virtually all branches, and even into the roots. As the resin canal cells are destroyed, the system is disrupted, resin flow slows, and the water transport system of the tree becomes clogged. Phytotoxins produced by the tree itself in response to nematode infection also play a primary role in plant death. When there is sufficient destruction of these systems in the trunk, the tree dies suddenly and the needles turn rapidly from off green to totally brown. Death can occur in as little as two months after introduction of the nematode into highly susceptible Japanese red and black pines. Dead wood is rapidly invaded by the bluestain fungi during warm weather (Figure 9). Like the sawyer beetles, these fungi also are an economic problem in the timber industry because they cause extensive wood discoloration in weakened and recently felled trees. When live tree cells are no longer available, the nematodes continue to feed and reproduce on the fungal hyphae that grow through the resin canals. Nematodes become inactive in late fall and overwinter in the wood of both live and dead trees. Activity resumes in the spring.

As the wood of the dead pine dries, begins to decay, and generally becomes inhospitable to the nematode, reproduction ceases and the second stage juvenile molts to the dispersal stage, rather than to the normal third-stage juvenile. The dispersal-stage nematode is dark as compared with the nearly transparent

appearance of the normal feeding stages, has a reduced, nonfunctional stylet, and is resistant to external stress. The population slowly converts to the dispersal stage until only this form can be found in the wood, generally 6 to 12 months after death of the tree. The dauerlarval stage, which has no visible stylet and is virtually undetectable in the wood itself, can remain alive within the beetle only as long as its vector host survives, usually one to three months.

Figure 9. Nematode-infected Scotch pine-extensive trunkwood discoloration by blue-stain fungi.

Female sawyer beetles are attracted to the wilt-killed pines for egg laying and begin the disease cycle again. Spring and summer mortalities become infested with beetle larvae during the year of death. During the summer, oviposition sites often can be found on the trunk as soon as resin flow in the nematode-infected tree has ceased, but before foliar symptoms can be detected. Because adult beetles usually die by autumn, most fall mortalities do not become infested with larvae. Thus, the disease cycle varies in length from one year to two or more years or may not be completed at all, depending on the season of death of the tree and the relative susceptibility ofl the pine species to the nematode.

Among the many insect species that attack both live and dead pines, only the sawyer beetles and a few related long-horned beetles are potential vectors of the pinewood nematode. Six species have been found to carry the pathogen in the United States, but the capacity of most to transmit the nematode is not yet known. The Carolina pine sawyer beetle, *Monochamus carolinensis* (Figure 5), appears to be the principal vector in Illinois and is widespread throughout the state. Larval activity can be detected in dead trees wherever pine wilt occurs. The beetles can harbor up to 90,000 pinewood nematodes in its tracheal system.

The Carolina pine sawyer beetle is grayish brown with dull white to very light yellow markings on its upper surface and is about 3/4 inch long. This species normally has a single generation a year in Illinois. Beetles emerge from early June to early September, mostly during June, and can live up to four months. Seldom seen, the beetles are active only at night. They remain hidden in foliage or camouflaged on the bark of pines during the day. At night, females chew characteristic coneshaped depressions at random in the bark of dead and dying pines and deposit one or two eggs at the base of each site just beneath the bark. These oviposition sites should not be confused with the patterned, cyclindrical drillings of the yellow-bellied sapsucker, a woodpecker that migrates through Illinois in early spring and autumn.

A second species of beetle, the southern pine engraver, *Ips grandicollis*, is intimately involved in the pine wilt disease cycle in Illinois. This tiny reddish brown to black beetle does not carry the pinewood nematode, but it transports spores of the bluestain fungi on its body. It is thought to be a principle means of dispersal of the fungi from dead pines to stressed and dying pines. Engravers heavily infest wilt-killed pines, and adults are readily attracted to weakened trees. Nematode-infected pines often are attacked before the onset of foliar symptoms of pine wilt. The beetle larvae feed beneath the bark, chewing narrow galleries along the surface of the wood. They produce very fine frass under the bark and in crevices on the exterior. Emerging adults chew tiny "shotholes" in the bark. There are several generations a year, and adult activity begins early in the spring.

SAMPLING

Although symptoms of pine wilt disease are usually obvious, the presence of the nematode must be confirmed. Its accurate identification requires microscopic examination because other species of

nematodes frequently inhabit dead or diseased wood; they feed only on fungi or bacteria in the tissues or associate only with insects in the wood. Samples can be sent to the Plant Clinic, 1401 W. St. Mary's Road, Urbana, Il 61802, for diagnosis. Sample **only** where there is a sudden, rapid death of the entire pine tree in less than a year. A slow decline is most likely not a pinewood nematode problem. There is an $18.75 charge for the diagnostic service.

Diagnostic sampling for pinewood nematode differs from that for soil-inhabiting nematodes. A sample should consist of at least two 8-inch long branch sections, 1 1/2 to 2 inches in diameter, taken near the trunk at or above head height from each of two branches, on opposite sides of the tree several feet apart. The branches should be dead but still retaining the brown needles; branches with green needles may not yet contain nematodes. If possible, include a disc of wood, 1 inch thick by 3 to 4 inches in diameter, cut from the trunk. If branches are not within reach and the tree is totally brown, four trunk borings to a depth of 4 inches should be taken with an increment core sampler at breast height and wrapped in aluminum foil. If the tree is relatively young and has only small diameter branches, a trunk section 8 inches long by 2 to 3 inches in diameter should be taken near midtree height.

Place nematode samples in a paper bag: plastic bags cause excessive molding of the wood, which kills the nematodes. Mail samples in a sturdy shipping box or padded mailing envelope as soon as possible. Samples from more than one tree must be bagged separately, identify each sample with the following information; 1) species of pine, 2) estimated age, 3) type of planting, 4) when symptoms were first noticed, 5) present coloration of the tree, 6) extent of occurrence in the planting, 7) date of sampling, and 8) name and address of owner.

CONTROL

1. **Sanitation**. Prune dead branches from live trees to minimize attractiveness to beetle vectors. As each tree is pruned, be sure to disinfect pruning tools before moving on to the next tree. Remove dead trees to the ground line or deeper as soon as possible and destroy the wood to reduce reservoirs of infection. Do not store the wood for firewood. Burn or bury the trees because beetles that would emerge from the wood and carry nematodes are capable of flying several miles. Remove dead pines in a radius of three miles for maximum protection of valuable plantings. If the disease cycle is broken, further spread will be prevented.

   At this time, we are recommending against the use of infested trees as a source of wood-chip mulch. There is some question as to whether or not disease spread can occur from such mulch, especially when it has not been composted. If you have a choice, do not use the wood from infected trees as a source of mulch.

2. Insecticide or nematicide treatments to control the beetle vectors or the nematode are impractical in Illinois because of the long period of beetle activity and the extreme difficulty in eradicating the nematode from infected wood.

3. **Resistant conifers**. Where replacement of dead pines with conifers is desired, replant suitable sites with Norway or blue spruce, Douglas fir (southwest seed source), cedar, or hemlock, which are virtually immune to the disease. The rare incidence of pine wilt in white pine indicates that this species can be replanted with relative safety at sites of disease occurrence.

4. **Resistant cultivars**. There are no known highly resistant cultivars within very susceptible species. Some Japanese black pine selections offer promise, and a search for assistance among selections of Scotch pine has begun.