Pest Management of Bareroot Hardwood Seedlings

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S.A. Enebak

Scott A. Enebak is professor and associate dean for instruction, School of Forestry and Wildlife Sciences, Auburn University, Auburn, AL

Outline

Facing Page: *Leaf spots on* Quercus *spp. indicating localized fungal infections. (Photo by Scott Enebak.)*

Disease Management

Root Diseases

Damping-off. A number of soilborne fungi, present in nursery soil, are capable of inciting disease in bareroot hardwood seedlings. The term "damping-off" describes the rapid and sudden mortality of young germinates prior to the lignification and hardening of the seedling stem, resulting in the seedling collapsing. Preemergence damping-off occurs before the seedling emerges from the soil and occurs when the fungi infect the seed or radical before the stem emerges from the soil. Preemergence damping-off appears to the manager as reduced or slower germination than what is expected of a particular seed source. In contrast, postemergence damping-off is mortality of the seedling after the young germinate has emerged from the soil (fig. 9.1). The seed/hypocotyls/seedling could have been infected at any time postsowing, but at least the seedling was able to emerge from the soil. As a general rule, smaller seeded species are more susceptible than larger seeded species to damping-off. Depending on the timing of infection and tree species, and because of their relative size, seedlings may not even "damp-off," but die, turn brown, and remain standing. This type of damping-off could be considered a seedling blight (the rapid and sudden death of a seedling) or could also be considered root rot, if later in the growing season.

The fungal genera responsible for damping-off include *Fusarium* spp., *Rhizoctonia* spp., *Cylindrocladium* spp., *Pythium* spp., and *Phytophthora* spp. These fungi are generally opportunistic saprophytes that feed on dead and decaying plant material and, under certain conditions, are capable of infecting seed, hypocotyls, roots and stems of hardwood seedlings. Infection by these soilborne fungi may result in mortality in the nursery, poor seedling quality (culls), or reduced survival after outplanting. Preemergent and postemergence damping-off will appear in nurseries as an expanding circle, either across or along a seedling bed as the fungi move through the soil infecting and killing seed/seedlings within the soil. Many times, infection is masked during cool periods but suddenly appears when temperatures increase and the seedling, its root system compromised by the fungal infection, cannot translocate enough moisture to remain turgid and damps-off.

Figure 9.1*—Postemergence damping-off of hardwood seedlings due to soilborne fungi. (Photo by Scott Enebak.)*

Both cultural and chemical methods can be used to minimize the effects of these fungi on seedling production. These fungi are usually present in low numbers and can survive in the soil in plant debris or, as in the case of *Rhizoctonia* and *Cylindrocladium*, in dormant spores that remain viable for years. Their effect on seedling mortality tends to increase when seedbeds are used continuously without rotations of cover crops, so crop rotation should be a part of the nursery's management plan. Excessive moisture and cool temperatures cause fungi to build up in large numbers, as cool, wet soil promotes fungi and slows seedling growth. Soils high in clay content or that drain poorly and retain moisture longer favor the damping-off fungi, especially the water molds *Pythium* and *Phytophthora*. Sowing hardwood seed in raised seedling beds and fields that drain excess water away from seedling roots will go a long way to controlling the fungi that infect seedling roots. Also, the addition of nitrogen early in the season favors soilborne fungi, so minimizing fertilizer until the seed has germinated will decrease the amount of damping-off that occurs early in the season. The soil pH also influences fungal behavior, with pH above 6 favoring the pathogen's growth at the expense of seedling performance. Nurseries that can maintain high levels of organic matter (greater than 3 percent) will find that damping-off is reduced due to the effects of the antagonistic, beneficial soilborne fungi that use organic matter as a food source and will outcompete the soilborne pathogens responsible for damping-off. In addition, damping-off is favored by organic materials that decrease soil pH and organic matter that increases the carbon nitrogen ratio.

While these cultural methods have been shown to be effective in minimizing damping-off, by far the most common and effective step in controlling damping-off diseases is the use of a soil sterilent prior to sowing. Historically, this has been either a fall or spring soil fumigation with combinations of methyl bromide and chloropicrin (98:2, 67:33, 80:20) at 350 to 400 pounds of active ingredient per acre (lb ai/ac) (388 to 444 kilograms of active ingredient per hectare [kg ai/ha]) or dazomet (350 to 400 lb ai/acre, 388-444 kg ai/ha). These compounds generally eliminate most of the soilborne fungi, weeds, insects, and nematodes within the soil profile, rendering the area semi-sterile. With the gradual phase-out of methyl bromide as a soil sterilent, compounds with 100-percent chloropicrin (table 9.1) have shown to be as effective as methyl bromide combinations in disease control, but are weak in weed control (South and Enebak 2005). Spring fumigation, followed by a spring sowing, will have less damping-off than any other option. For those nurseries that use some type of soil fumigation, hardwood seedlings should always be sown in first-year fumigation soil to reap the benefits of the reduced weed, insect, fungal, and nematode pressure.

Unlike soil fumigants that are presowing, there are fungicides that can be applied as a soil drench during the growing season, if necessary. These treatments will work only for a few targeted damping-off pathogens, which will need to be identified before treating the area. Damping-off caused by a specific soilborne pathogen can be controlled using the fungicides listed in table 9.2.

Root rot. Later in the growing season, the same soilborne fungi responsible for damping-off are capable of causing root rot, which may result in seedling stunting, mortality, or poor survival after outplanting. Depending on the fungus involved, the disease may be either *Cylindrocladium* root rot or *Phytophthora* root rot, as a number of species within each fungal genera can be responsible. Many hardwood species can be infected by these three fungi, including sweetgum (*Liquidambar styraciflua* L.), yellow poplar (*Liriodendron tulipifera* L.), black walnut (*Juglans nigra* L.), dogwood (*Cornus florida* L.), eastern redbud (*Cercis canadensis* L.), chinquapin (*Castanea* spp.), and many oak species (*Quercus* spp.). In addition to root decay, the fungi can be spread by rain and soil splash, resulting in stem lesions and foliage blights.

Table 9.1—Soil fumigants used to treat nursery soils prior to sowing.

Soil fumigant	Percent compound
Methyl bromide /chloropicrin	67/33 or 80/20
Chloropicrin	100%
Chloropicrin +	80% & 20% solvent
Dazomet	100%
Chloropicrin & 1, 3-dichloropropene	60% & 40%
Metam / potassium sodium	
Methyl iodide / chloropicrin	98/2 or 67/33
Dimethyl disulfide (DMDS) / chloropicrin	79/21

Figure 9.2—Dark-stained roots indicative of root-rot caused by Cylindrocladium *spp. (Photo by Scott Enebak.)*

Identification of these diseases on hardwood seedlings is based on the dark blackening of the roots or stems typically has longitudinal swellings and cracks along the infected area (fig. 9.2). Seedling mortality caused by root rot will appear as an expanding circle, either across or along a seedling bed, as the fungi move from seedling to seedling. The same cultural techniques can be used to control these fungi as are used to minimize damping-off: good soil drainage, proper soil pH, and high organic matter. If root rot does occur, then soil drenches of the

Table 9.2—Fungicides to control damping-off and root rot soilborne pathogens.

Soilborne fungi	Compound	Fungicide
Pythium spp and *Phytophthora* spp	Aliette	Aluminum tris (o-ethyl phosphonate)
	Sudue Maxx	Mefenoxam
	Pageant	Pycraclostrobin & boscalid
	Banrot	Thiophanate-methyl & etridiazole
	Captan	Captan
	Terraclor 75 wp	Pentachloronitrobenzene (pcnb)
Fusarium spp and *Rhizoctonia* spp	Cleary's 3336	Thiophanate methyl
	OHP 6672	Thiophanate methyl
	Banrot	Thiophanate-methyl & etridiazole
	T-Methyl	Thiophanate-methyl
	Pageant	Pycraclostrobin & boscalid
Cylindrocladium spp	Cleary's 3336	Thiophanate methyl
	Omega 50˚F	Fluazinam
	Terraguard 50W	Triflumizole

infected area have been shown to be effective in stopping the continued spread of the disease. Culling and destroying infected seedling material from the nursery beds will decrease inoculum later in the season and future crops.

Foliage Diseases

A multitude of leaf diseases occur on hardwood seedlings, most of them caused by fungi within the large fungal group *Ascomycota*. Fungi growing on leaf surfaces can be a concern because they reduce the area for plant photosynthesis and growth. Reduced vigor makes trees more susceptible to attack by insects and other fungi and appear unhealthy. Foliage pathogens are considered weak pathogens and generally do not kill trees, but can do so under extreme conditions. *Anthracncose*, as a rule, are the most severe pathogens on hardwoods and result in tree mortality, especially dogwood and sycamore anthracnose. Some foliage diseases are host-specific, having evolved to infect only one or two hosts. Some foliage diseases are not host-specific and can occur on any number of hardwood species, resulting in symptoms that include localized necrotic leaf spots to total death of the leaf. Severe infections may result in terminal growth reduction and mortality of smaller hardwood species. Hardwoods are less susceptible to foliage diseases than conifers; hardwoods have the ability to refoliate, whereas conifers will die once leafless. The fungi responsible for foliage diseases are spread via wind and rain, and infection occurs when specific temperature, moisture, and humidity requirements are met, along with a suitable host tissue. The fungi typically over-winter in the infected leaves that have been cast onto the nursery soil. Eliminating the leaves at the end of the growing season and/or rotating a nonhardwood crop in heavily infected areas will decrease disease incidence in future crops.

Powdery mildew. Seven fungal genera are responsible for powdery mildews on hardwood seedlings: *Erisyphe, Phyllactinia, Microsphaera, Podosphera, Sphaerotheca, Cystotheca,* and *Unicula*. All of them are obligate plant fungal parasites in that they do not live outside their specific host. Unlike most other fungal pathogens, powdery mildews do not require moisture for infection to occur. These fungi are host-specific and there are genotypes within a tree species that can be either resistant or susceptible to infection. Susceptible hardwood species include *Acer* spp., *Carya* spp., *Cornus* spp., *Juglans* spp., *Populus* spp., *Plantanus* spp., *Quercus* spp., and *Ulmus* spp. Superficial mycelia cover the plant surface giving it a blotchy, powdery, white, gray or tan appearance (fig. 9.3). Close examination of the leaf surface will reveal small black fruiting structures (cleistothecia) that are used to identify

Figure 9.3—*Powdery mildew growing on the leaf surface giving the seedling a white, gray or tan appearance. (Photo by Scott Enebak, Auburn University, 2004).*

the fungus to species. Damage caused by powdery mildew is typically minor, with leaf surfaces becoming blistered and distorted. Severe infections may result in terminal growth reduction and mortality of smaller hardwood species. In some cases, nursery managers have used powdery mildew as a natural top clipping to maintain seedling height. A number of fungicides are available that can control this common and widespread fungal disease and can be applied at the first sign of infection and carried throughout the growing season (table 9.3).

Anthracnose. A number of hardwood species are susceptible to anthracnose diseases, which is a name given to fungi that cause a characteristic lesion, necrosis, and incomplete leaf/twig/branch development on hardwood

Table 9.3—*Fungicides to control powdery mildews, anthracnose, leaf spot, and rust foliage diseases on hardwood seedlings.*

Disease	Compound	Fungicide
Powdery mildew	Aliette	Aluminum tris (o-ethyl phosphonate)
	Sudue Maxx	Mefenoxam
	Pageant	Pycraclostrobin & boscalid
	Banrot	Thiophanate-methyl & etridiazole
	Captan	Captan
Anthracnose	Cleary's 3336	Chlorothalonil
	OHP 6672	Mancozeb
	Banrot	Mancozeb
Leaf spots/blights	Cleary's 3336	Thiophanate-methyl
	Bravo 720	Chlorothalonil
	Topsin M	Thiophanate-methyl
	Captan	Captan
Leaf rusts	Bayleton	Triadimefon

seedlings, resulting in defoliation, cankers, and dieback of seedlings. Like powdery mildews, a number of pathogens are responsible for these symptoms on seedlings, which include fungi in the genera: *Apiognomonia*, *Asteroma*, *Colletotrichum*, *Cryptocline*, *Gnomonia, Gnomoniella, Discella, Discula* and *Monostichella.* With numerous fungal genera responsible for infection, there are many hardwood species that serve as hosts to the pathogens. These include seedlings in the genera *Acer* spp., *Betula* spp., *Carya* spp., *Fraxinus* spp., *Quercus* spp., *Tilia* spp., *Ulmus* spp., and other commonly grown hardwood species. Some of the more sensitive species include sycamore (*Plantanus occidentalis* L.), black walnut (*Juglans nigra* L.), and *Quercus* in the white oak group. Symptoms on infected leaves depend on the tree species, but begin as tiny dead spots, becoming large and irregular. Dead areas turn brown, black, or purple and may merge until the whole leaf dies (fig. 9.4). Seedlings infected in the early spring resemble leaves damaged by frost. If they are not killed by the fungi, young leaves may become distorted by the unequal growth in healthy and infected parts. When severely infected, trees may lose their leaves, but if defoliation occurs in spring, seedlings may produce a second crop of leaves. The disease is most severe when growing conditions in the spring are cool and moist. The fungi tend to be more active when temperatures remain below 10 ˚C (50 ˚F) for a period of 72 hours, which favors spore production. In contrast, temperatures above 16 ˚C (61 ˚F) do not favor the development of the disease and, depending on the weather conditions, there may be multiple periods of infection over the growing season. The fungi responsible for anthracnose diseases overwinter in leaves and cankers on small twigs and spores and spread via wind, rain, and irrigation. Multiple and severe infections can weaken infected hardwood seedlings, predisposing them to other fungi and insects.

Since the fungi overwinter in soil debris, sowing hardwood seed in newly fumigated soil will reduce the chances of carryover from the previous year's crop. Removal and destruction of infected material will also decrease the amount of inoculum present in the area. Timely application of fungicides registered for use on anthracnose pathogens is one method to decrease seedling culls and increase seedling growth and appearance. A number of fungicides are labeled for use in nurseries and should be alternated to avoid developing pesticide resistance (table 3).

Leaf spots, blights, and rusts. A number of other fungi are capable of infecting various hardwood species that result in spots, blights, blotches, blisters, or rusts. Unlike anthracnose diseases, leaf spot diseases are characterized by well-defined necrotic leaf lesions (fig. 9.5). Seedling species and fungi determine the shape, size, and color of the spot, which may be limited by the venation. Necrotic spots may be bordered by yellow or purple margins. Some of the hardwood species more sensitive to leaf spot diseases include *Populus* spp. and *Quercus* spp., both of which have a number of fungal diseases specific to them. Most of these hardwood diseases are not serious unless the infection occurs early in the growing season, when young or smaller seedling species are defoliated. Severe infection may result in complete defoliation, resulting in seedling mortality or poor-quality seedlings that may not be shippable. While there are some fungicides labeled for use on foliage diseases, managers need to positively identify the causal agent before treating. Generally, these types of foliage diseases are cosmetic and treatment to control them is not warranted (table 9.3).

Figure 9.4—*Symptoms of anthracnose infection on hardwood seedlings. Severe infection may result in complete defoliation of the seedling and stem dieback. (Photo by Scott Enebak, Auburn University, 2004.)*

Figure 9.5—*Leaf spots on* Quercus *spp. indicating localized fungal infections. (Photo by Scott Enebak, Auburn University, 2004.)*

Nematode and Insect Management

Nematodes

Hardwood seedlings are particularly susceptible to parasitic nematodes. Continuous cultivation of the same species within an area is conducive to the buildup of nematode populations that, if not controlled, can result in significant seedling mortality. Nematodes are found throughout North America and certain nematodes have a wide host range and feed on many hardwood hosts, while other nematodes have a limited host range in their feeding habits. Nurseries with sandy, well-drained soils tend to have more nematode problems than heavier soils (e.g., more silts and clays). The nematodes most damaging to hardwood seedling crops are the root knot nematode (*Meloidogyne* spp.), the lance nematode (*Hoplolaimus* spp.), the lesion nematode (*Pratylenchus* spp.), the stunt nematode (*Tylenchorhynchus* spp.), the stubby-root nematode (*Trichodorus* spp.), and the dagger nematode (*Xiphinema* spp.).

The response of hardwood seedlings to infestation by nematodes varies with the seedling-nematode combination. The aboveground symptoms are similar to root diseases, as the nematodes' feeding activities interfere with normal root/shoot physiology. Generally, infected seedlings are stunted, lack vigor, and have foliage that is reduced in size and number, eventually becoming chlorotic (resembling nutrient deficiency) despite adequate soil fertility. In periods of high heat and low moisture, seedlings with nematode problems may wilt due to lack of turgor pressure. Symptomatic seedlings will appear in small circular patches that enlarge over the growing season and coalesce with other infestations. Belowground symptoms of the roots depend on the nematode species. Root-knot nematodes cause galls to form, with a proliferation of roots near the galls. Stubby and stunt nematode feeding activity results in root discoloration, surface lesions, and stunting of the lateral root systems. Dagger nematodes cause galls at the root apex and distortion of the lateral roots. Lesion and lance nematodes result in necrosis of the root cortex that appears like root decay of the feeder roots and creates wounds for soilborne pathogens (e.g., *Fusarium* spp., *Pythium* spp., etc.) that are only a problem on seedlings when nematodes are present.

Culturally, selection of a nonhost cover crop and using proper crop rotations will go a long way to keep nematode species and numbers below threshold levels. Certain crops like corn and sorghum can increase nematode populations, whereas cover crops like pearl and brown-top millet decrease nematodes (Cram and Fraedrich 2005). In addition to crop rotation, hardwood seedlings should be sown only in first-year fumigated soil. Broad-spectrum preplant soil fumigants that include combinations of methyl bromide, chloropicrin, or 1,3-dichloropropene have been shown to be the most effective in reducing nematode populations (table 9.1) when used prior to sowing. Nematodes cannot be eliminated from soil, but proper rotations and soil fumigations can reduce nematodes to levels that will not affect seedling production.

Piercing and Sucking Insects

There are many insects associated with hardwood seedling production, and they vary in the activities that are detrimental to hardwood seedling health. One large group of insects are those that use their mouthparts to pierce into seedling tissues (leaves, stems, buds) and remove (suck) the cellular contents as part of their feeding activities. In addition to removing sugars and photosynthates from the tree, some insects inject materials that are detrimental to the hardwood seedling health. These include growth hormones, viruses, bacteria, and toxins that may appear weeks to months after the insect has fed and moved on. Often the insect pest may be long gone but the damage is already done. Hundreds of different insects feed on hardwood species, with some more host-specific than others. This section breaks them down into three large, artificial groups, based on their feeding habits and movements.

Leafhoppers. Leafhoppers are small insects, usually less than 13 millimeters (mm) (1/2 inch [in]) long and can be either brightly colored or drab, but are usually patterned with stripes. They are wedge-shaped and tend to "hop" around the seedling when disturbed. They use their piercing/sucking mouthparts to feed on the leaves and stems of many hardwood species grown in the Eastern United States. With many leafhopper species, their feeding introduces viruses that can block conductive tissue and alter leaf physiology. Cupping, curling, and leaf distortions are common when populations are high. These insects tend to come and go, so a watchful eye is necessary, along with an active insecticide spray program that includes systemic insecticides for control (table 9.4).

Aphids. Aphids are small (2 to 5 mm), soft-bodied insects that have a tremendous capacity for reproduction (fig. 9.6). They can be identified by their characteristic pear-shaped body and tube-like projections from the rear of the abdomen. They have a complex life cycle that

***Figure 9.6**—Aphids feeding on the underside of leaves may cause cupping, curling or even stem dieback if populations are high enough. (Photo by Scott Enebak.)*

includes flight and flightless forms and they can reproduce without males. A single female can quickly become hundreds in a short period of time. They vary in color, ranging from green to black, and feed on the undersides of leaves and seedling stems, often congregating in family groups. Like leafhoppers, they feed on hardwood seedling tissue, remove nutrients from the seedling, and can introduce viruses that alter leaf hormone physiology. One unique feature of aphids is the production of honeydew, a sticky substance excreted from their bodies which is high in sugar content and attractive to ants. The ants will "farm" the aphids and go to great lengths to protect the aphids from other insect predators. Aphids tend to be more sessile and move less than either leafhoppers or plant hoppers, and thus they tend to be noticed more often. An active insecticide spray program that includes both contact and systemic insecticides will minimize the effects of these insects on hardwood seedling production.

Scale insects. Of the piercing and sucking insects, scale insects are the least mobile and, therefore, the least problematic of this group on hardwood seedling production. Most of their life cycle is spent as a wingless, legless female covered with a waxy or resinous secretion (fig. 9.7). They are loosely divided into three groups: mealy bugs, soft scales, and armored scales, based on the type of scale the insect produces while attached to the seedling. They have piercing/sucking mouthparts and, once established, will sit on a seedling stem and feed for the duration of their life. The waxy coating or scale the insect produces protects the insect from predators and insecticide applications that rely on contact exposure. One symptom that may appear when either aphids or scale insects are present is the development of sooty molds. These black to brown fungi do not hurt the seedling, but are living off the insects' honeydew and result in leaf curling, cupping, or defoliation. Systemic insecticides generally are best for piercing/sucking

***Table 9.4**—Insecticides to control insects on hardwood seedlings. (Photo by Scott Enebak.)*

Disease	Compound	Fungicide
Leafhoppers/Plant hoppers	Sevin	Carbaryl
	Diazinon	Diazinon
	Talstar	Bifenthrin
	Astro	Permethrin
Aphids	Safer soap	Insecticidal soap
	Orthene	Acephate
	Astro	Permethrin
Scales	Sevin	Carbaryl
	Astro	Permethrin
	Safer soap	Insecticidal soap
	Malathion	Malathion
Spider mites	Safer soap	Insecticidal soap
	Talstar	Bifenthrin
	Malathion	Malathion
May, June, and Japanese beetles	Sevin	Carbaryl
	Malathion	Malathion
	Astro	Permethrin
	Orthene	Acephate
Grasshoppers	Diazinon	Diazinon
	Astro	Permethrin
	Pounce	Permethrin
	Orthene	Acephate
Caterpillars	Sevin	Carbaryl
	Astro	Permethrin
	Pounce	Permethrin
	Orthene	Acephate
Leaf-tiers, rollers, and miners	Orthene	Permethrin
	Pounce	Permethrin
	Astro	Permethrin
White grubs	Dursban	Chlorpyrifos
Cutworms	Astro	Permethrin
	Pounce	Permethrin
	Orthene	Acephate
	Dursban	Chlorpyrifos

Figure 9.7—Scale insects feeding on a water oak seedling stem. (Photo by Scott Enebak.)

insects (table 9.4).

Spider mites. Spider mites are small (1 to 3 mm) noninsects (Arachnida) that occur in many of the same habitats occupied by insects. They are oval in shape with two body parts, have no wings, and are easily transported by wind. A small hand lens is needed to identify this insect. The two most important species of mites on hardwood seedlings is the two-spotted spider mite (*Tetranychus urticae*) and the European red mite (*Panomychus ulumi*). Spider mites feed on the underside of leaves, stems, and buds, removing nutrients from seedlings in a similar way to aphids and scales. Extensive outbreaks of the spider mite usually have mats of webbing that protect and shelter the mite colony as they feed. Leaves with large populations of mites turn yellow, then brown, and can result in leaf curling and premature defoliation. Stunting and deformation of small-statured hardwood tree species is also possible. Controlling either mite species requires compounds specific for mites, because many "insecticides" are ineffective for this purpose.

Leaf Feeding Insects

There are hundreds of insect species that have mandibles they use to bite, chew, and digest hardwood plant tissue for food. To make things simple, they have been broken down into groups with similar damage, life habits, and control methods: beetles, grasshoppers, caterpillars, leaftiers, leaf-rollers, and leaf-miners.

May, June, Japanese, blister beetles and borers. The adult stage of white grub larvae (discussed later) feed on the leaves, stems, and buds of hardwood seedlings. There are hundreds of beetle species in many genera that feed on all hardwood species. Some beetles are host-specific, like May and June beetles (*Phyllophaga* spp.) that tend to favor *Quercus* spp., and the cottonwood leaf beetle that feeds only on *Populus deltoids* (L.). In contrast, others like the Japanese beetle (*Popillia japonica*) will feed on hundreds of different hardwood species. The insects, depending on the species, range in color from brown to black, and can have spots, stripes, or metallic shine (fig. 9.8). The beetles range from 2 to 4 centimeters (cm) (3/4 to 1 1/2 in) length and can fly great distances. The feeding activities of the adults are capable of damaging the stem and defoliating hardwood seedlings. Damage to the stems may result in top dieback or infection by fungi. Damage to the leaves can range from marginal, interveinal, to complete skeletonizing of the leaves. Severe outbreaks may result in defoliation that can reduce seedling growth resulting in stunting and poor appearance that may need to be culled. Nursery beds near *Quercus* spp., bodies of water, and lights tend to have increased incidence compared with areas away from those nursery borders. The beetles can appear suddenly and quickly damage seedlings. An active insect monitoring program should be part of a nursery's daily activities. Insects can be controlled with timely applications of foliar insecticides that can provide either contact, stomach, or systemic activity (table 9.4).

Grasshoppers. Insects similar to the beetles in their feeding activities and damage include those in the order *Orthoptera* in the genus *Melanoplus*. Many different grasshopper species within this genus have large wings and can fly great distances to nurseries and feed upon the foliage of susceptible hardwood seedlings. The population of this insect varies greatly from year to year and is closely tied to the temperatures and moisture. Severe outbreaks are typically preceded by several years of hot, dry summers and warm winters. In contrast, cool, wet winters interfere with the insect's life cycle, decreasing its numbers and its potential risk on hardwood seedlings. An active insect monitoring program that examines hardwood foliage for the presence or sign of feeding damage will keep managers alert to the potential for treatment. To con-

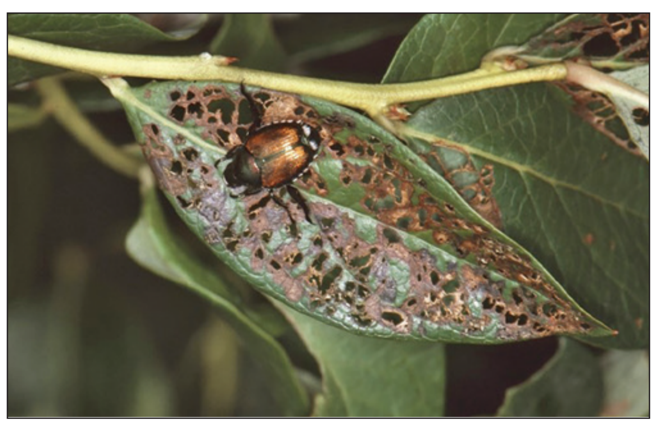

Figure 9.8—Adult stage of white grubs in the genus Phyllophaga *feed on hardwood stems and foliage. The larval stage of this insect feeds on seedling root systems causing stunting and mortality. (Photo by Scott Enebak.)*

firm damage caused by grasshopper feeding, look for ragged feeding damage on the stem or the foliage that may have a shredded appearance. Grasshoppers can be controlled with contact, stomach, or systemic insecticides (table 9.4).

Caterpillars. Caterpillars are the immature (larval) stage of moths and butterflies in the order Lepidoptera. Generally, moths are drab colored and active at night, while butterflies are colorful and active during the day. Both have species within their respective groups where adults will lay their eggs on emerging hardwood seedlings and the subsequent larvae (caterpillars) will feed on the foliage of seedlings during the growing season. One of the more detrimental larvae on hardwood trees is the gypsy moth; it has defoliated and killed thousands of acres of forests throughout the Eastern United States. Fortunately, their life cycle is such that the gypsy moth is not an issue in hardwood nurseries. There are, however, a few notable caterpillars that can become established in hardwood seedling beds. These include caterpillars in the genus *Anisota* with the common names of spiny, orange-striped, and pink-striped oakworms. These larvae feed on many *Quercus* species as well as *Carya* and *Betula*. Other less common larvae that occur in hardwood seedling beds include the variable oakleaf caterpillar and the green-striped maple worm. These larva feed on *Quercus*, Acer and *Ulmus* species. Like other hardwood seedling insects, a monitoring program that examines hardwood foliage for their presence or signs of foliage feeding damage will keep managers alert to the potential for treatment. Most of these caterpillars can be controlled with contact, stomach, or systemic insecticides (table 9.4).

Leaf-tiers, leaf-rollers, and leaf-miners. Within the Lepidopera order is a subset of caterpillars that feed on the foliage of hardwood seedlings either within a tent-like structure formed by the insect (leaf-rollers or leaf-tiers) or within the upper and lower leaf surface (leaf miners). Leaf-tiers bind two or more leaves together with strands of silk where it then feeds, rests, and hides from predators within the leaves (fig. 9.9). A leaf-roller folds or rolls one leaf and binds it with silk strands that it produces. Like the leaf-tier, the larva of the leaf-roller will feed, rest, and hide from predators within the rolled leaf. Leaf-miners are small larva that feed between the upper and lower surface of leaves that create mines, blotches, or leaf deformities. Holding the leaf up to the light will reveal small larva through the semi-transparent damaged areas. While there are many different leaf-tiers found in North America, one of the most common leaf-tiers is *Croesia semippurpurana*, a small green larva that prefers *Quercus* spp. A few common leaf-rollers include *Archips semiferanus, A. argyrosplilus,* and *Choristoneura fractivittanna* that feed mostly on *Quercus* spp. but will feed on other hardwood seedlings as well. There are many different species of leaf-mining insects associated with hardwood species and include the solitary oak leaf-miner (*Camararia hamadryadella*), the gregarious oak leaf-miner (*C. cincinnatiella*), the elm leaf-miner (*Fenusa ulmi*), and the birch leaf-miner (*F. pusilla*). These are specialized insects that, because of their unique feeding habits (between the upper and lower epidermal leaf cells), tend to be host-specific. Damage usually results in necrotic, brown leaf tissue that may be cast if severe enough. Like other hardwood defoliating insects, the leaf-miners, leaf-tiers, and leaf-rollers can be controlled with timely applications of foliar insecticides that can be either contact, stomach, or systemic (table 9.4).

***Figure 9.9**—A number of insects in the order* Lepidoptera *(butterflies and moths) will roll or tie up leaves and feed within the leaf nest. (Photo by Scott Enebak.)*

The effects of these insects on seedling health, vigor, and survival are relative to the number of insects and the size

***Figure 9.10**—White grub larvae are always "C-shaped" and feed on their sides. With a 2- to 3-year life cycle, these insects are capable of killing seedlings through root feeding activity. (Photo by Scott Enebak.)*

of the seedling. Many leaf-miners on a small seedling are more detrimental than a similar number of insects on a larger seedling. While no one likes the appearance of foliage insects on their seedlings, when the seedlings drop their leaves in the fall, the evidence of foliage damage disappears. Thus, in many cases, treating the nursery for foliage insects is more for the nursery managers' comfort than to stop actual damage to the seedlings.

Root Feeding Insects

White grubs. White grubs consist of over 100 different species within the genera *Diplotaxis, Dichelonyx, Serica,* and *Catalpa* and are found throughout North America. They are most severe in newly established nurseries, 2 to 3 years after soil fumigation, and on agricultural sites being converted to forests. The larva are always "C-shaped," generally white, and are found near seedling roots upon which they feed (fig. 9.10). All hardwood species are susceptible. Root systems will appear sparse and have symptoms of chewing and gouging of lateral and tap roots. Seedling foliage will turn yellow, then brown, and cause stunting and seedling mortality. Infested areas will appear stunted in patches within and across a nursery bed as the larva feed and move through the soil. As few as one white grub per square foot is capable of causing significant seedling damage. Adults of the larval stage are May, June, green, and Japanese Beetles. Their life cycle is 2 to 3 years in the soil, with damage increasing each successive year post fumigation, due to increasing relative larva numbers and size of the larva. Adults feed on *Quercus* spp., thus nursery areas surrounded by oaks have increased incidence and damage due to the larval stage. Because adult beetles are attracted to light and are lazy fliers (less than 100 yards), sowing seedlings away from mature oaks near the nursery will go a long way to minimizing the effect of white grubs on seedling damage. By far, the most effective method for control is soil fumigation with broad-spectrum preplant soil fumigants prior to sowing. Combinations of methyl bromide, chloropicrin, or 1,3-dichloropropene have been shown to be the most effective in reducing white grub populations (table 9.1). Spot treatment with granular or soil drenches of insecticides is also effective for control (table 9.4).

Cutworms. Another soil-inhabiting insect that feeds upon hardwood seedlings are the cutworms in the genus *Noctiduae*. These small (1/4 in) (6 mm) worms or larva can be dull gray, brown, black, striped, or spotted, are found throughout the Eastern United States, and can destroy thousands of hardwood seedlings in a week. They are stout, soft-bodied, smooth, and tend to curl up in a ball when

Figure 9.11*—Cutworms feed on small succulent hardwood seedling stems and cotyledons early in the growing season. (Photo by Scott Enebak.)*

disturbed (fig. 9.11). The larvae hide during the day and emerge at night to feed upon the young succulent stems, cotyledons, leaves, and roots of hardwood seedlings. They tend to cut the cotyledons/leaves from the stem, leaving just a small stub of a seedling stem remaining, thus their name: cutworms. Because of their size, smaller seeded hardwoods are more susceptible to their feeding activities than larger seeded species, and they are more problematic during the early periods of germination than later in the season. As with white grubs, broad-spectrum preplant soil fumigants have been shown to be the most effective in reducing cutworm levels (table 9.1). Monitoring nursery beds early in the season for their damage and spot treating with granular or liquid insecticides are recommended (table 9.4).

Animal Damage Management

Seed from mature hardwoods and small seedlings in the forest environment are a normal and natural source of nutrition for numerous mammals (mice, voles, deer, and rabbits) and birds in the wild. Acorns are a favorite for squirrels and deer, pecans are crow magnets, and rabbits prefer succulent flowering dogwood seedlings. However, when these same seed and seedlings are planted in rows for human use (reforestation), animals are just doing what is natural for them—looking for something to eat (food)—and interfering with a manager's objective of selling trees. Unlike diseases and insects that tend to be random and arbitrary, animals and birds are searching for seed and seedlings; it is all they do, all the time, and they will never stop trying.

Deer

One of the more troublesome mammals is the white-tailed deer (*Odocoileus virginianus*), which has seen populations reach damaging levels throughout its range due to harvest restrictions and modified land use (Russell et al. 2001). The effect of browse damage on hardwood seedlings depends on the amount of browse, the season of browse, and the relative seedling size. Smaller seedlings are more susceptible to damage than larger seedlings. With respect to *Quercus* spp., deer browse that occurs during the growing season is more detrimental than deer browse during the dormant season (Woolery and Jacobs 2010). To reduce deer damage, numerous odor and taste repellants have been developed; unfortunately, no standard method to test repellent effectiveness has been adopted. Currently, there are three types of repellents: area, contact, and systemic. Area repellents act by odor and include things such as soap bars, blood meal, feather meal, and even human hair balls. Contact repellents are sprayed or dusted onto the foliage of hardwood seedlings to protect against browse. These include compounds such as hot sauce, Ro-Pel®, and Hinder®. Systemics are compounds that are applied to the growing area and are taken up by the plant, making them unpalatable to deer feeding. Their ease of use also mitigates the problems of washing away or retreating that is required with contact repellents. A systematic analysis of deer repellent products by Hani and Conover reported that Deer-Away Big Game Repellent® and predator odors were more effective than all other repellents tested (El Hani and Conover 1997). However, while there were differences in effectiveness and cost of application, even the best deer repellent did not reduce browse to zero. So, if any damage is unacceptable, then another method must be employed.

Scare tactics are steps taken to frighten deer away from nursery beds that would reduce damage caused by their feeding or migrating activities. These include motion-sensing pyrotechnics, noise, light, and irrigation. While good in theory, pyrotechnics (fireworks, gunfire, propane cannons) tend to annoy neighbors in urban settings, and studies have shown that deer get used to the disturbance and over time gradually ignore the noise. Thus, scare tactics could work in situations where short-term control is needed.

Short of deer repellents and scare tactics, by far the most effective method to minimize deer damage is a well-built fence. Deer can breach fences by going over, through, or under, but studies have shown that an 8-foot (ft) (2.4-meter [m]) fence surrounding nursery beds sown to hardwood seedlings would keep 99 percent of the deer out (USDA 2007). Of the 23 nurseries reporting on methods to control deer, all that had put in a deer exclosure fence mentioned it being "by far the absolute best monies we ever spent." In many situations, the entire nursery does not need to be fenced, only the portion that is used to sow hardwoods and allow for a complete crop rotation (conifer, cover crop, etc.) within that area. Access gates into the area need to be the same height of the fence and must be secured during the growing season. As one nursery manager noted, "You don't want a bunch of deer enclosed in the hardwood seedling beds, either."

Birds

Seed predation by birds on certain hardwood species can result in complete failure of the seedling crop to poor stocking levels due to seedling culls. Minimizing bird predation of hardwood seed can be done via physical, scare tactics, poisons, and repellants. Many different bird species are involved with seed predation, depending on the hardwood seed. Crows (*Corvus* spp.), common grackles (*Quiscalus* spp.), mourning doves (*Zenaida* spp.), turkeys (*Meleagris* spp.), and the common blackbird (*Turdus* spp.) are the most common seed predators found in hardwood nurseries. Like a deer fence, a netting constructed over hardwood seedbeds after sowing reduces predation to zero. This method is costly in both labor and materials to construct and then remove later in the growing season. Tactics using shotguns, predator calls, and scarecrows have some success but, like deer, birds eventually become accustomed to their use and ignore all tactics to frighten them away, feeding on the seed at will.

Poisons (avicides) are available, but their restrictions by State and Federal laws, as well as their lack of selectivity for killing bird species, keeps their use in controlling hardwood seed predation to only the most severe cases. One step below poisons is the use of seed repellents (table 9.5). As a standard practice in conifer bareroot nurseries, seed is pretreated with thiram prior to sowing. This works both as a fungicide to control damping-off and as a mammal and bird repellent. Despite its effectiveness on conifers, few (1 out of 84) hardwood nurseries use thiram as a seed treatment to control damping-off (South and Carey 2008). A seed predation trial conducted by the Southern Forest Nursery Management Cooperative in 2010 reported that seed color was the most important factor in determining whether or not seed was eaten (Starkey et al. 2010). Simply coating seed with a clay powder reduced seed predation over all other treatments tested. Other trials on seed predation noted that both seed size and mulch type affected seed predation by birds. Generally, the larger the seed, the more seed predation and the smaller the seed, the less seed predation. The addition of mulches on seedbeds decreased seed predation as seed size increased, but increased seed mortality of small seed. Thus, manipulating the appearance of the seedbeds with the use of seed treatments and mulches can reduce seed predation. Similar to deer repellents, there are a myriad of products available for discouraging bird predation. The efficacy of some of these products in hardwood seeding beds has not been tested, but some possible seed treatments to control bird predation can be found in table 9.5.

***Table 9.5**—Bird and mammal repellents used on hardwood seed and foliage to deter seed and seedling predation.*

Predation	Compound	Active Ingredient
Seed/foliage	Defiant	Thiram 75%
	Flight control	9,10 Anthraquinone
	Deer-away big game repellent	36% Putrescent whole egg solids
Seed	Chlorpyrifos	Tchlorpyrifos
	Kaolin clay	Kaolin clay

Small Mammals

Small mammals such as rabbits, mice, moles, and gophers can damage hardwood seedling production either by seed predation (mice, moles, squirrels, and chipmunks), seedling feeding (mice, rabbits, and gophers) or tunneling activities (gophers, mice, and voles). Eliminating their habitat near seedling beds will go a long way to keep the mammals away from the nursery and out of the seedling beds. Mowing the grass and keeping fence rows clean of trees removes the areas that would allow small mammals a place to rest and hide from predators and away from seedling beds. Similar to bird predation, small mammals' feeding activities can significantly affect seeding production. Seed treatment with thiram has been shown to deter seed predation from small mammals and the use of thiram as a spray will deter rabbit and deer from feeding on seedlings. Bait stations that attract small mammals to food treated with poison have also been shown to be effective, as well as trapping (gophers) and using firearms with a permit.

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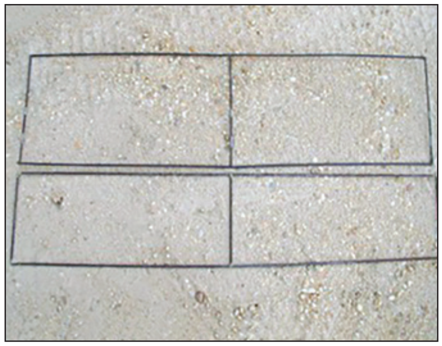

Inventory Methods