Water Stress in Trees

By Eric Wiseman

Topics in Plant Health Care is a regular column, featuring information on pests, beneficials, and Plant Health Care practices. If you have a topic you'd like to see in the future or if you wish to submit something, contact Ian Wilson at iwilson@city.kelowna.bc.ca.

Water stress is the most often cited cause of poor survival and growth of woody landscape plants. Insufficient soil moisture is the most common form of water stress, but excess moisture that leads to poor soil aeration (hypoxia) can also result in reduced plant vitality. The purposes of this article are to describe conditions that lead to excessive soil moisture and poor soil aeration, to describe plant responses to soil aeration stress, and to suggest management strategies for minimizing soil aeration stress on woody landscape plants.

Soil Conditions

Drainage and aeration are dictated by soil physical properties, including texture, structure, bulk density, and porosity. The physical properties of landscape soils are modified to some extent during the construction of surrounding hardscapes and buildings. Removal of organic and surface mineral horizons during excavation and grading creates an artificial soil surface horizon composed of displaced clay subsoil.

Clay, which consists of a high percentage of small mineral particles, possesses a large internal volume (porosity) that permits substantial water storage. A well-structured clay soil that contains both large (macro) pores and small (micro) pores provides adequate drainage and aeration for plant vitality.

Figure 1. Poor aeration in clay soil can limit root growth, especially when compacted.

Unfortunately, soil disturbance and manipulation degrade soil structure. Compaction causes the majority of soil structural degradation by decreasing overall porosity, increasing microporosity, and increasing bulk density (Harris et al. 1999). As macroporosity decreases, drainage and aeration also decrease (Figure 1). This condition is the result of greater matric potential (the force with which soil minerals hold water) and greater resistance to oxygen diffusion within micropores.

Soil structural degradation can cause widespread drainage and aeration issues in the landscape. Subsurface compacted layers (hardpans) may be created by differential compaction during excavation and grading. Hardpans restrict subsoil drainage and may result in perched water tables that limit the aerated rooting depth (Harris et al. 1999). Alteration of soil drainage patterns and local hydrology during grading can also result in a shallow water table and chronic soil saturation. At the other extreme, landscape soils can suffer from hypoxia due to surface crusting of bare soil and construction of impervious hardscapes (Figure 2). Soil crusting occurs when water droplets strike soil unprotected by vegetation or mulch, causing compaction of the surface layer. As a result, resistance to oxygen diffusion is greatly increased. Impervious hardscapes also hamper oxygen diffusion into the soil as a result of the physical barrier that is created and soil compaction that occurs during hardscape construction.

Figure 2. Trees surrounded by impervious surface often suffer from soil hypoxia.

Plant Responses

Growth and maintenance of the root system require large quantities of oxygen for respiration. When bulk air oxygen concentration in the soil drops below 10 percent, root growth of most plants will be limited (Kramer and Boyer 1995). Of greater importance is the rate at which oxygen diffuses to the root surface. In general, an oxygen diffusion rate greater than 0.4 mg/cm^2/min is adequate for root growth, and a rate less than 0.2 mg/cm^2/min limits root growth (Costello et al. 1994). Limited oxygen availability also decreases ion transport (nutrient movement) and water flow through the roots. Without adequate aeration, roots will convert to anaerobic respiration to sustain metabolic activities. Anaerobic respiration is an effective mechanism for surviving short-term hypoxic conditions. However, significant root injury and death occur over extended periods as the byproducts of anaerobic respiration accumulate in root tissues. These byproducts include incompletely oxidized compounds such as aldehydes, organic acids and, most important, ethanol (Kramer and Boyer 1995). Other compounds harmful to roots, such as methane, sulfides, and reduced iron, accumulate in chronically saturated soil.

Plants in chronically saturated or compacted soil often develop a shallow root system in surface soil above the hypoxic zone. Alternatively, adventitious roots that possess large air spaces in the cortex (called aerenchyma tissue) may be produced in response to soil hypoxia. Oxygen diffusion is enhanced in the aerenchyma tissue. Limited amounts of oxygen can also move from shoots to roots along a diffusion gradient from the leaves and lenticels in the stem. Additionally, some plant species tolerate chronic soil hypoxia through increased alcohol dehydrogenase activity, an enzyme that breaks down ethanol accumulated in the roots.

In intolerant species, chronic soil hypoxia impairs root function and leads to root death, which ultimately manifests as aboveground decline. Shoot responses include wilting, reduced growth, epinasty (deformed growth), chlorosis, and death. Wilting and reduced growth result from diminished water flow to the shoot, although disruption of nitrate metabolism is also involved in growth reduction. Chlorosis and shoot death have been attributed to a decrease in cytokinin supply from the roots (Kramer and Boyer 1995).

Management Strategies

Strategies for managing the effects of soil aeration stress on woody landscape plants include proper plant species selection, soil modification, and irrigation management. Choosing plant species adapted to the existing soil conditions often minimizes the need for intensive management practices. Species selection should be based on an evaluation of soil physical properties and overall site hydrology. Clay and other fine-textured soils may provide poor drainage and aeration, especially if bulk density has been increased by grading or vehicular traffic. Low areas or areas exposed to concentrated runoff may experience short-term soil hypoxia following significant rainfall. Alders (*Alnus*), maples (*Acer*), and birches (*Betula*) thrive in chronically wet soils (Figure 3), while lindens (*Tilia*), elms (*Ulmus*), and ashes (*Fraxinus*) are consistent performers in compacted soils (Gerhold et al. 1993).

Figure 3. Red maples may be a good choice for low-lying areas, which often suffer from poor drainage and aeration.

In some circumstances, it may be appropriate to modify soil physical properties before planting. It is difficult to modify soil texture short of complete soil replacement. To produce a significant change in soil texture, a large volume of amendments must be added (at least 50 percent of total volume), which is rarely feasible (Harris et al. 1999). Cultivating the soil to break up surface and subsurface compacted layers and incorporating organic matter improve drainage and aeration. Exposed soil should be covered with a layer of mulch to minimize compaction and to provide an ongoing source of organic material for the root zone.

Figure 4. A small soil corer is ideal for quickly assessing soil moisture content.

Changes in landscape topography and hydrology patterns may result in chronic soil saturation. Improving drainage on these sites may require regrading or installing an internal drainage system before planting. Increasing soil depth by building mounds or raised beds creates a region above the high water table where roots can thrive. For plants surrounded by impervious surfaces, efforts should be made to maximize root zone surface area available for oxygen infiltration. Aeration systems, porous pavement materials, and structural soil mixes may improve soil aeration in situations such as parking lots and sidewalk plantings where exposed soil area must be limited.

An irrigation management plan is necessary for minimizing soil moisture conditions that lead to aeration stress. Soil moisture monitoring is a critical aspect of irrigation management. Visual evaluation of the plant is often an inadequate means of soil moisture monitoring because many of the plant symptoms of insufficient soil moisture are also the symptoms of excessive soil moisture, which could mistakenly lead to overwatering. A small soil corer is ideal for quickly assessing soil moisture content (Figure 4). Advanced tools, such as a tensiometer, are available for more accurate measurements. Regardless of assessment technique, it is important to understand how soil moisture content relates to soil aeration. This relationship varies with soil physical properties, and changes to irrigation regimes should be dictated by the soil moisture and aeration needs of the resident plant species.

Identifying the cause of woody plant stress can be difficult. An unhealthy root system is often the underlying cause of poor plant vitality. Adequate aeration is necessary for root growth and acquisition of soil resources. Soil aeration is influenced by soil physical properties, which are often degraded by manipulation of landscape soil. Minimizing soil disturbance, choosing adaptable plant species, improving soil drainage and aeration before planting, and monitoring soil moisture are effective strategies for helping ensure that woody plants thrive in the landscape.

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