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FACT SHEET

Soil structure and tree health in urban areas. What do we need to know?

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Urban trees are exposed to a variety of deleterious environmental conditions such as soil compaction, air pollution, de-icing salts, and heat loads along with impacts from construction, buildings, and vehicle debris. Soils provide plants with water, nutrients and root anchorage. Soils also hold water in which soil nutrients are changed into ions that are available for plant uptake, air essential for root respiration, and the chemicals that determine soil pH and salinity. When planting trees, soil characteristics such structure, texture, pH, organic matter and nutrients must be considered, because these properties determine the soil's capacity to maintain tree health in urban environments.

Soil compaction is a common cause of suboptimal plant growth because it limits the flow of air and water through the soil, thus restricting root growth. Compaction degrades soil structure by diminishing porosity (number and size of soil pores) which decreases moisture replenishment, retention and supply; diminishes aeration; and increases the physical resistance to root penetration. Because trees are especially sensitive to both compaction and low soil oxygen levels, planting trees in small pits or adjacent to roads further impacts soil drainage and reduces the ability of plants to acquire sufficient water and nutrients needed to withstand drought (Fig. 1). Roots in compacted soils are highly branched with thicker, stubbier roots because of shallower rooting depth. Trees growing in compacted soils vary in their susceptibility to compaction stress; while some species are somehow pre-adapted to grow in dense soils (those with shallow roots), other less adapted species will try to survive by developing surface roots that can damage sidewalks and curbs (Fig. 1b).

Figure 1. Trees planted in urban areas near road sides. Recently planted white oak (a), and a mature London plane (b). Many urban trees in plazas, streetscapes and parking lots are growing in small pits (3' x 3' or 5′ x 5) surrounded by pavement. Tree root system is confined belowground unless cracks or other openings are present.

Soil structure and texture

Soil structure is formed by macro- and micro-organisms' activity, freeze/thaw cycles and root penetration, combined with inorganic and organic cementing agents. Water holding capacity, nutrient retention and supply, drainage, and nutrient leaching are all highly dependent of soil structure. Accordingly, the capacity to hold water (by macropores) or air (by micropores) depends on the size and arrangement of soil particles. However, soils in urban areas are often heavily compacted during construction of buildings and roads. This compaction breaks down the structure of the soil; reducing the pore space and thereby decreasing the air and water holding capacity of a soil (Fig. 2).

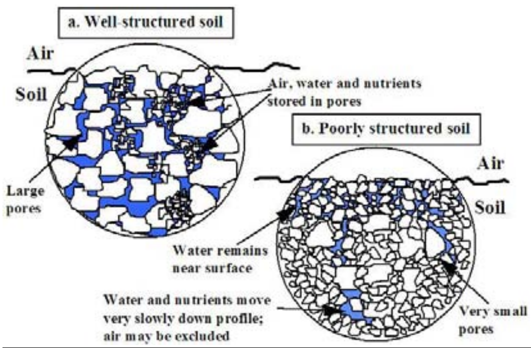

Figure 2. Soil structure of (a) well-structured soil, and (b) poorly structured soil. A well-structured soil will enhance root penetration, water movement and water retention because of the wide range in pore sizes. In a poorly structured soil, root penetration, water movement and gaseous diffusion is restricted, reducing tree vigor. Source: http://www.depi.vic.gov.au

Texture is another important soil characteristic. Soil texture is defined by the size distribution of mineral particles (fineness or coarseness), specifically the relative proportions of sand, silt and clay (Table 1). Texture, in part, determines how well a soil retains water (available water), its cation exchange (ability of soils to store a particular group of nutrients) and buffering capacity (ability to maintain a constant pH level). Soil texture also influences the relative air capacity which plays an essential role in aeration, infiltration, and drainage. In general, coarser (sandy) soils have lower water holding and cation exchange capacity, but higher air exchange, than finer (clay) soils. When selecting a tree for a new planting, it is important to select a species that is adapted to the soil texture because not all species succeed equally in all soils.

Table 1. Root growth capacity based on bulk density for different soil textures. Sources: Jim, 1993. *In*: Soil compaction as a Constraint to tree growth in tropical & subtropical urban habitats. Dallas & Lewandoswki, 2003. *In*: Protecting Urban Soil Quality. Examples for landscape codes and specifications.

Soil mineral	**Particle description**	**Particle size (mm)**	**Ideal bulk density (g/cm^3)**	**Bulk density that may affect root growth (g/cm^3)**	**Bulk density that restrict root growth (g/cm^3)**	**Air capacity**	**Available water**
Sand	Coarse	0.02 to 2.0	<1.60	1.69	>1.80	High	Low
Silt	Fine	0.002 to 0.02	<1.40	1.63	>1.80	Medium	High
Clay	Very fine	Smaller than 0.002	<1.40	1.60	>1.75	Low	Medium

The degree of soil compaction can be measured by bulk density. Bulk density is weight of a soil for a given volume – commonly expressed as grams per cubic centimeter. Bulk densities above the thresholds in Table 1 can decrease tree health by depressing root growth. In order to install pavement, for example, soils are typically compacted to 95%, or 1.8 g/cm^3, which are bulk density values higher than those on this table. Bulk density corresponding to ranges of 1.39 g/cm^3 for clay soils and 1.69 g/cm^3 for sand and loamy sands correspond to an 80% to 85% of compaction that is highly limiting for root growth.

Soil with aggregates (particles) between 0.5 and 2.0 mm in diameter are good for plant growth because they have good aeration and drainage, allowing rapid exchange of air and water within plant roots. Air space allows gas exchange and water uptake for tree growth. Although there may be soil underneath a sidewalk, if it is heavily compacted, it becomes functionally unavailable for tree growth.

pH

pH is a useful indicator of the soil chemical environment. It measures the hydrogen-ion concentration of the soil solution; low pH indicates soil acidity and high pH indicates alkalinity. A pH between 6.0 and 6.5 is favorable for most trees. However, in urban areas impervious surfaces can affect soil microbe communities that influence the rate of nitrogen mineralization and soil pH. In addition, environmental pollution can in impact soil pH.

Trees will not thrive in soils that are either too acidic or too alkaline. At higher pH (alkaline soils), many tree species undergo deficiencies of some micronutrients (boron, copper, iron, zinc, manganese) that are in insoluble forms unavailable for root uptake. Because iron and manganese are crucial for photosynthesis, their unavailability in high pH soils can decrease the photosynthetic capacity of trees. High pH may also alter the composition and abundance of mycorrhizae fungi, which play a crucial role in nutrient uptake. Soil acidity increases the solubility of certain elements, such as aluminum which can be toxic to the roots.

Organic Matter

Organic matter serves as a reservoir of nutrients and water in the soil. Although soil organic matter is typically only a small percentage of the total volume, the organic matter provides a slow-release form of essential plant nutrition minerals specially nitrogen, phosphorus and sulfur. Urban soils usually have less organic matter than in forests (Fig. 3), and therefore have lower nutrient availability for tree development. Because of the limited moisture and aeration in urban soils, nitrifying and nitrogen-fixing bacteria are limited. Organic matter in forests is replenished each year by organisms in the duff decomposing fallen leaves; whereas in urban environments, leaves are often raked up, bagged, and removed.

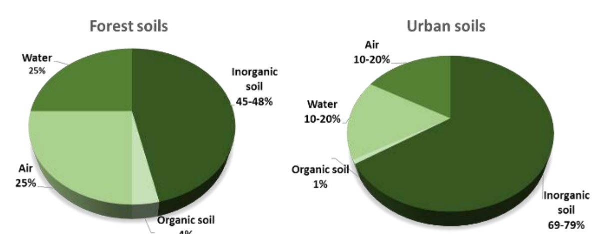

Figure 3. Organic and inorganic matter, air and water percentage in forest soils versus urban soils. Organic matter increases soil water holding capacity, provides nutrient reservoir and helps build soil structure.

Nutrients

Macronutrient (nitrogen, phosphorous and potassium) and micronutrients are necessary for plant development. Soil nutrients are generally derived from the parent material (underlying rocks). Sandy soils, for example, develop from geologic material composed mainly of quartz with very low nutrient value. Silty and clay soils are derived from limestone which usually has higher levels of mineral nutrients. When a nutrient deficiency is suspected as the cause of poor tree vigor, a soil test can determine which nutrients should be added. More information on soil testing can be found at (http://www.ct.gov/caes/cwp/view.asp?a=2836&q=378206).

Taking action

Understanding soil characteristics is of crucial importance to determine the best practices and growth conditions for tree health in urban environments. Considering that trees cannot move and are dependent on the existing environment -planning and designing optimal conditions for tree growth is essential for maintaining healthy trees in our urban areas. Soil compaction can be prevented by proper planning and use of soil preparation techniques prior tree planting. Several options for improving soil compaction include:

1. Mechanical loosening of soil before tree planting. Care should be taken not to plant trees too deeply.
2. Soil aeration by injecting pressurized air into the grounds can be used to improve gas diffusion. Periodic aeration is recommended around tree roots in areas with high foot traffic.
3. Vertical mulching (numerous auger holes generally filled with sand and milled fir bark).
4. Partial or total soil replacement - depending compaction level. Replace dense soil with loose soil or topsoil. This will require very careful removal of compacted soil so as to not wound the roots.
5. If the subsoil layer is restricting root growth, raising the soil surface with new soil can ameliorate compaction. Be careful not to add more than an inch per year. Adding too much soil at once can suffocate roots by decreasing gas exchange.
6. Damage to existing lawns can be minimized by sub-soiling (breaking up of soil layers) to increasing water infiltration, drainage and root penetration.
7. Install subsurface drainage with perforating pipes connected to vertical pipes open to the atmosphere.
8. Addition to organic materials to provide sufficient aggregation agents will create a stronger soil structure that is resist to deformation.
9. Introduction of earthworms and other burrowing soils organisms will increase the number of macropores and decrease compaction.
10. Select species with an inherent capacity to grow in compacted soils. For example, many species that are naturally adapted to grow well in wet and poorly-drained marshy habitats, such as river birch (*Betula nigra* L.), riverbank grape (*Vitis riparia* Michx), and black willow (*Salix nigra* Marsh.) are often tolerant to soil compaction.