Abiotic factors, such as improper planting technique and the incompatibility between plant species and planting site, kill more roots than pests or diseases. Understanding the causes of root mortality can improve plant success in landscapes.

ROOT DEATH in the *Landscape*

Roots — especially in landscape plants — are extremely susceptible to abiotic (nonbiological) factors that can weaken plants and increase the risk of pathogens and pests. Many people think insects and diseases are the major causes of landscape planting deaths; however, abiotic diseases are responsible for approximately 85 percent of plant disorders in landscapes. Symptoms of abiotic diseases range from slight to severe, and they can result in plant decline and death.

Plant success in landscape situations results from factors occurring before, during and after transplanting. Planting stock quality is related to the ability of roots to grow and function after planting. Root growth after planting is a function of nursery production practices, handling during transport and storage prior to transport. Transplanting method, time of transplanting and amendments used during transplanting will also influence root growth in the landscape. Root mortality in established landscape plantings will be influenced by the compatibility of plant species with environmental conditions and cultural practices used at the site.

by Carolyn Scagel *and* Hannah Mathers

Why is root system health important?

Roots are vital to plants for water and nutrient uptake, storage and mechanical support. Structure and function of roots are interrelated, and the proportion of different types of roots that compose a root system change as plants age. Seedling root systems consist mainly of many ephemeral (short-lived), fine roots responsible for nutrient and water uptake. As a plant matures, structural roots responsible for anchorage start to develop. A root system consists of an abundance of different types of roots that are necessary to perform different functions.

As the root system develops, factors that influence root growth change. During the establishment phase, growth of fine roots in the upper layers of the soil depends primarily on soil moisture and temperature. As roots proliferate away from the original planting hole down through the soil, they are more restricted by excess soil moisture, poor aeration, soil strength and permeability.

Roots die or turn over, just like leaves, needles and branches above ground. This natural root death is a result of seasonal or environmental conditions. The important thing isn't that roots die, but that new roots are initiated and grow to compensate to meet the demands of the plant. Complete plant root systems consist of different types of new roots, mature roots and dead roots.

One primary reason for slow and reduced plant growth — or plant death after transplanting, called "transplant shock" — is an unhealthy root system. Transplant shock can last up to three years and appreciably affects a landscaper's bottom line. When a plant is transplanted into the landscape, rapid root growth into the surrounding soil is critical. Root growth after transplanting is necessary if the plant is to obtain water and nutrients required for growth. The rate and time of root growth varies with species, environmental conditions and seasons. The time between transplanting and new root growth is generally longer for species considered difficult to transplant.

Frequent application of dinitroaniline herbicides results in poor rooting and susceptibility to lodging or plants falling over.

Girdling roots are shown on a Douglas fir two years after transplanting.

PHOTOS COURTESY OF HANNAH MATHERS; COURTESY OF CAROLYN SCAGEL

What you don't look for will hurt you. The first factors that influence root development in landscape plants are those that occur during nursery production. An example is placing plants too deep, called too deep syndrome (TDS), which occurs when the soil covering the roots actually smothers them. This is a major concern and focus of research in the nursery and landscape industry. Many believe it is an issue that begins first in the nursery and follows through or intensifies in the landscape.

The depth from the soil surface to the root system affects root health in two main ways. First, roots require oxygen for respiration to consume stored energy for survival and growth. Oxygen deficiencies impair this respiration. As a result, some plants will compensate for this oxygen-deficient environment by sprouting adventitious roots from the trunk. These roots are often small, weak (easily succumbing to drought or flooded conditions) and well above the scaffold roots that should be at the soil surface. The results of TDS can be root circling, poor anchorage for the tree and increased, susceptible abiotic and biotic factors.

Second, whether plants are grown in containers or as bare-root stock, production methods during this time influence how roots will grow and survive in the landscape. Plant condition or stock quality prior to transplanting can alter plant performance in the landscape.

The results of planting roots too deep can be root circling (pictured), poor anchorage for the tree and increased, susceptible abiotic and biotic factors.

Container construction. Growing plants in containers is cost-effective, but can have a negative impact on root growth and form. Densely matted, kinked and downward-deflected surface roots are common in vigorous-growing plant species or plants held too long in a container. When roots reach the container wall, they start circling, in time taking the shape of the container (pot-bound).

Unless root balls of these plants are manipulated prior to transplanting, the roots will continue to grow in circles after transplanting, resulting in poor establishment, reduced aboveground growth, increased trunk breakage, poor mechanical stability and girdling of the stem or roots. Containers of various shapes, designs (such as air pruning), composition (such as fabric, plastic or metal) and coatings (such as copper) can limit root circling for some species.

Container size also influences success in outplanting in the landscape by affecting the size of the root system. Mountain

The roots on the right have a "hockey stick" or "J" root formation, which is caused by improper planting procedures, lack of manipulation of root at planting and planting in soils that are considered too wet.

laurel (*Kalmia latifolia*) established better in hot, dry environments after transplanting from 7.6-liter (2 gallon) containers than when transplanted from 19-liter (5 gallon) containers. This suggests that smaller plants will be less stressed the first season after transplanting and will likely stand a better chance for successful establishment.

Researchers found that smaller plants have higher leaf conductance, water-use efficiency and shoot elongation after transplanting than larger plants, indicating less transplant stress. Thus, smaller plants are better candidates for transplanting in most circumstances because they recover from transplant shock more quickly than larger plants. However, transplants with relatively large root systems generally suffer less post-transplanting stress and thus come into production earlier than plants with small root systems.

Container temperature. In container production, roots are exposed to temperature extremes that are not common in soil. High temperatures in containers caused by direct solar radiation on the pot and growing medium surface can cause death of roots at the perimeter of the root ball. Low temperatures in containers caused by poor insulation can also kill roots, especially during dry and cold winter months.

Death of feeder roots at the perimeter of the root ball results in poor root growth beyond the root ball, after transplanting into the landscape decreases stability and predisposes plants to nutrient and water stress. Production of plants in pot-in-pot containers decreases root exposure to temperature extremes; however, roots on these plants can have difficulty tolerating higher temperatures during transportation and sales.

Bare-root and B&B harvesting damage. Bare-root harvesting procedures can decrease the plant root system by up to 90 percent of its original size, creating a significant imbalance between roots and shoots. Transplanting plants with this type of root damage can cause transplant shock.

With some species, increased root ball size has been shown to influence establishment — bigger root balls equal better growth. But this generalization can be misleading. Characteristics of the root ball, such as root mass, volume, surface area, length and type, have different effects on root function after transplanting. Root mass and volume do not give an accurate representation of root fibrosity because plants with many fine roots may weigh or displace the same amount as one with a large taproot.

Total root length is a better measure of fibrosity or absorptive surface, but it is extremely tedious and time-consuming as a measure of practical value. If plants are placed too deep in the soil and the ball is dug with a spade, the root system is truncated, and the size of the root system in the ball will be significantly smaller than what is required by American Nursery & Landscape Association standards (www.anla.org/applications/Documents/Docs/ANLAStandard2004.pdf).

If possible, inspect roots prior to purchasing or transplanting.

Chemical applications. Any chemical that influences plant growth in the nursery may carry over into the landscape, including plant growth regulators, herbicides, pesticides and fungicides. Herbicide injury to root systems in the nursery can cause poor rooting-out after transplanting. It is known that root inhibition and lodging frequently occur with dinitroaniline (DNA) herbicides. The mode of action of DNA herbicides is through root inhibition.

Extreme conditions. Extreme environmental conditions — such as temperature, light and moisture — and chemical applications can increase death of surface roots and roots in contact with container walls. For many plant species, the function of these roots is primarily nutrient and water uptake. Transplanting plants with this type of root damage results in poor establishment, unless new roots grow immediately after transplanting. Poor transport and handling can deplete the reserves necessary for new root growth to occur after transplanting. Inspection of plants for root system damage prior to transplanting, as well as decreasing nutrient and water stress after transplanting, can minimize the impact of root damage.

Look before you plant. To minimize the impact of root damage and deformation on transplanting success, inspect the root system prior to purchase. When inspecting container-grown plants, select ones that are not pot-bound and have healthy-looking root systems. When inspecting bare-root plants, select varieties with fibrous root balls that form 360 degrees around the trunk of the tree.

What you do may hurt you more. When, how and where you plant, as well as what you do to the plant after transplanting, can influence root growth and function. Even when stock quality is high, poor planting technique or maintenance after planting can result in root death.

For example, lack of manipulation of the root system — especially of bare-root-planted materials — to ensure 360-degree root development away from the trunk or dragging plants during nursery field planting can also result in "hockey stick" or "J" root formation. Hockey stick roots can be caused by improper planting procedures, such as unsuitable planting

Piling mulch against a tree trunk will promote waterlogged conditions around the trunk, and plant diseases will establish. Ideally, mulch should be placed at least 4 to 6 inches away from the trunk.

shoes on planting equipment; however, they are most often the result of planting in soils that are too wet.

Planting technique. One standard planting procedure does not exist: Root systems can vary between species (rhododendrons have hair-like roots, whereas poplar have coarse roots). A common planting strategy to encourage root development after outplanting in the landscape includes the following steps:

1. Dig holes larger than the size of the root system or into a prepared bed for multiple trees.
2. Break apart the root ball prior to planting.
3. Place plants in a hole no deeper than the root collar.
4. Fill with loose soil and compress to stabilize plant.
5. Decrease nutrient, water, heat and light stress after transplanting until plant becomes established.

If planted in a hole that is the same size as the container, or if the root systems and roots are not spread out, the plant will probably grow slowly and decline. The growth of roots outside of the root ball is important for access to water.

As previously discussed, plant decline and death in the landscape can result from excessive amounts of soil over the root system. Prolonged moisture at the base of stems can also increase root and collar rot diseases. Mulch should be kept at least 4 to 6 inches away from the trunks of trees. If mulch is placed closer than 4 inches to the trunk, it should be applied thinly.

If mulch is piled against tree trunks in formations similar to "mulch volcanoes," two possible scenarios may occur. First, the trunks will stay constantly moist; the mulch will promote waterlogged conditions around the trunk, and plant diseases will establish. Second, oxygen depletion to the roots will occur in the heavily mulched region, especially if fine-textured materials have been used. In an attempt to get oxygen, roots will grow in these mulch volcanoes. This region will be more susceptible to drying out, and the trees will suffer severe drought stress and/or die. Shallow planting increases root death due to temperature extremes, increases moisture and nutrient stress, and decreases stability.

Time of planting. Root growth following transplanting is necessary for water and nutrient uptake. Time of year of planting affects root growth, as the rates of root growth and root growth periodicity vary with species, environmental conditions and seasons. The potential for plant success after transplanting is greatest when roots are actively growing and have time to establish before the demands for aboveground growth are high.

Autumn transplanting can improve post-transplant growth and survival for some plant species, but establishment of other species is better after spring transplanting. Low survival of fall-transplanted species has been related to their low potential for root regeneration at the time of planting, as well as low soil temperatures. In contrast, late-spring transplanting after a burst of root growth may result in reduced reserves for aboveground growth. Effective transplant strategies require a complete understanding of species-specific root growth patterns.

Time of the day, phase of the moon, zodiac star — it probably doesn't matter as much as decreasing nutrient, water, heat and light stress after transplanting until the plant becomes established *and* determining when to transplant based on species differences in seasonal root growth.

Additives. Many "non-nutritional" and "nutritional" products reportedly reduce transplanting stress and stimulate root growth or health: biostimulants, vitamins, humates, seaweed, yucca, hormones, alginates, acrylimides, mycorrhizal fungi and beneficial bacteria. Application of any product does not guarantee successful plant establishment, root growth or health. Reasons for successes and failures of these products include species-specific responses to compounds, application timing, and environmental and cultural practices interfering with product activity. Before making large financial investments, always test products on a small scale, using untreated plants for comparison.

Soilless media/soil water relations. The air-filled porosity levels commonly used in soilless substrate during container production often result in suboptimal water-holding capacity when the container is transplanted into the landscape. Unless drainage is impeded, water can rapidly drain from the original root ball of the container into the surrounding backfill soil. The rate of water loss from the root ball to the surrounding soil varies with soil type. Until new roots grow beyond the original root ball into the surrounding soil, roots within the root ball are extremely susceptible to desiccation and death.

Container-grown plant roots are thought to respire more than mineral soil-grown roots because of faster plant growth rates increasing their irrigation demands. Evaporation of moisture at the surface can be slowed by mulch, but plants may require more frequent irrigation after transplanting, depending on the type of soil at the planting site.

Care and tending. Plants in the landscape are frequently subjected to a number of cultural practices, such as fertilization, irrigation, herbicides, pesticides or pruning, which may adversely affect the growth and health of roots. The activities of people, heavy equipment, lawn mowers, weed-eaters, pets and wildlife may also cause root death. The majority of roots for many species are in the top few inches of the soil; therefore, chronic movement or cultivation of even the top few inches of soil can cause root death.

Symptoms of root death. For obvious reasons, diagnosing root problems can be

This shows the influence of preplanting application of slow-release ethylene (Ethrel; middle) and auxin (IBA; right) compounds on root growth of plug stock.

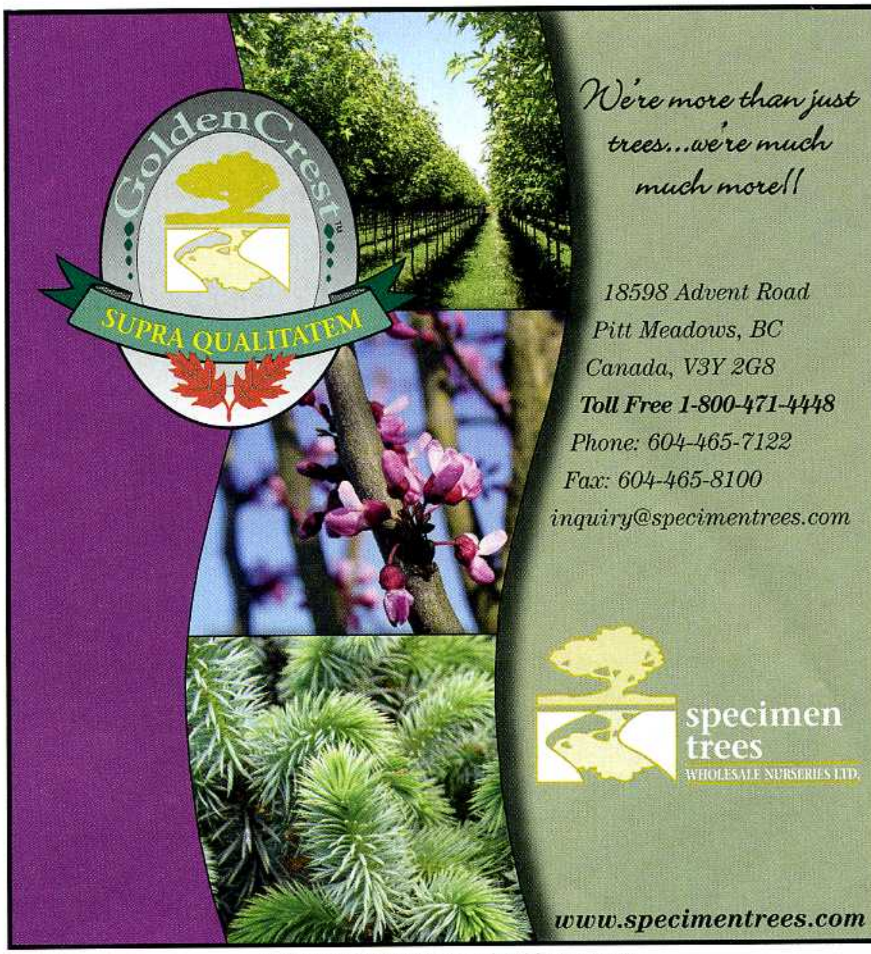
PHOTO COURTESY OF HANNAH MATHERS

difficult; in most cases, you cannot see the roots unless you dig up the plant. Often, aboveground symptoms of root death are vague or nonspecific and can resemble those caused by pathogens, pests and other problems. Often, visual symptoms appear above ground before you realize roots are in trouble. The following are common symptoms of root death.

Nutrient deficiency: Nutrient deficiency results when a nutrient limits plant growth (abnormally slow growth or deformity). The effects of heat, drought, waterlogged soil and herbicide injury on root growth can mimic many symptoms of nutrient deficiency. Visual symptoms could be due to low nutrient availability or low root uptake resulting from an unhealthy root system. Treating nutrient-deficiency symptoms by increasing fertilization may actually accelerate plant decline when a root system is unhealthy due to non-nutritional factors.

Water stress: Native plants are adapted to seasonal and annual variations in water supply characteristics of their local climate. Nonadapted plants often show symptoms of severe water stress. When water loss exceeds the rate of water absorption by roots, water stress appears on the leaves (wilting, browning or drying) and, in extreme cases, on the entire plant. Symptoms of water stress appear during hot, dry, windy weather when soil moisture is low, in warm weather during winter and in spring when the soil is cold or frozen. Water-stress symptoms could be due to low availability of water in the soil or low root uptake resulting from an unhealthy root system. Treating scorch or drought symptoms by increasing water application may actually accelerate plant decline when root death has not been a result of low soil moisture.

Air pollution: Plant disorders caused by air pollutants vary with concentration of pollutant, duration of exposure, natural



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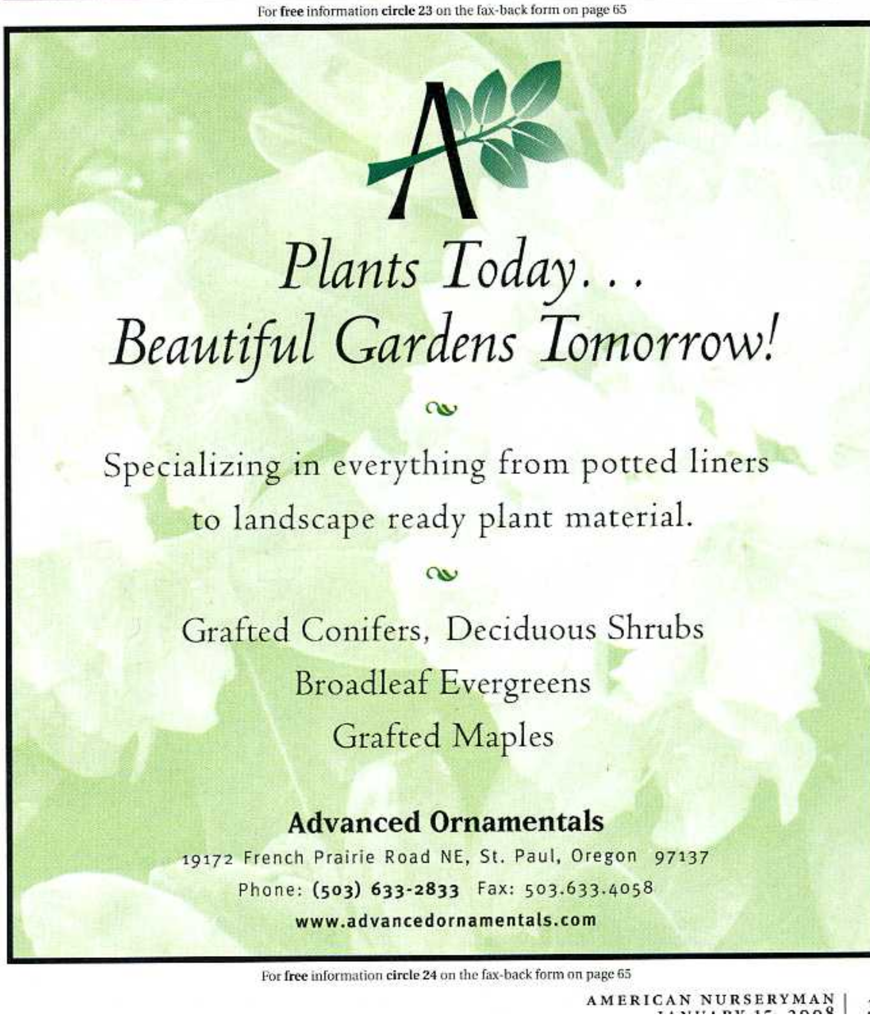

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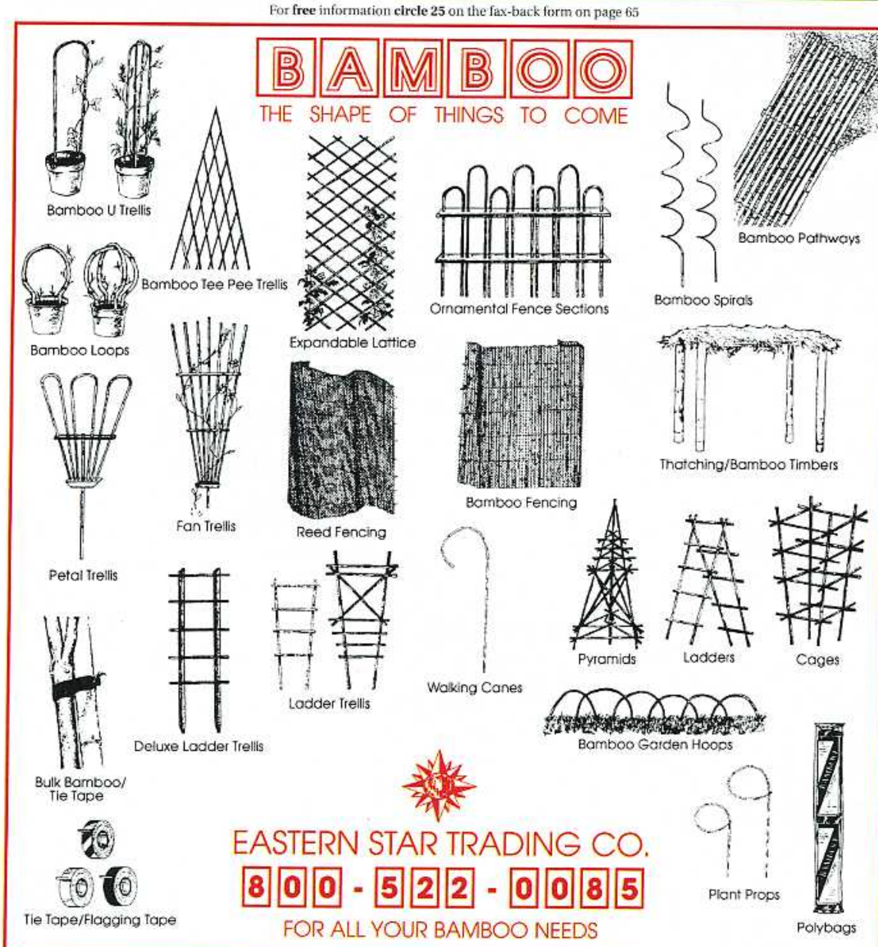

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sensitivity of the plants and environmental conditions affecting the plants before and during exposure. Acute injury is a direct result of the pollutant contacting leaves. Chronic injury results from repeated absorption of a pollutant over time and may indirectly cause root death and subsequent symptoms above ground. Symptoms include chlorosis and premature foliar senescence, reduced growth and, in some cases, progressive decline in plant health. Visual symptoms of chronic air-pollution exposure occur on foliage, and root function is also impeded. Root death occurs sooner than visual symptoms appear on leaves.

Oxygen deficiency: Roots require oxygen for normal growth and function. Raised soil grades, asphalt, poorly draining soils, plastic weed barriers and waterlogged soils decrease oxygen supply to roots and cause root death. Above ground, visual symptoms of oxygen deficiency include downward bending of leaf petioles, stem swelling, chlorosis, red or purple pigmentation in leaves, browning of leaf margins, twig dieback, wilting and leaf drop. Below ground, roots will appear rotted or dark, short and thick with hypertrophied lenticels. Sublethal stresses from oxygen deprivation can lead to numerous secondary problems, including disease and pest damage, and water and nutrient stress. Oxygen deficiency in the root zone is primarily a result of poor site selection, planting technique and cultural practices in the landscape.

There are numerous factors that influence root mortality in the landscape. One of the primary reasons for slow plant growth or plant death after transplanting is an unhealthy root system. Some of the reasons for root death in landscape plantings include pretransplant factors that influence stock quality (such as container size, plant selection and transport condition), planting method and time, and post-transplant factors (such as soil type, amendments, mulches, fertilizers and root treatments).

The potential for root death and plant decline can be minimized by selecting stock with the best qualities for the specific planting site and using proper transplanting techniques and landscape cultural practices that minimize physical damage to roots and disturbance to the environment around established root systems.

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