# Prevention of Hazardous Tree Defects

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## Introduction

The fundamental goal of tree risk management is to prevent development of hazardous tree defects and reduce the risks hazardous trees pose to public safety. Development of many hazardous defects in trees can be prevented through effective planning, and the implementation of sound arboricultural practices. Post-storm tree damage surveys document that appropriate species composition, and proper planting and maintenance practices can help prevent the formation of many structural defects that predispose trees to branch and stem failures. (Dempsey 1994, Johnson 1999). This chapter discusses how communities can prevent development of many hazardous tree defects through effective streetscape planning and design. Designing a species-diverse, uneven-aged forest, matching tree species to site conditions, purchasing high quality nursery stock, implementing proper planting and pruning techniques, and protecting trees from construction damage help to promote healthy trees and reduce development of hazardous tree defects.

## Designing a Species-Diverse, Uneven-Aged Urban Forest

When many of our older cities were established, there were initially few large trees present. Tree planting programs lined the streets of many communities with avenues of even-aged trees all of the same species. While these planting programs eventually resulted in aesthetically beautiful tree-lined boulevards, this practice led to problems that eventually convinced arborists that this practice should be avoided. The vulnerability of an urban forest to insect and disease outbreaks is much higher where a single species of tree dominates the landscape. This problem was dramatically illustrated during the Dutch elm disease epidemic that altered forever the character of so many eastern city streets.

As many of the avenue trees planted in the early 20$^{th}$ century are rapidly approaching the end of their normal lifespan in an urban setting, urban forest managers have an opportunity to develop a well-designed, species-diverse, uneven-aged management system. In such a system, replacement trees are of varying species with different life expectancies. While this system will not recreate the avenues of majestic single-species canopies of eras past, it will help to provide sustainable tree cover over a large part of the urban landscape. Even in those communities where trees are somewhat haphazardly replanted as they die, the result will be an unavoidable shift from an even-aged management system towards a more sustainable species-diverse, uneven-aged management system.

## Matching Tree Species to Site Conditions

Tree species vary in their nutritional, water, and light requirements, and in their resistance to environmental and chemical extremes. Match tree species to each site by considering both the silvical characteristics (requirements) of the tree, and the conditions of the site. The Silvics Manual of North America, volumes 1 (conifers) and 2 (hardwoods) are excellent sources of information on plant/site requirements (Burns and Honkala 1990). Both publications are available through the publications link on the following website: http://www.na.fs.fed.us/spfo.

## Site Characteristics that Affect Tree Species Selection

When choosing a species to fit a site, consider soil and light conditions; exposure to sun, wind, ice, snow, and de-icing salt; space limitations (both above and below ground); and human use of the site. Soil conditions, especially in urban areas, often drive tree species selection. In addition to the site factors listed above, trees in areas that are converted from woodland to urban through new construction require specific consideration. Each site characteristic is described below in more detail.

### Soil pH

Apply soil and percolation tests to all potential planting sites. Soil texture and pH test results will provide the most valuable information for tree selection. Trees that require loose and organic soil should not be planted on sites that are primarily compacted, heavy clay soils. Always plant trees that perform best on neutral to alkaline soils on sites with soil pH levels greater than 7.2. Trees that perform better than others on neutral to alkaline soils include hackberry (*Celtis*), basswood (*Tilia*), ginkgo (*Ginkgo biloba*), and most crabapple species (*Malus*).

### Soil Compaction

Compaction can be measured with a penetrometer, a field instrument that measures the pressure required to push a probe through the soil to various depths. Compaction can also be approximated with a digging spade. If a shovel can easily penetrate the soil to a depth of two spade blade lengths, compaction is not limiting. If the shovel requires a person to jump on it and provide weight to penetrate the soil, compaction may limit certain species. If a pick-axe is required to break the ground and dig the planting hole, compaction will be severely limiting to all but a few (mostly undesirable) tree species.

Soil compaction problems can be minimized by site preparation and plant selection. Often, trees that perform well in wet areas do better than others in compacted, clayey soils since potential oxygen limitation is similar in both environments. Chisel tooth plowing or otherwise fracturing the soil prior to planting creates loosened avenues for tree roots to expand. This advantage may be relatively short-lived and limited in relationship to the entire compacted site, but it does allow the tree to recover from transplant shock and become adjusted to the harsh site.

### Soil Drainage

Percolation rates are likewise relatively easy to determine. Dig a hole in the planting area to a depth of 24 inches. Fill the hole with water and allow it to completely drain. Fill the hole with water a second time. If the hole drains within a couple of minutes, choose trees that survive in drier sites, such as coffeetree (*Gymnocladus dioicus*), corktree (*Phellodendron*), and elm (*Ulmus*), or surface mulch the area to build up an organic layer and conserve moisture. If the hole drains completely within 24 hours, the soil is suitable for most tree species. If the hole takes several days to completely drain (or never drains), plant only trees that survive in waterlogged conditions. Alder (*Alnus*), willow (*Salix*), tamarack (*Larix laricina*), and black ash (*Fraxinus nigra*) are all suitable for wet sites.

***Urbanized* soils are often altered significantly from their native condition.**

*The chemical, physical, and biological changes listed below all affect tree species selection.*

**Chemical Changes**

- Increased soil pH
- Reduced nutrient recycling
- Increased soil pollutants (heavy metals, de-icing salts)

**Physical Changes**

- More shallow soil profile
- Reduced organic matter content
- Increased concentration of buried debris (asphalt, concrete, etc.)
- Reduced percolation rate (soil drainage)
- Reduced oxygen concentration due to soil compaction

**Biological Changes**

- Increased competition by turf grasses, such as Kentucky bluegrass
- Reduced numbers of symbiotic microorganisms (mycorrhizal fungi, bacteria, and actinomycetes)
- Increased numbers of opportunistic pathogens and insect pests

### Low Light Situations

Canyons are commonly found in urban areas, most commonly in larger cities with tall buildings. Trees planted in these areas must be able to thrive in low-light situations. Often, trees that naturally occur as understory trees are better choices for these sites. For example, redbud (*Ceris spp.*), ironwood (*Ostrya virginiana*), hemlock (*Tsuga*), and bladdernut (*Staphylea*) thrive in low-light situations.

### Exposure to Sun and Wind

Exposure to sun and wind can limit tree selection choices and tree health. Sites that are fully exposed tend to dry out faster, heat up faster, and make it harder for trees to establish and thrive. Sites that are fully exposed to wind can further compound these problems. Trees that are native to prairies, exposed outcroppings, or savannas, such as honeylocust (*Gleditsia*), hawthorn (*Crataegus*), spruce (*Picea*), and bur oak (*Quercus macrocarpa*), would be better choices than trees that are native to shaded, organic-rich forest situations.

### Susceptibility to Ice, Snow, and Wind Damage

Trees vary in their susceptibility to ice, snow, and wind storms (Table 4.1). In general, trees fail when their ability to withstand loading events from storms is surpassed. Wood strength has been suggested as a primary determinant of tree susceptibility to storms. While wood strength is important, other factors, including leaf morphology, canopy density, tree architecture, decay susceptibility, included bark, and rooting patterns, also determine storm resistance in trees.

**Table 4.1** *The ice storm susceptibility of tree species commonly planted in urban areas.*

| Susceptible | Intermediate | Resistant |
|---|---|---|
| American elm | Bur oak | American Sweetgum |
| American linden | Eastern white pine | Arborvitae |
| Black cherry | Northern red oak | Baldcypress |
| Black locust | Red maple | Black walnut |
| Bradford pear | Sugar maple | Blue beech |
| Common hackberry | Sycamore | Catalpa |
| Green ash | Tuliptree | Eastern hemlock |
| Honeylocust | White ash | Ginkgo |
| Pin oak | | Ironwood |
| Siberian elm | | Kentucky coffeetree |
| Silver maple | | Littleleaf linden |

partially adapted from Hauer et al (1993)

### De-icing Salt Damage

In many areas of the northern tier states, de-icing salt spray drift is a major limiting site factor. Trees that are located within 60 feet of an arterial street or highway that support 10,000 or more vehicles per day are particularly vulnerable to de-icing salt spray damage (Johnson and Sucoff 1995). De-icing salt spray places significant stress on trees, even if it does not always kill the tree. Typically, trees within the spray zone area become disfigured and generally unhealthy (e.g., poor growth rate, scorched, or lost foliage) and are more vulnerable to secondary problems and decay. De-icing salts can accumulate in the soil, and cause trees to exhibit foliar symptoms induced by excess sodium and chlorine levels, and leaf scorch due to reduced uptake and translocation of water within the tree. If trees are to be planted in areas where de-icing salts are a limiting site factor, only use tree species that are tolerant to salt injury. Black alder (*Alnus glutinosa*), white ash (*Fraxinus americana*), Japanese tree lilac (*Syringa reticulata*), and Norway maple (*Acer platanoides*) would be suitable for these sites (Johnson and Sucoff 1995).

### Human Use of the Area

No matter where the planting site is (e.g., residential, park, tree lawn, sidewalk, or plaza), consider how the area will be used. Human activities have long-term effects on tree condition and health. Unintentional wounding and landscape management practices are the most notable causes of damage.

Trees in tree lawns, plazas, and parks are particularly susceptible to wounding by unintentional vandalism. Car doors and bumpers wound stems, signs are nailed or stapled to public trees, and branches are broken when children climb trees. Locate trees far enough away from curbs, sidewalks, and intersections (i.e., areas where traffic is concentrated) to reduce chances of wounding. Do not use species that are notoriously poor compartmentalizers (e.g., beech (*Fagus*), red maple (*Acer rubrum*), silver maple (*Acer saccharinum)*, hackberry (*Celtis*), red oak (*Quercus rubra*), and many poplars (*Populus*) in areas where wounding is likely. Avoid the use of low-branched species where climbing and subsequent wounding is likely. Although low-branched species can be pruned to raise their canopies, the frequent pruning required to remove lower branches only adds to the amount of wounding and the maintenance care such trees receive.

**Figure 4.1.** *Lawn mower and string trimmer damage caused by mechanical injury and subsequent decay at the base of the tree.*

All trees are vulnerable to wounding where turf grass is allowed to grow up to the stems. Invariably, lawn mowers and string trimmers will wound the base of these trees repeatedly (Figure 4.1). If for no other reason, all trees should have a mulched area around their stems to prevent the need for trimming grass away.

Sites that are characterized by clay soils can become particularly vulnerable to foot traffic compaction if the activities in the area are frequent and well attended. State parks, picnic areas, fairgrounds, school-yards all have the potential of many feet compacting clay soils. Although this does not normally result in direct damage to trees, it indirectly weakens trees by adversely changing soil moisture and oxygen availability, and reduces the ability of trees to recover from wounds and other site stresses or attacks from insects and diseases.

Planting trees in groupings rather than as specimens can reduce the site stresses that weaken individual trees. Especially where groupings are mulched or understory planted, the trees are much less susceptible to unintentional vandalism, soil, and exposure stresses. The beauty of the planting becomes more important than the beauty of the individual trees.

### Space Limitations

The most common space-limiting sites are the areas that occur between street curbs and sidewalks (e.g., tree lawns, boulevards, parkways, or medians), sidewalk planting pits, and plazas. Tree lawns usually offer the most confining situations for trees: limited root volumes, limited canopy width, greatest minimum height to the first set of branches (if over hanging an arterial street), and limits to height (if above-ground utilities are present). Other variables that further limit the success of a tree in a tree lawn include de-icing salt spray or deposits in the soil, buried utility lines within the rooting area, and highly altered soils.

Tree lawns must be at least 10 feet in width to support a large tree through maturity at an accepted level of risk to public safety. Large trees (>60 feet in height) are more prone to windthrow during wind loading events. This becomes more of a problem when the inevitable root cutting takes place during installation or repair of streets, sidewalks, curbs, and buried utilities (Figure 4.2). The problem is further compounded if the trees in question have dense canopies, which offer significant resistance to wind and make the already unstable trees even more likely to fail.

Plant small- and medium-sized trees in tree lawns that are less than 10 feet wide. The rooting volume afforded by tree lawns less than 10 feet in width is more in scale with supporting the growth of small- to medium-sized trees. In these narrow planting spaces, tree species with smaller crowns and root systems are the best planting choices. Examples of trees suitable for these sites include crabapple (*Malus*), hawthorn (*Crataegus)*, ironwood (*Ostrya virginiana)*, silverbell (*Halesia*), and water-ash (*Ptelea*). These trees are more likely to be healthier in these root-limited environments, and therefore better able to recover from both above and below ground wounding. They will also compartmentalize wounds more effectively and limit the amount of potential wood decay.

**Figure 4.2.** *Tree with excessive root severing caused by curb and sidewalk reconstruction damage. Root severing can compromise the structure of a sound, healthy tree and increase its susceptibility to windthrow during wind loading events.*

Small- to medium-sized trees also create fewer problems with above ground utility line conflicts. For example, tree species that do not exceed 30 feet in height at maturity are the best choices for locations with overhead wires.

Trees planted in tree lawns should also have a growth form that allows them to be pruned up to a height that allows pedestrian and vehicular traffic to safely pass under their branches. Further, species that do not require excessive amounts of pruning to maintain a safe height of the lowest branches are the best choices. Trees that require excessive pruning are likely to be poorly maintained. Even if the trees are regularly maintained, the frequent pruning operations will create excessive amounts of pruning wounds and increase the potential for wood decay problems to develop.

Do not plant trees where conditions exist that prevent the use of smaller trees (e.g., de-icing salt spray, truck traffic that limits the height of the lowest branches to 12 to 14 feet above ground). If trees must be planted in these areas, they should be planted on the property-side of the public sidewalk. Planting on the property-side of the sidewalk may require that the community pass a "green easement" ordinance, and develop a memorandum of understanding regarding tree maintenance with the property owner. Alternatively, tree lawns can be designed so that they are greater than 10 feet in width. This design approach will greatly reduce the incidence of tree roots causing sidewalk buckling or curb damage. Reciprocally, if sidewalk or curb repair is needed, damage to tree roots will be reduced in larger sized tree lawns, and tree mortality or growth rates should not be adversely affected.

Sidewalk and plaza planting pits may present the same limitations on tree selection that tree lawns do, but normally they are most restrictive in terms of rooting volume. Generous planting pits are 5 feet square by 3 feet deep, providing only 75 cubic feet of rooting volume. A healthy small- to medium-sized tree requires 300 to 1,000 cubic feet of rooting volume to reach maturity (Urban, 1992). Planting pits must provide adequate soil drainage to sustain tree health. If larger planting pits cannot be incorporated into current streetscape planning and design, consider fewer but larger planting islands. These islands would have a larger volume of soil that could successfully support a group (copse) of trees that would share the larger rooting volume. Structural soils are also an option to increase soil rooting volume in downtown and parking lot situations. Structural soils are a combination of crushed stone, clay loam, and hydrogel (a copolymer that helps hold the stone and loam together) that can be used under pavement such as sidewalks (Bassuk et al. 1997). These soils allow for suitable compaction under sidewalks while still providing a root-friendly environment.

Sidewalk or plaza trees also need to be tall enough that the lowest branches can be removed to allow pedestrians safe passage under them, usually a minimum of 8 feet above ground. Island plantings, especially if the planting is slightly elevated, reduce the need for pruning all trees in the group. Only the edge trees would require elevation pruning (pruning for clearance).

As discussed, the presence of overhead utility wires and limited space for planting sites are two common factors that restrict the choices of tree species that are suitable for use in community tree planting programs. A publication entitled Compatible Tree Factsheets for Electric Lines and Restricted Spaces compiles information that will aid communities in the selection of trees for planting sites under electric wires, in narrow tree lawns, and other places where small crowns and root systems are advantageous (Gerhold et al. 2001). This publication focuses on tree species suitable for planting in USDA Hardiness Zones 3-6. It is available from the Municipal Tree Restoration Program at 109 Ferguson Building, The Pennsylvania State University, University Park, PA 16802.

Park trees generally experience fewer pressures resulting from space restrictions. Parks are the best location for large trees since the rooting volumes are not limited and utility lines are rare. The most common space restriction in parks is the distance from the ground to the first set of branches. Trees selected for planting in parks should be species that mature to a height that proportionately allows the lower branches to be pruned up to provide human traffic clearance (minimum of 8 feet), or unrestricted light diffusion from street/park security lights (usually, at least 12 feet above ground).

## Urbanization of Woodlands

Forest trees that have been in relatively protected and undisturbed environments for all of their lives become very vulnerable to exposure when these forests are urbanized, that is, when residential or commercial subdivisions are built in or around the forests. Suddenly, the trees that were once protected from wind and sun are exposed, in particular those that have now become edge species. Typically, these trees are tall and slender, with very high canopies and very shallow root systems, and are more prone to windthrow.

Roots of the new edge species are commonly lost during development of wooded areas, either directly through cutting, or indirectly through exposure, loss of soil moisture, and subsequent death of the shallow network of supportive, fine roots. As a result, they become less stable and more vulnerable to winds and windthrow. In addition, they produce more dead wood in the canopies as a result of defensive dieback in reaction to the root loss and death. So even if they are able to remain vertical despite the increasing wind loads, they often produce a significant amount of deadwood high in the canopies that presents a threat to people and structures below.

Root loss can be prevented during the design stages of woodland development by avoiding injury to the critical root area of the edge trees, or at the very least, by not cutting any roots within the dripline. Construction activities should be avoided within the CRR (Figure 4.3) to ensure the tree's root zone is adequately protected.

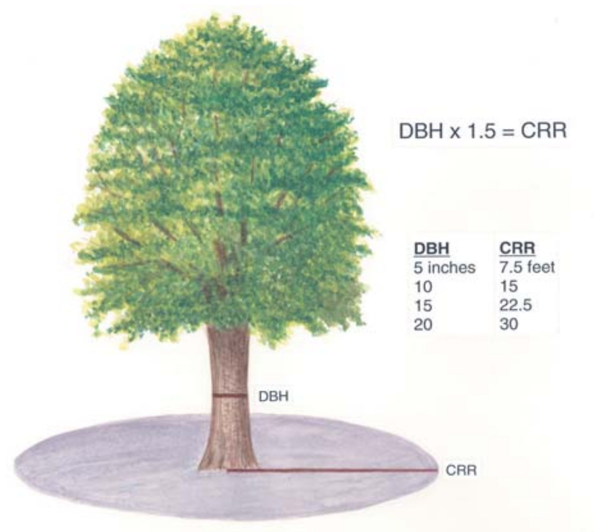


**Figure 4.3.** *Critical Root Radius (CCR) and critical rooting area.*

Indirect root death as a result of forest floor exposure to wind and sun can be minimized by keeping the area mulched with an organic mulch, irrigating during and after construction activities, and underplanting the areas where sun and wind are more pervasive. Understory shrubs and small trees will help reduce the amount of drying wind and sunlight that reach the forest floor, that area where the shallow, fine roots proliferate. Under no circumstances should the forest floor be "cleaned up" and converted to a competitive, turf grass groundcover.

## Purchasing High Quality Nursery Stock

Just as it is important to select the right trees for the right places, it is equally as important that the trees selected for planting are of high quality. Planting unthrifty planting stock is money wasted, and sets the stage for future tree health problems and unsuccessful streetscape designs. Communities that invest in high quality trees and proper planting and maintenance practices will enjoy the benefits of a tree resource that increases in aesthetic and economic value, possesses fewer hazardous defects, and lives longer.

### *What Determines Tree Quality?*

Industry standards for nursery stock have been established by the American Association of Nurserymen and are published in the American Standard for Nursery Stock, ANSI Z60.1 (ANSI 1996). These standards cite height/caliper relationships for shade trees, and a recommended minimum root ball size based on tree caliper. These standards were established to help ensure that nursery stock would have enough sound roots present to support healthy tree growth. Community program managers responsible for community tree planting should be familiar with these industry standards. Implementation of these standards is voluntary, and communities may opt to establish their own set of standards. A copy of The ANSI Z60.1 standards can be purchased from the American Nursery & Landscape Association, 1250 I Street NW, Suite 500, Washington D.C. 20005-3922 or through their publications/ general business link at http://www.anla.org.

When communities purchase trees for planting along streets or sidewalks, quality specifications are different than those for trees used in other landscape situations. For example, street trees should have a single, straight trunk that is free of branches to a height where limbs will not obstruct pedestrian or vehicle traffic or block the line of sight to traffic signs and lights. Municipal buyers should ensure that bidding specifications state the height to which the tree should be free of branching, at the time of planting. Specifications will vary according to individual community bidding guidelines, however, a height of 6 to 8 feet is commonly cited. If the community is able to perform frequent pruning (every 3 years), pruning up at the time of planting can be delayed. If low-branched trees are planted, tree establishment and growth is improved, stem taper is increased, and trees require staking less frequently, however, the community must have in place a follow-up pruning schedule to raise the crown over time.

Here are some tree quality characteristics that communities should look for when purchasing nursery stock for tree planting operations:

**Figure 4.4.** *Avoid purchasing nursery stock with codominant leaders (more than one leader), or select stock that can be successfully pruned back to a single leader. Even though these branch attachments are not weak, this codominance began 3 feet above ground, far too low for a tree that will mature to 40 to 50 feet in height.*

- Single, straight trunk that is free of branches below 6 to 8 feet (for trees to be planted within a few feet of a sidewalk or street)
- A strong form with well-spaced, firmly attached branches
- A trunk free of stem defects such as mechanical wounds, flush cut pruning wounds, cankers, insect injuries, or cracks
- Adequate root ball/container/root spread size in relation to tree caliper see American Standard for Nursery Stock, ANSI Z60.1.

### *Inspect Nursery Stock to Verify Quality*

Retain the right to inspect trees at the time of delivery and reject those that fail to meet stated specifications. Consider rejecting trees with the following problems:

**Figure 4.5.** *Branch with included bark that failed and caused extensive damage to the stem.*

- **Trees with double or multiple leaders:** Trees with double or multiple leaders and included bark in the attachments have an increased likelihood of stem failure, and often suffer the greatest damage during and after storm events (Figure 4.4).
- **Trees with weak branch unions (e.g., narrow, V-shaped) and included bark in branch unions:** Branches with included bark in their attachments are always weak and are one of the primary causes of branch failure. If they are not pruned out when the branches are small, even minor thunderstorm loading events can

cause premature failure of branches with included bark and extensive damage to the stem (Figure 4.5). Two types of branch attachments are shown in Figure 4.6: The branch attachment to the left is strong and the branch attachment to the right is weak, with included bark.

- **Trees with defects on the main stem:** Common stem defects include mechanical injuries, flush cut pruning wounds, cankers, insect injuries, or cracks (Figure 4.7). Tree wraps can conceal stem defects, so remove tree wraps to inspect the trunk.

- **Trees with serious root related problems:** Such problems may predispose trees to opportunistic root pathogens or the development of stem girdling roots. Examples include:

    - Balled-and-burlapped and tree-spaded trees with root collars that are deeply buried within the root ball (> than 4 inches). With balled and burlapped plants that are buried too deeply in the soil ball, there are two problems: 1) the risk that they will be planted too deeply in the landscape which may lead to development of stem girdling roots, and 2) the limited amount of roots that may be in the soil ball (Figure 4.8).

**Figure 4.6.** *The branch attachment to the left is strong, with the branch bark ridge pushing up. The attachment to the right is weak, with extensive included bark. This attachment (to the right) targets the branch that should be removed.*

**Figure 4.7.** *Don't buy this plant! That wound on the stem is extensive and decay has already entered the wood. Even if the wound is sealed by new wood, the stem wood can continue to discolor and decay.*

**Figure 4.8.** *This hackberry was buried by 12 inches of soil in the soil ball, and had very few roots to support the tree after the excess soil was removed.*

The location of the root collar can be determined by inserting a steel wire (coat hanger gauge) or metal probe into the root ball (at several points) and measuring the depth at which the first primary root(s) attach to the stem (Figure 4.9).

- Bare-root trees with moderate to severe amounts of "J" roots or encircling roots (Figure 4.10).

- Container grown trees that are root bound and have moderate to severe amounts of encircling roots (Figure 4. 11). If only a few non-woody roots are encircling, cut them away with a sharp tool.

- Container grown trees that have root collars that are deeply planted in the container or within plastic or fabric bags (> than 4 inches deep) or have incomplete or poorly developed root systems.

- Trees with moderate to severe amounts of crushed or torn roots. If only a few roots are crushed or torn, use a sharp tool to prune them to remove the injured tissues. Make the cuts immediately before planting and watering.

**Figure 4.9.** *The location of the root collar can be determined by inserting a metal probe into the root ball (at several locations) and measuring the depth at which the first primary root(s) attaches to the stem.*

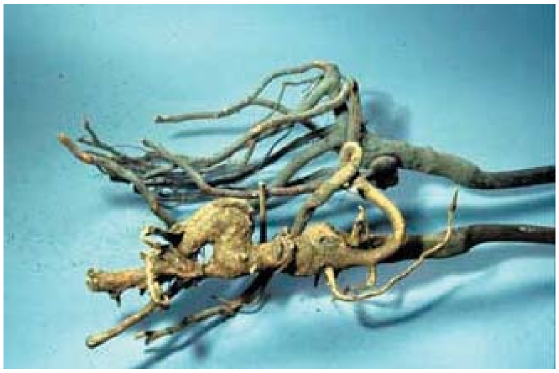

**Figure 4.10.** *Avoid purchasing bare-rooted nursery stock that has extensive J-root problems. If left untreated, these root systems will continue to develop as dysfunctional root systems.*

**Figure 4.11.** *Encircling roots from pot-bound, containerized trees do not self-straighten. If correction of the root system is not made at planting time, the dysfunctional root system will remain and only worsen with time.*