

JOURNAL OF ARBORICULTURE

January 1982
Vol. 8, No. 1

PINE WILT—A DISEASE YOU SHOULD KNOW¹

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Abstract. Pine wilt is a disease characterized by sudden death. The needles remain attached, but become reddish brown. It is currently a major problem in Japan on *Pinus thunbergii* and *P. densiflora*. It was first identified in the U.S. in Columbia, MO in 1979. It is now known in 32 states on 20 species of pine, two of larch, two of spruce, two of cedar, and on balsam fir. The causal agent is a nematode, *Bursaphelenchus xylophilus*, transmitted by Cerambycid beetles. Ornamental plants of *P. sylvestris* and Christmas tree plantations of this species suffer damage. Forest trees of various species have also been found to have the disease. Some pine species are more susceptible than others. Although pine wilt is not a major problem in the U.S. it is potentially dangerous. The only practical control now available is removal and burning of dead trees.

A pine tree of almost any age may look healthy in the spring and early summer. One day you may notice that this tree no longer secretes resin at a wound, although its color is still green. In a few weeks the green of its needles becomes pale, then yellowish, and then the whole tree is unmistakably dead. It is now rust colored, but the needles remain attached. The best thing to do is to remove and burn it before the following spring.

What causes the sudden death of pine trees? Is it a serious problem to arboriculturists? What can we do about it? These are the questions we are concerned with. The answers are not simple or easy to obtain. Pine wilt is now a major problem in the forests of Japan. It is also killing pines in scattered locations across the U.S. especially in ornamental plantings of Scotch pine, and in Christmas tree plantations, as well as in forests. This disease also occurs in France.

In the winter of 1979, a Columbia, MO man brought a large piece of wood from the trunk of an Austrian pine into the diagnostic clinic of the

Department of Plant Pathology at the University of Missouri. The tree had been planted on the day this man was born and it died suddenly in its 39th year during the summer of 1978. By chance a Japanese plant pathologist was visiting the clinic at the time. He insisted that we examine the tree for nematodes. We removed a small cube from the center of the wood, placed it in water, and were amazed to see the thousands of active nematodes that emerged. In the next few months we found other examples of dead pines in Columbia, especially on a golf course, and also around homes. After a publication appeared announcing the find, others looked for the disease and we now know that it occurs in the U.S. in 20 species of pine, one of spruce, 2 of larch, two of cedar, and on balsam fir. Pine wilt is reported from 32 states. Nowhere in the U.S. does it cause major losses comparable to the situation in Japan although it is potentially a serious disease.

Pine wilt was first reported by a forest entomologist in 1913 as important in Kyushu, Japan. It had originated in Nagasaki in 1905, possibly from imported lumber. Since then it has spread through southern and central regions and is now present in northern Honshu as well. Japanese authors record the loss of 1.25 million cubic meters of wood in 1948, one million in 1975 and two million in 1978. Despite strenuous efforts to contain the disease, the annual loss is estimated as 400,000 cubic meters. In 1980, the Japanese government appropriated \$35 million to solve the problem. Most of this is spent on aerial sprays to control the insect vector in an effort to protect the forests.

¹Presented at the annual conference of the International Society of Arboriculture at Boyne Falls, Michigan in August 1981.
Agricultural Experiment Station Journal Series 8929

Japanese investigators have studied the disease intensively. They first found in 1969 that large numbers of a nematode species are present in wood of pine trees killed by pine wilt. In 1971 they inoculated healthy pines with nematodes and reproduced the disease. The problem is acute in Japan because two of the major forest trees, black pine (*Pinus thunbergii*) and red pine (*P. densiflora*) are highly susceptible and because they have an efficient vector. Reviews by Mamiya (1972, 1976) should be consulted for full accounts.

The Disease Cycle

Symptoms appear during the middle or late sum-

mer. An adult long-horned beetle (cerambycid) carries nematodes in its air passages when it emerges from a dead infected tree. The insect flies to a healthy pine to feed for about 30 days on succulent growing branch tips, stripping the bark to reach cambial tissue. During this time its ovaries mature. While the insect feeds, nematodes emerge from the spiracles and enter the pine through the wound. Once within the pine, the nematodes find the resin ducts where they reproduce rapidly and disperse within the tree. A mated female lays about 80 eggs; four days later at summer temperatures the next generation is ready to reproduce. Within three to four weeks after inoculation the tree shows symptoms of

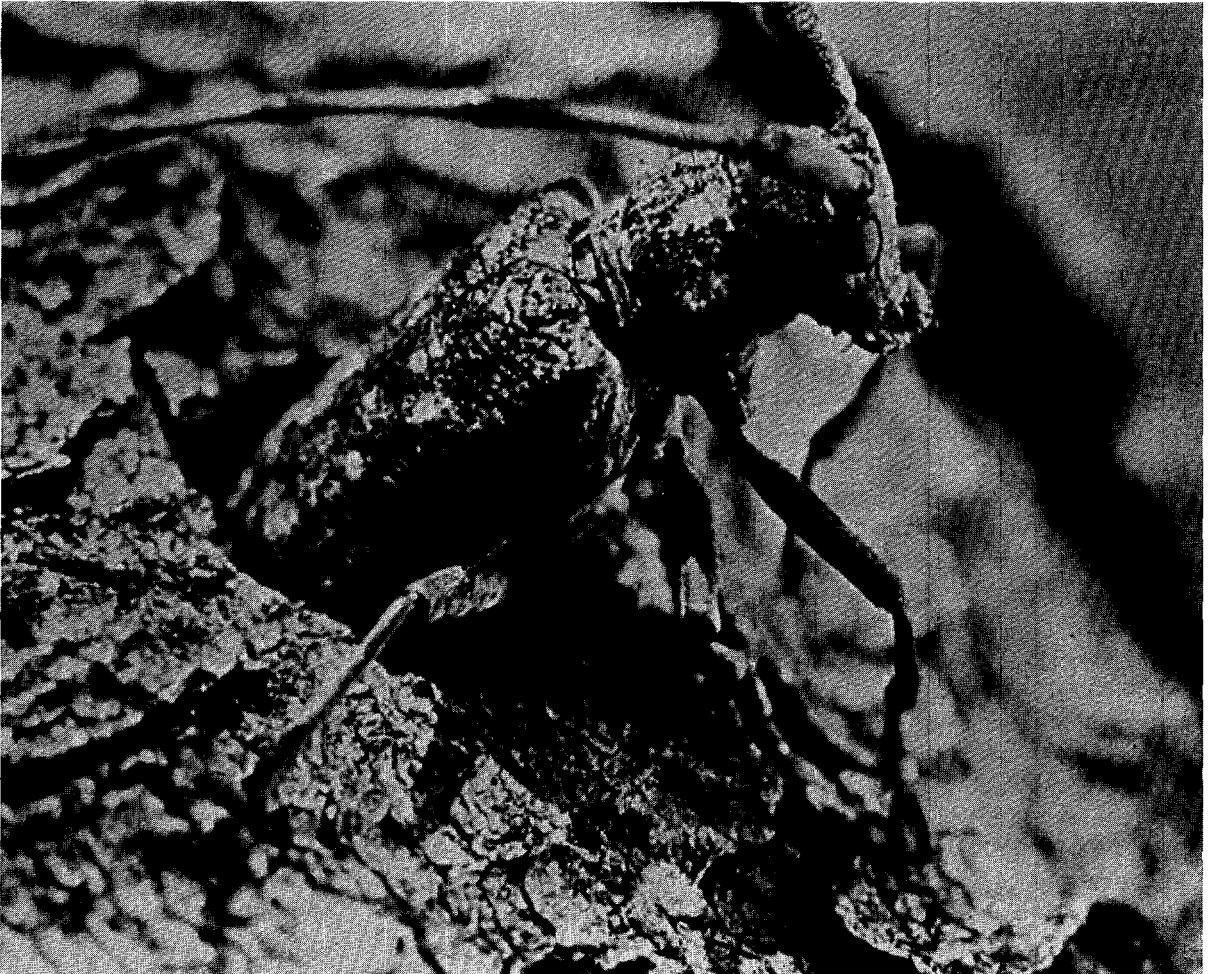


Fig. 1. Adult pine sawyer beetle (*Monochamus alternatus*) emerging from pine tree (Photo courtesy of Y. Mamiya).

stress and in five to six weeks it dies. The first sign of stress is that oleoresin stops exuding from wounds. Later the needles lose their green coloration and eventually show a characteristic reddish brown color. Mature beetles oviposit under the bark of stressed or dead trees. Their larvae burrow under the bark, then invade deeper layers of the wood to pass the winter. In the spring a larva excavates a chamber in which it pupates and from which an adult emerges by chewing its way to the exterior.

At Urbana, IL on the campus of the University of Illinois, about ¼ of the Scotch pine trees died from pine wilt during 1980-81. Some of these were 75 year old trees. In contrast to the quick death just described as typical of pine wilt, some trees showed different symptoms. Dead branches appeared in the fall, but the rest of the tree remained green over Winter. In the following spring or summer, the rest of the tree died with typical pine wilt symptoms. We believe that the nematodes were immobilized by the cold. When the temperature rose, they became active again, invaded the rest of the tree and killed it. Similar symptom expression has also been seen in the northern parts of the range of pine wilt in Japan.

There is an amazing adjustment between the organisms involved in this disease. When the insect flies to a succulent branch tip of a healthy pine tree it may carry up to 20,000 or more nematodes in its air passages. These are a stage of nematode adapted to resist starvation. This stage appears in dead trees in the spring of the year. As the beetle larva burrows through the wood the nematodes do not seem to respond to its presence. But by the time the larva excavates a chamber in which it pupates, most of the nematodes in the tree have transformed into the resistant stage. These aggregate in the pupal chamber, and when the adult beetle emerges, the nematodes invade the thoracic spiracles and pack themselves into the large air tubes of the insect. As the insect feeds, they emerge from the spiracles, enter the wound, and find their way to the resin canals. In a day they develop into adults, feed and mate. The adults are long, thin, active nematodes, about .08 mm × 0.02 mm. They feed on cells lining the resin canals. In a few

weeks they may be found throughout the tree from the roots to the highest branches. After the tree dies, fungi penetrate the wood, and the nematodes build enormous populations in the dead tree by feeding on the fungi. We have recovered living nematodes for more than a year from a Scotch pine that died during the summer of 1979.

Our discovery of pine wilt in Missouri raised a number of questions (Dropkin and Foudin, 1979). Is the disease present in other locations in the U.S. in addition to Missouri? Which species of pine are susceptible? Is the nematode present here the same as that in Japan? Why is pine wilt a devastating disease in Japan and only sporadic in the U.S.? Why do the trees die so fast? Perhaps other organisms in addition to nematodes play some role — is this the case? We have addressed ourselves to some of these questions by assembling a team consisting of a nematologist from Japan who had some experience with this disease, an entomologist fresh from his Ph.D. on bark beetles, and two chemists.

Geographical Distribution

At present pine wilt disease is known in 32 states. The distribution runs across the U.S. from Minnesota to Louisiana and from California to Maryland. Scotch pine in ornamental plantings is the most frequently reported species, but a total of 20 species of pines are known to have died from pine wilt both in ornamental plantings and in forests. Table 1 lists the pine species and other conifers in which dead trees had *Bursaphelenchus xylophilus*, the pinewood nematode.

Host Susceptibility

The Forest Service supported a conference held in November, 1979 at Columbia, MO. As a consequence, we received pine seedlings of various species from around the U.S. and inoculated them with nematodes according to techniques developed in Japan. Table 2 shows that 3-5 year old seedlings vary in their susceptibility to pine wilt.

This limited test revealed differences among pine species. The distinction between susceptible, intermediate, and resistant species was ap-

parent in the inoculations with 1000-2000 *B. xylophilus*. Susceptible species lost 60-73% of inoculated seedlings, intermediate species lost 30-42%, and the resistant ones lost 0-22%. This difference was not apparent when the seedlings were inoculated with 20,000 nematodes. However, both Jeffrey and Lodgepole pine remained healthy. Subsequent tests showed that Jeffrey pine did not succumb to inoculations of 200,000 nematodes.

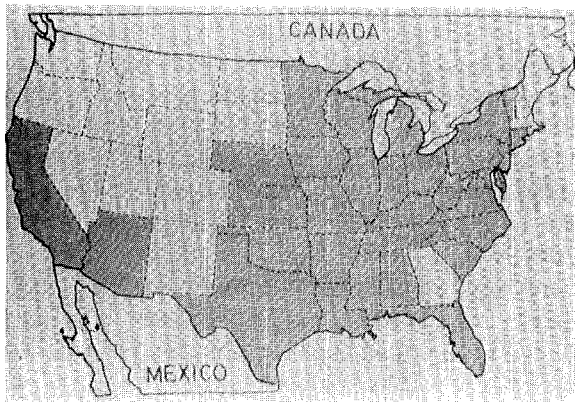


Fig. 2. Distribution of pine wilt in the United States. Each shaded state indicates that one or more confirmed examples of dead pine trees infected with pine wilt nematodes have been recorded in that state.

Variability of the Nematode

Pine wilt disease is probably cosmopolitan. It has already been identified from three regions of the world (Japan, U.S., and France) and we may surmise that it will be found elsewhere. We must therefore inquire into the variability of the nematodes. We made a comparison of nematodes from Japan and from Missouri to determine whether Japanese findings are applicable here. We have learned that:

1. Pine wilt nematodes from southern Japan interbreed freely with those from Missouri;
2. there are no significant morphological differences between nematodes from each source; and
3. minor differences in pathogenicity are present.

We conclude that both populations belong to the same species and that they are similar enough to permit investigators in Japan and the U.S. to benefit from each others' findings.

Hazard to Christmas Tree Production

We have surveyed four Christmas tree plantations in Missouri during October, 1980 to determine whether pine wilt is important. The year was exceptionally dry and a number of trees had died suddenly during the summer. Almost all of these contained pine wilt nematodes (102 with nematodes in a total of 109 trees examined). Although the total losses were not devastating, each tree represents a potential source of inoculum for the plantation. The youngest dead trees were 8 years old. In one plantation, the insect infestation of diseased trees was high, and we found a native species of the same genus of wood-boring beetles known to be the principal vector in Japan. *Monochamus carolinensis* is a vector in Missouri and *M. alternatus* (see Figure 1) in Japan. In the spring and summer of 1981, beetles carrying up to 79,000 nematodes per adult insect emerged from sections of Scotch pine kept in cages out of doors over the winter.

Control

The control of pine wilt in the U.S. is mostly a matter of sanitation. By the time a tree shows symptoms it is already too far gone to save. In Japan, some individual trees are treasured, and protection of these is economically justified. Japanese reports of protection by drenching and by the injection of systemic compounds are in the literature, and some tests are underway in the U.S., but I have not seen any reports yet. A grower of Christmas trees and of nursery stock would be well advised to remove and burn all conifers that die suddenly. To prove that a tree died from pine wilt, the nematode must be extracted from the wood and identified. This is not especially difficult but identification must be made by a competent microscopist on the basis of characteristics of the adult male nematodes.

Until now there is no evidence that the nematode is transmitted without passing through the insect vectors. There seems to be little risk of contamination from bark mulches. We have wondered about the possible role of sapsuckers in disease transmission but have no evidence on this point.

Control of vector insects by use of insecticides

Table 1. Species of conifers killed by pine wilt disease in the U.S. as of June, 1981 (compiled by K. Robbins, U.S. Department of Agriculture, Forest Service, S. & P.F., St. Paul, MN)

Pine Species	No. of	
	Counties	States
<i>Pinus sylvestris</i>	108	AR, DE, IL, IN, IA, KS, KY, MD, MN, MO, NJ, NY, OH, OK, TN, VT, VA, WV, WI
<i>P. resinosa</i>	27	DE, IL, IN, IA, OH, TN, VT, WV, WI
<i>P. taeda</i>	23	AL, DE, FL, IL, LA, MD, MS, NC, TN, TX, VA
<i>P. nigra</i>	21	IL, IN, IA, KY, MD, MN, MO, PA, TN, WI
<i>P. strobus</i>	20	CT, DE, IL, IA, KY, MD, MI, MN, MO, NE, NC, TN, VA, WV, WI
<i>P. thunbergii</i>	18	AR, DE, MD, MO, NJ, NY, OK, VA
<i>P. elliotii</i>	12	FL, LA

The following species in 10 counties or less: *P. banksiana*, *P. cembra*, *P. clausa*, *P. contorta* var. *murrayana*, *P. echinata*, *P. halepensis*, *P. mugo*, *P. palustris*, *P. ponderosa*, *P. radiata*, *P. rigida*, *P. virginiana*, *Larix laricina*, *L. decidua*, *Abies balsamea*, *Picea spp.(2)*, *Cedrus deodora*, *C. atlantica*.

Data are assembled as counties from which the disease has been reported and nematodes have been identified as *B. xylophilus*. The prevalence within counties is not recorded.

does not seem to be practical under our conditions. The flight range of Cerambycid beetles carrying nematodes is not known but it is likely to be considerable. The Japanese found that the disease moves in the forest one to two kilometers per year.

In the long run, genetic control offers excellent possibilities. There is good evidence of resistance of individual trees in a pine species that is generally susceptible. Methods that permit large scale screening for resistant germplasm must be found. Long term support of basic research on this

Table 2. Number of dead seedlings of various pine species 53-56 days after inoculation with *Bursaphelenchus xylophilus*.

Species	Numbers of nematodes inoculated		
	0	1000-	
		2000	20,000
Susceptible			
Monterey (<i>P. radiata</i>)	0/7 ^a	11/15	2/2
Sugar (<i>P. lambertiana</i>)	0/5	7/11	1/2
Scotch (<i>P. sylvestris</i>)	0/4	3/5	1/2
Shortleaf (<i>P. echinata</i>)	0/3	3/5	1/1
Intermediate			
Western white (<i>P. monticola</i>)	0/5	5/12	1/2
Red (<i>P. resinosa</i>)	0/5	3/10	2/2
Resistant			
Ponderosa (<i>P. ponderosa</i>)	0/4	2/9	1/2
Lodgepole (<i>P. contorta</i>)	0/4	1/6	0/2
Southwestern white (<i>P. strobiformis</i>)	0/6	2/14	2/2
Eastern white (<i>P. strobus</i>)	0/4	0/5	2½/2
Jeffrey (<i>P. jeffreyi</i>)	0/4	0/10	0/2

^aNumber of seedlings dead/number inoculated.

disease will be required. In my view this is the most practical way to solve the problem of pine wilt.

Summary

Pine wilt, a disease characterized by sudden death of pines, was first reported in 1913 in Kyushu, Japan, as a local epiphytotic. It is now of major importance in much of Japan. The first symptom of disease is failure of resin flow from wounds, followed by loss of green color of needles. About two months after infection, the needles become reddish brown and remain attached. The causal agent is a nematode. An adult wood-boring long-horned beetle becomes infected with thousands of nematodes as it emerges from a dead tree. They invade the air passages of the insect, and when it flies to a

healthy tree to feed while its ovaries mature, the nematodes leave the insect to penetrate the tree through the feeding sites. The nematodes enter resin canals and invade the entire tree. The disease was found in Missouri in 1979 and is now known in 32 states on 20 species of pine as well as on spruce, cedar, larch, and fir. There are differences among pines in susceptibility. *Pinus sylvestris* suffers damage in ornamental plantings and in Christmas tree nurseries. Other species are also affected in forests. Although not now a major problem, pine wilt is potentially serious in the U.S. The only practical control now available is to remove and burn infected trees before the beetles can emerge. In the long run genetic control should be feasible.

Acknowledgments

This work was partly supported by funds from USDA Forest Service, RUWFS-NC-2205, cooperative agreement 13-710 with the University of Missouri.

Grateful acknowledgment is made to the government of Japan for permitting Dr. Eizo Kondo to spend a year in the Dept. of Plant Pathology, UMC, and to Michael Smith for excellent technical assistance.

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ABSTRACT

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Urban environments impose severe stresses upon landscape vegetation, making simple solutions quite difficult. When selecting plants for a specific site, a landscaper must consider the site's problems, such as poor soil conditions and temperature stresses. Proper plant selection increases the effectiveness of any design by ensuring that the plant adapts to its proposed habitat. The roots of trees and shrubs are aerobic. There must be an exchange of oxygen and carbon dioxide between the air and the soil for them to survive. In saturated or poorly drained soils, roots suffocate; the plant declines and dies. The best way to avoid problems with excess moisture is to determine the soil moisture and drainage patterns of an area. Avoid planting in areas that retain water after rains or that are flooded in spring, unless water-loving trees are used in the design. Excessively wet soil also favors root disease fungus attacks and thus affects roots indirectly. Poor aeration also prevents roots from absorbing minerals from the soil solution. Root development near the soil surface is also a result of poor aeration. We have provided lists of plants that perform well under varying soil conditions.