5.0 URBAN SOILS

Soil as a growing medium may be defined as a natural system, comprised of mineral particles, organic matter, water, and air, all supporting growing plants. (Hopper, 2007) Soil is second only to water, in most limiting factors for good plant growth. Water Relations of Plants and Soils, Paul J. Kramer and John S. Boyer, Academic Press, 1995. Therefore, the interrelationships of the *soil* system must work in tandem to fulfill its function as a rooting medium, both in nature and in the designed environment.

In the urban setting, where impacts to soil are both huge and constant, it is critical to understand the limitations the existing soil profile presents. Early evaluations of soils provides the necessary information needed to prepare a plan that correlates with projected use to allow for optimum allowable plant growth. In the field of forestry, traditional forestry has always placed the trees first. With the urbanization of our lifestyles, urban forestry places humans first and trees second.

To this end tree health and growth is all important. Good tree health not only affects tree growth and mature size, but can decrease risk of failure. A healthy large tree decreases the heat island effect, increases carbon uptake and oxygen output, and offers a multitude of other positive benefits for the environment.

This section will provide descriptions/explanations/overview of urban soils versus forest soils, the effects of soil volumes on tree growth, soil types, soil testing mechanisms, suggested ways to improve the health and quality of soil around a tree, and ways in that early planning, coordination and design can help assure that trees are given the optimum space for their growth and sustained health.

5.1 Soil Basics

A balanced soil will contain equal parts air and water with the remaining being different percentages of minerals and organic materials (Figure 1)

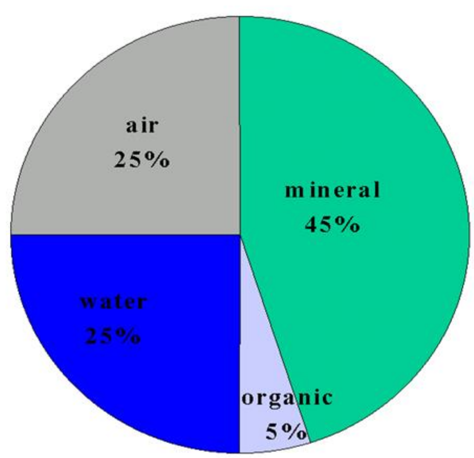


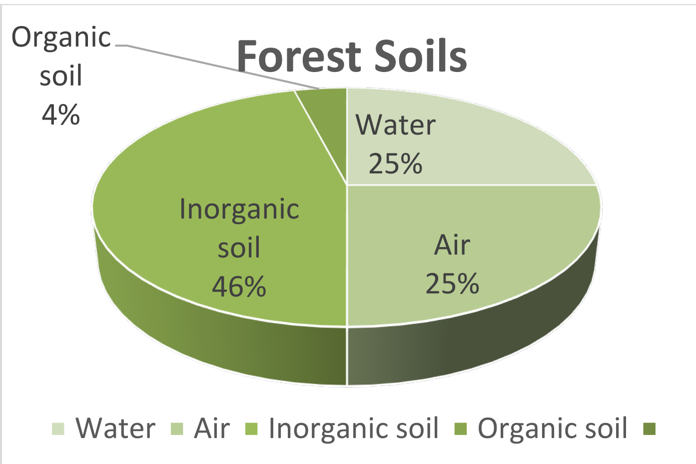
Figure 1. Balanced Soil (North Carolina State University)

Image provided by North Carolina State University

Knowing what a balanced soil means, and the prevalence of both compacted and non-mineral soils found in our urban landscape, how this affects the water percentage is key to work with or providing solutions to your soils.

Forest Soils versus Urban Soils

Forest soils are what most think of whether in the forest or not. Unfortunately, this picture perfect soil very rarely occurs within any urban area (Figure 2)



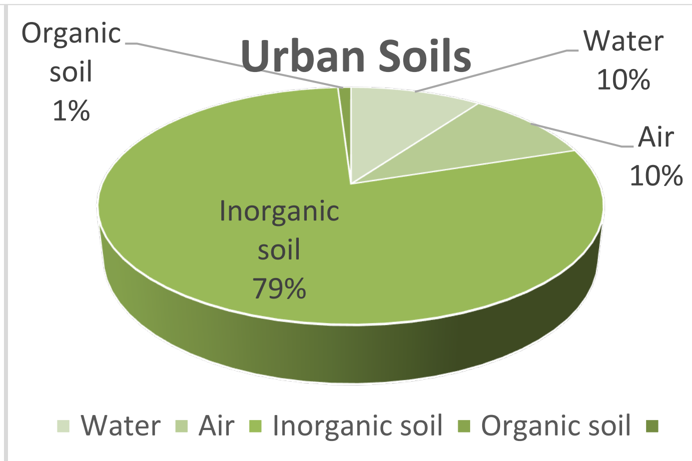


Figure 2. Organic and inorganic matter, air, and water percentage in forest soils versus urban soils. Organic matter increases soil water holding capacity, provides nutrient reservoir and helps build soil structure.

Urban soils are "created" through common construction activities. Grade changes regularly remove organic rich topsoil from building sites, while compaction is caused access by construction equipment and building structures. Measures can and should be taken to mitigate for this degradation to the soils in which we expect our urban trees to grow.

5.2 Common Soil Issues affecting vegetation growth

Flooding - Flooding results in poor soil aeration because the supply of oxygen to flooded soil is severely limited. Oxygen deficiency is likely the most important environmental factor that triggers growth inhibition and injury in flooded plants. Flooding of soil also increases the pH of acid soils and decreases the pH of alkaline soils.

Organic Matter - The rate of decomposition of organic matter in flooded soil tends to be only half that in an unflooded soil. The major end products of decomposition of organic matter in flooded soils are carbon dioxide, methane, and humic materials. In addition, high concentrations of ethanol and hydrogen sulfide are produced in waterlogged soils which can be damaging to root systems.

Sedimentation – during flooding events deposits of silt or sand as shallow as three inches may seal over and smother tree roots by limiting the supply of oxygen. Species vary in tolerance to sedimentation, but all

seedlings are susceptible to root injury. Eastern cottonwood, bald cypress, tupelo, and black willow seedlings can withstand moderate siltation.
Scouring - during flooding events strong currents, waves, or suspended particulates may cause soil around the base of the tree to be washed away, exposing tree roots. Exposed roots can lead to not only tree stress but can make the tree more vulnerable to wind throw.

http://www.na.fs.fed.us/SPFO/pubs/n_resource/flood/toler.htm
Dry soils – Drought normally will impact your soil by making it more acidic.

Fertility - Nitrogen, phosphorus, and potassium fertility levels and availability are effected by cation exchange capacity (CEC), which in turn is more affected by the soils pH than any other factor.

http://www.allabs.com/download/Drought%20soil%20fertility%20Facts%203.pdf

Wind and erosion – Wind erosion is a natural process that moves soil from one location to another by wind power. It can cause significant economic and environmental damage.

Compaction - Ideal soil is porous, allowing ample air flow between particles. When soils become compacted, these spaces are reduced, forcing plants to work much harder just to survive. The effects of soil compaction on plants include reduced water infiltration into the soil, increased potential for surface water runoff, and reduces the ability of soil to hold water necessary for plant survival.
https://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex13331

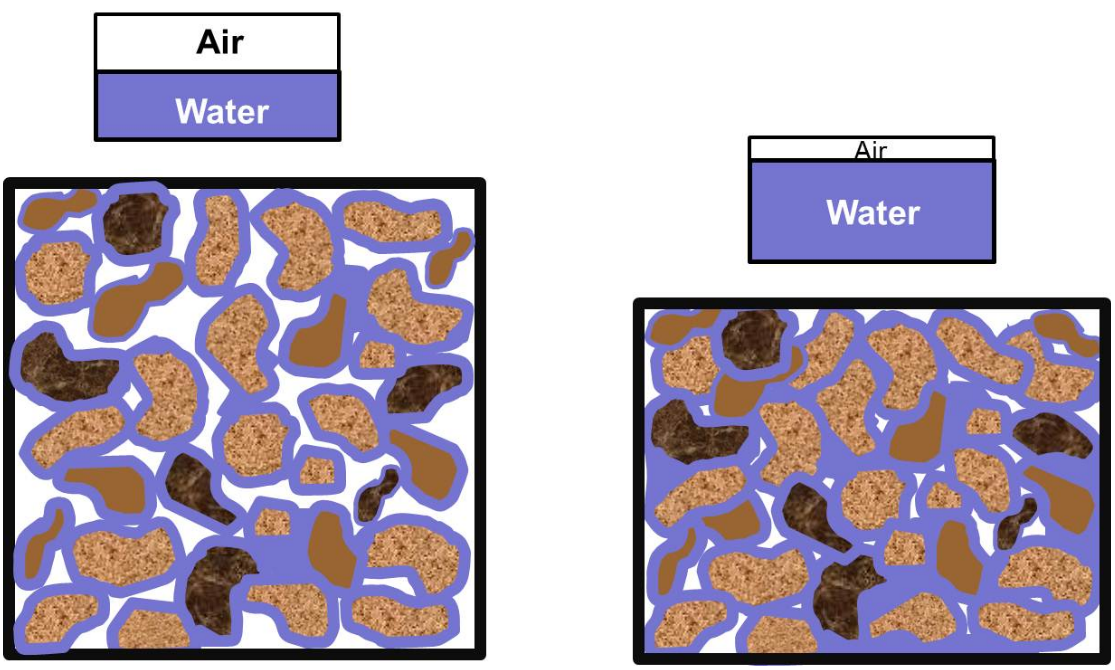


Figure 1: Effects of compaction on pore space.
https://extension.umn.edu/soil-management-and-health/soil-compaction

Contamination - Small amounts that are not detected until the plant life dies.
Due to possible past uses of urban sites, having soil tested is important to learn as much as possible about any contaminants, such as unsafe levels of lead or other heavy metals. Elevated levels of lead in particular are fairly common in urban soils, and pose health risks, especially to young children who can ingest soil while playing or helping in gardens. Other contaminants are possible, especially if the site has any industrial or manufacturing history. Test soil at a qualified laboratory.
http://ucanr.edu/sites/UrbanAg/Production/Soils/Soil_Contaminants_and_Soil_Testing/

Does your site have the necessary soil quality to perform its function? Is it *"fit for use"* & does it have the *"capacity of a soil to function"*? Existing soils must be evaluated to identify what actions need to be taken to ensure a viable planting environment for tree growth. A standard soil test used for crop production is not sufficient to identify the soil's "health" in order to sustain trees in an urban environment. *The Natural Resources Conservation Service has developed Soil Quality Indicators which evaluate the Physical, Chemical, & Biological indicators of the soil.*

Soil Quality Indicators		
Physical	**Chemical**	**Biological**
Aggregate Stability	Reactive Carbon	Earthworms
Available Water Capacity	Soil Electrical Conductivity	Particulate Organic Material
Bulk Density	Soil Nitrate	Potentially Mineralizable Nitrogen
Infiltration	Soil pH	Soil Enzymes
Slaking		Soil Respiration
Soil Crusts		Total Organic Carbon
Soil Structure & Macropores		

5.3 Soil Volumes

"The ecological processes which govern tree survival and growth are concentrated around the soil/root interface." ***Soil Compaction & Trees: Causes, Symptoms & Effects, Dr. Kim Coder, University of Georgia, 2000***

Given that the size and health of a tree depends on a variety of factors including the species of tree, the site, soil, and more, the ratio between the amount of available soil and size of the tree are directly correlated. The diagram below depicts Jim Urban's research on the correlation between tree size and soil volume. (Figure 3)

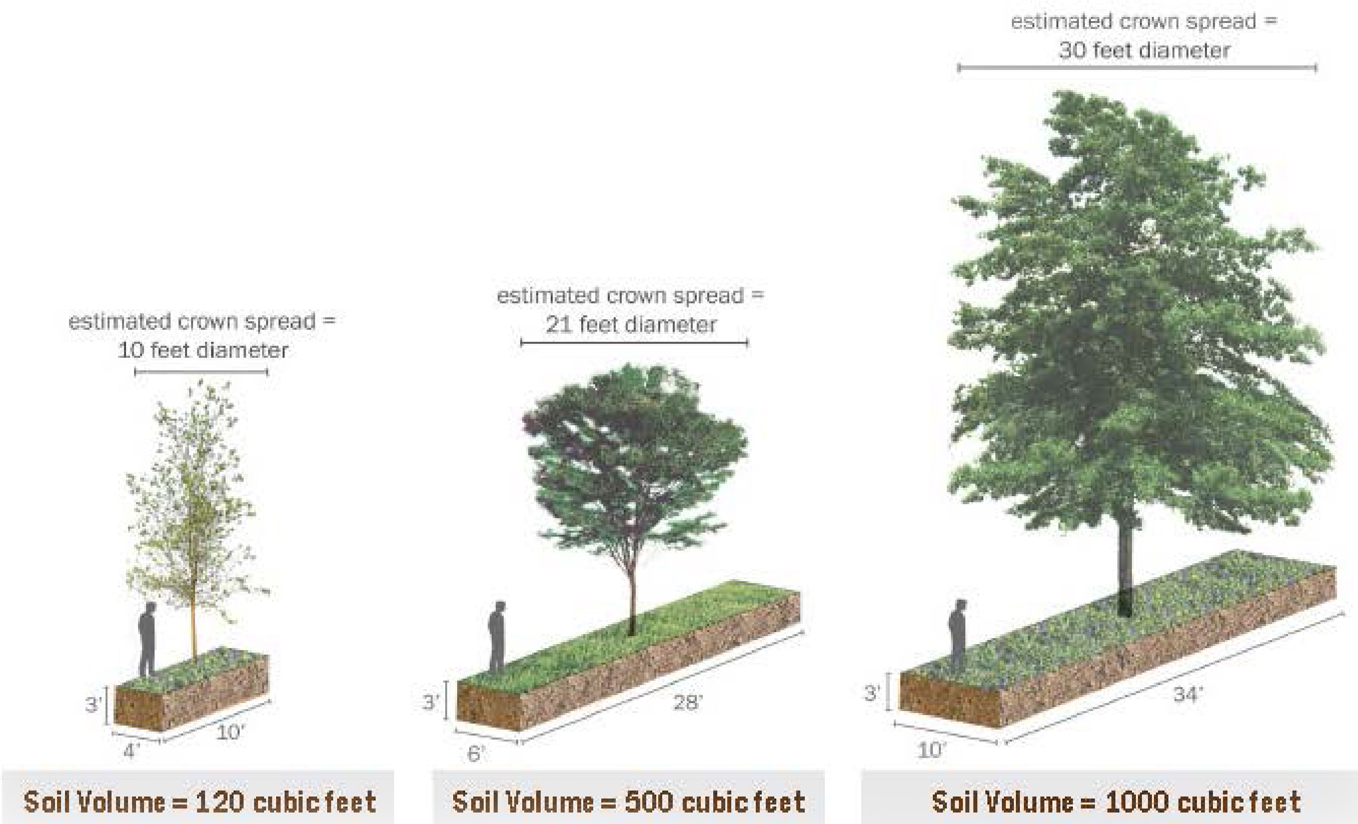


Figure 3. Soil Volume and Tree Growth (Jim Urban)

Image provided by Jim Urban

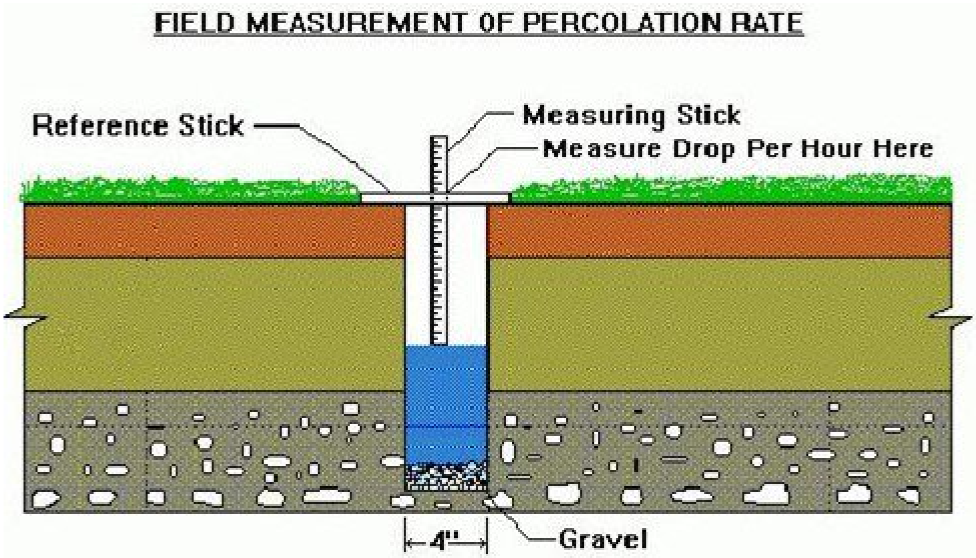
Although 1,000 cubic feet of soil per tree would make an extraordinary impact on our urban forest, very few communities strive for this goal as urban space is at a premium. At this time Ontario, Toronto, Markham, Kitchener, and Oakville are the leaders in this area, mandating just over 1,000 cubic feet of soil per street tree.

Our largest need is shade for expansive areas of impervious surfaces, such as parking lots. At this time the City of Dallas Article X states 160 sq ft for parking lot trees, which if 3 feet of soil depth was provided would equal 480 cubic feet. Given our less than optimum requirements, choosing the right tree for the right place and making sure we are providing the best soil possible becomes even more important.

<u>Percolation Test Procedure</u>

Do a simple percolation test by digging a hole 12 to 18 inches deep and filling it with water. If any water is still in the hole 12 to 18 hours later, then you have compacted or heavy clay soils. Heavy, compacted soils with poor water percolation may hold too much water and cause roots to suffocate.

Missouri Urban Trees, 1997, The Conservation Commission of the State of Missouri; Revised 2009



https://theconstructor.org/geotechnical/percolation-test-soil-absorption-capacity/8714/

Soil Nutrient Test Procedures

There are three steps involved in obtaining a soil test:

1) Obtain sample bags and instructions

2) Collect composite samples

*In fields up to 40 acres, collect at least 10 to 15 cores or slices of soil per composite sample. Composite samples should represent the smallest acreage that can be fertilized or limed independently of the remaining field or acreage.

* Soil samples are collected to a depth of 6 inches.

3) Select the proper test

***Routine** test determines the soil pH, salinity, nitrates (NO3-N), and levels of the primary nutrients (P - Phosphorus, K - Potassium, Ca - Calcium, Mg -Magnesium, Na - Sodium, and S - Sulfur) available to plants.

***Micronutrient** test estimates the levels of Zinc (Zn), Iron (Fe), Manganese (Mn) and Copper (Cu) in the soil that are available to plants.

***Boron** test determines the level of water extractable Boron (B) in the soil.

***Detailed Salinity** test uses a saturated paste extract to measure the pH, electrical conductivity and water soluble levels of the major cations in the soil. From these levels, the Sodium Adsorption Ratio (SAR) is calculated.

***lime requirement** determines the amount of lime needed to raise the soil pH to a desired level. This determination is needed on very acidic (pH <5.2) or acidic soils (pH <6)

***Texture and organic matter** are specialty tests for specific applications.

Complete the information sheet and mail to the Soil, Water, and Forage Testing Laboratory at 2478 TAMU, College Station, TX 77843-2478 for U.S. mail or 2610 F&B Road, College Station, TX 77845 for commercial deliveries. Contact the lab at (979) 845-4816, FAX (979) 845-5958, or at the Web site http://soiltesting.tamu.edu for additional information.

http://soiltesting.tamu.edu/publications/E-534.pdf

5.4 Soil Protection Plan

Soil quality is "*The capacity of soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health.*" (Doran, J.W. and T.B. Parkin. 1994. Defining and assessing soil quality. In: J.W. Doran et al. (eds.) Defining Soil Quality for a Sustainable Environment. Soil Science Society of America, Madison, WI, Special Publication 35, pp. 3-22.)

<u>Before Construction</u>

- Inventory all vegetation – a complete inventory makes it much easier to complete a soil protection plan.
- Create a base map - Identify priority vegetation and conflicts, to include but not limited to grading, drainage, utilities, property lines, existing hardscape/buildings/vegetation and any features of note.
- Preparation of a soil protection plan - Designate Tree Protection Zones (TPZ) through coordinated planning with all interested parties, such as but not limited to the arborist, architect, builder, engineer, landscape architect, etc…so that all potential conflict can be identified and solutions found. Conflicts normally include construction requirements and activities, site access, & grading and drainage.
- Identify locations for temporary soil protection fencing locations and create a schedule with monitoring and vegetation management.
- Erect Soil Protection Zone (SPZ) Fences - Once an area has been earmarked for retention, a SPZ (Soil Protection Zone) must be identified. The SPZ comprises the area in which no grading or construction should occur.

  Soil Protection Zones shall consist of the following: protected with five or six (5' - 6') foot high chain link fences. Fences are to be mounted on two inch diameter galvanized iron posts, driven into the ground to a depth of at least 2-feet at no more than 10-foot spacing. 'Warning' Sign - A warning sign shall be prominently displayed on each fence.
  The sign shall be a minimum of 8.5 x 11-inches and clearly state: WARNING - Soil Protection Zone - This fence shall not be removed until all construction activities are completed during construction, and is subject to a penalty.

<u>During Construction</u>

- Prohibit or restrict access to SPZs
- Review soil protection plans, activity restrictions. Ensure activities such as storage, vehicle services, parking, etc…DO NOT take place within the SPZ.
- Monitor SPZ - Use professionals or trained staff to monitor soils, existing vegetation, fencing and inspect the SPZ on a monthly basis.

5.5 Soil Restoration and Revitalization (Mitigation for soil compaction)

"The health and structure of trees are reflections of soil health." ***Soil Compaction & Trees: Causes, Symptoms & Effects, Dr. Kim Coder, University of Georgia, 2000***

Compaction Definition(s)
To properly discuss soil compaction as seen in the field which limits and damages tree health, a clearer definition is needed regarding soil compaction. A more precise and accurate definition is needed in order to discuss tree symptoms and managerial solutions. In this discussion the word "compaction" will be used as a composite, generic, negative impact on tree growth and soil health.

Compression -- The process which damages soil around infrastructures called compaction starts with soil compressibility or loss of soil volume. Soil compression leads to a loss of total pore space and aeration pore space, and an increase in capillary pore space. In other words, large air-filled pore spaces are crushed leading to more small water-filled pores. Compression is most prevalent in soils under wet conditions.

Compaction -- The next process soil undergoes is true compaction. Compaction is the translocation and resorting of textural components in the soil (sand, silt, and clay particles), destruction of soil aggregates, and collapse of aeration pores. Compaction is facilitated by high moisture contents.

Consolidation -- The third primary component of soil compaction is consolidation. Consolidation is the deformation of the soil destroying any pore space and structure, and water is squeezed from the soil matrix. This process leads to increased internal bonding and soil strength as more particle to particle contacts are made and pore space is eliminated.
The three components of the generic term "soil compaction" listed above do not necessarily occur in order, or on any given soil. A general summary of compaction as applied to tree and soil health problems would be a soil which has: loss of soil aggregates; destroyed aeration pore spaces; crushed or collapsed pore spaces; and, undergone extensive resorting and packing of soil particles. The depth to which a soil is compacted is determined by the compacting agent or process. Every type of management which requires soil contact has a characteristic compaction zone / layer either at the surface or at some given depth below the surface. Cultivation or management pans or layers form from soil cultivation, packing of soil fills or lifts, and various types of traffic patterns. New compaction requirements may be developed over the top of past compaction problems. **Soil Compaction & Trees: Causes, Symptoms & Effects, Gr. Kim Coder, University of Georgia, 2000**

Additional Components – In addition to the "3Cs" of compaction listed above (compression, compaction, and consolidation), generic compaction problems can often also include crusting, puddling, and rutting. These latter components represent the extent and depth of a damaged top surface layer of the soil or a top seal on a soil column. In addition to compaction, these components can generate soil conditions difficult for tree health maintenance and for effective remediation. Crusting, puddling and rutting generate soil and tree damage similar to applying a plastic sheet to the soil surface. Crusting is the dislocation and packing of fine particles and organic matter on the soil surface. In addition, natural products and pollutants can be associated with the surface making a hydrophobic surface, and preventing water and oxygen infiltration. Primary causes of crusting is the impact of rain drops on open soil surfaces, irrigation impacts, and animal and pedestrian traffic. Small local impacts on the soil surface help facilitate crusting.

In urban areas, soil compaction is the most prevalent impact due to development and construction but is also just day to day life in the big city. Remember that composition of undisturbed soil, by volume, is 45 percent mineral matter, 25 percent soil water, 25 percent soil air, and 5 percent organic matter. Composition of compacted soil, by volume, is 74 percent mineral matter, 18 percent soil water, 6 percent soil air, and 2 percent organic matter. (NRCS)

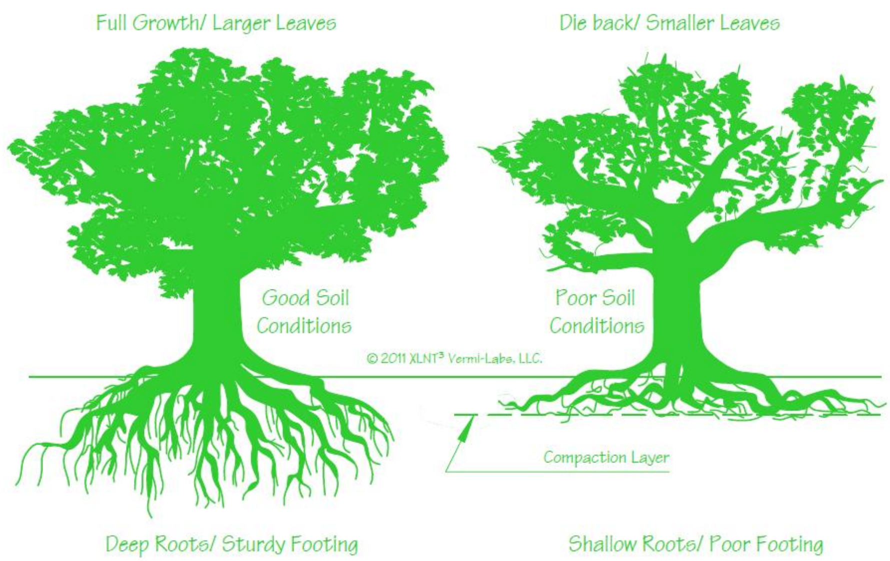


Figure 4. Soil Conditions Image provided by XLNT³ Labs

A soil is considered compacted when airspace drops to 10 – 15% of the total soil volume. In terms of Proctor units, "the maximum compaction should be 80 percent of maximum dry density" when considering planting soils. (James Urban in *Arborist News*, June 2008) When this airspace, or pore space, that is located between soil particles is decreased, also decreased is the space that allows the movement of air and water throughout the soil. (Figure 5)

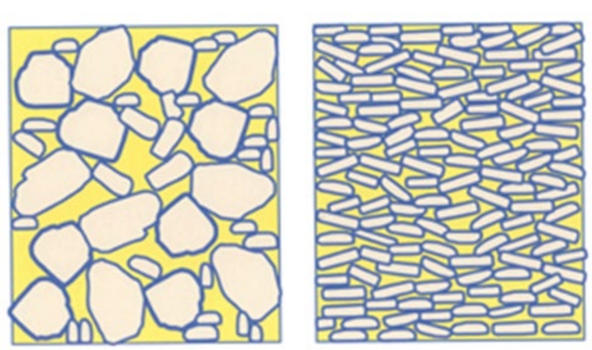


Figure 5. Image provided by Colorado State University

There are two compaction levels of severity. Surface compaction, or minor compaction, is found within the root zone, up to 12 inches deep caused by an axle load greater than 10 tons. The axle load is only a fraction of total vehicle weight resting on a given axle. Deep compaction can be found up to 2 feet deep and is caused by an axle load greater than 20 tons. Deep compaction is found most often in construction of roadways, foundations, etc.

To improve disturbed, nutrient deficient or compacted soils requires a process of restoring soil porosity and/or adding a soil amendment, such as compost, for the purpose of reestablishing the soil's long-term capacity for infiltration and pollution removal.

The process or strategy may include physical means, such as subsoiling/tilling, fracturing, trenching, or adding soil amendments. An airspade can be used to "fluff" the soil but is only effective on minor compaction.

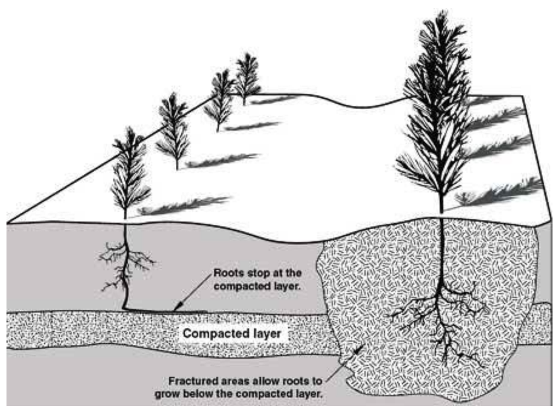


Image provided by USDA Forest Service

Vertical Mulching

Vertical mulching is a technique used to assist in alleviating soil compaction within critical root zones of trees. It reduces damage from excessive water by allowing necessary aeration during wet periods and sub-soil water penetration during dry periods. The technique also aids greatly in promoting the formation of fine feeder roots.

https://tfsweb.tamu.edu/uploadedFiles/TFS_Main/Urban_and_Community_Forestry/About_Urban_and_Community_Forestry/Urban_Forest_Information_Sheets/Technical%20Tree%20Solutions%20-%20Vertical%20Mulching_Composting.pdf

5.6 Engineered Soils

Considering that urban areas are rarely designed with trees mind but rather for pedestrian and vehicular safety. The most significant problem urban trees face is the scarcity of soil suitable for root development. Species can be examined to tolerant many challenges, but there are no tree species that can tolerate extreme soil compaction.

The soil under sidewalks, adjacent to sidewalks, and in sidewalk cutouts is usually compacted to prevent the walk from settling. This prevents many tree roots from growing in soil under the walk. Growth can be severely restricted, creating unhealthy trees, but if soil is not compacted the walk will settle.

"There are two critical effects of soil compaction which directly impact plant growth and limit useable rooting space:

1. Soil structure is destroyed, and the majority of large interconnected pores (macropores) are crushed. This results in a restriction of the soil's water drainage and subsequent aeration.
2. As the marcopores are crushed soils become denser, eventually posing a physical barrier to root penetration. (Patterson, J. C., J. J. Murray, and J.R. Short. "The impact of urban souls on vegetation." Proc. 3rd METRIA Conference (1980): 33-56)

A structural soil or an engineered soil mix is a two-part system comprising of a stone lattice for structural strength and soil for horticultural needs. The material supports pavement designed to withstand pedestrian and vehicular traffic. (Hopper, 2007). Because these engineered soils rely on larger rock aggregate to supply their weight bearing capacity, the actual volume of nutrient containing planting media makes up only about 20% of its volume. In order to provide a comparable amount of planting media, the volume of engineered soil would need to be increased about four fold.

Warning: not all structural soils are created equal and if your contractor does not understand the specifications, structural soils can be adversely affected very easily. Other issues with infrastructure and ongoing maintenance have been found.

5.7 Structural Soil Cell Systems

Perhaps the best way to create root space without compromising soil strength for sidewalk support is to use a soil cell system. Structural soil cell systems (Silva Cell, Stratavault, etc.) allows the utilization of the soil mixture that best accommodates trees while also accommodating infrastructure. Structural soil systems are a modular suspended pavement system that uses soil volumes to support large tree growth and provide powerful on-site storm water management through absorption, evapotranspiration, and interception.

Each structural soil cell is composed of a frame and a deck. The deck is designed to support the surface (normally a paved surface such as a sidewalk), while the frame transfers the load to a bearing surface approximately 2 to 4 feet beneath the surface. This framework creates an area for planting soil best suited for the trees and allows for infrastructure (utilities) to occupy some of the area as well. These cells can be stacked one, two, or three high before they are topped with a deck to create a maximum containment area for lightly compacted loam soil. Silva Cells can be spread laterally as wide as necessary. Each unit is more than 90% void space, making it easy to accommodate utilities.

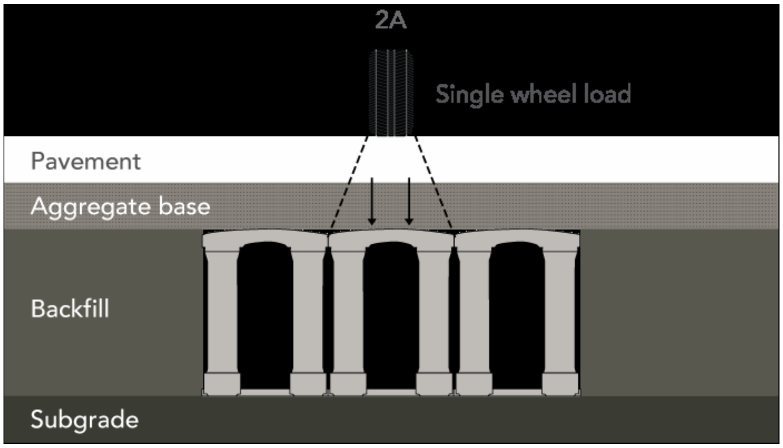


Image provided by Deep Root

http://www.deeproot.com/products/silva-cell/overview

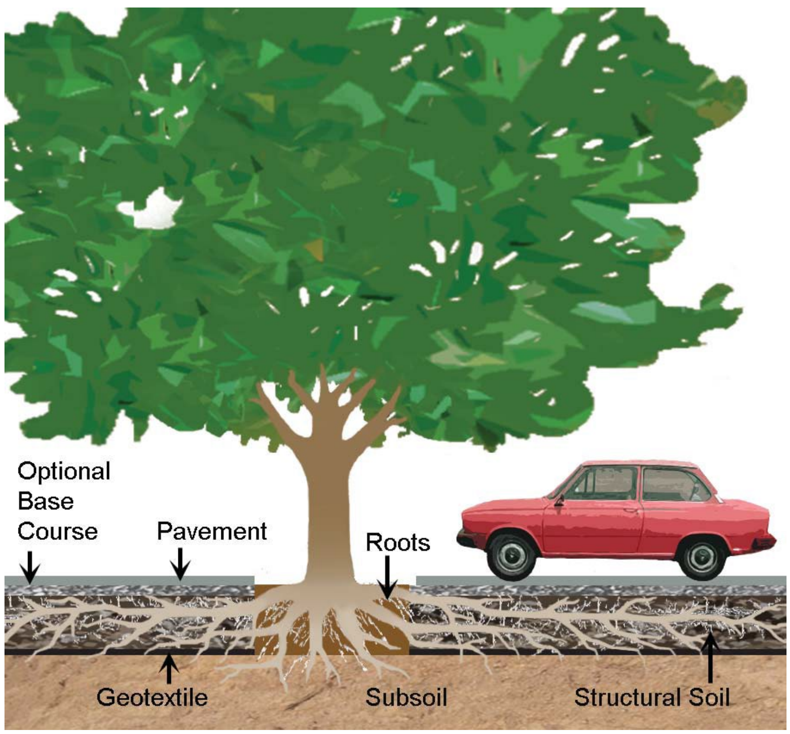


Image provided by Day, S.D, and S.B. Dickinson (Eds.) 2008. Managing Storm water for Urban Sustainability using Trees and Structural Soils. Virginia Polytechnic Institute and State University, Blacksburg, VA.

5.8 Soil Protection and Drainage

Soil conservation measures should aim at preventing or at least minimizing the soils loss. This can be accomplished through several procedures. After choosing the best access and staging areas, something as simple as laying down mulch to a 6 inch depth, where large machinery may pass, can minimize soil compaction and protect any tree roots that may be in the area.

Other tools to protect the soil include laying down plywood, flex base or root system bridges with steel plates suspended over railroad ties, to name a few.

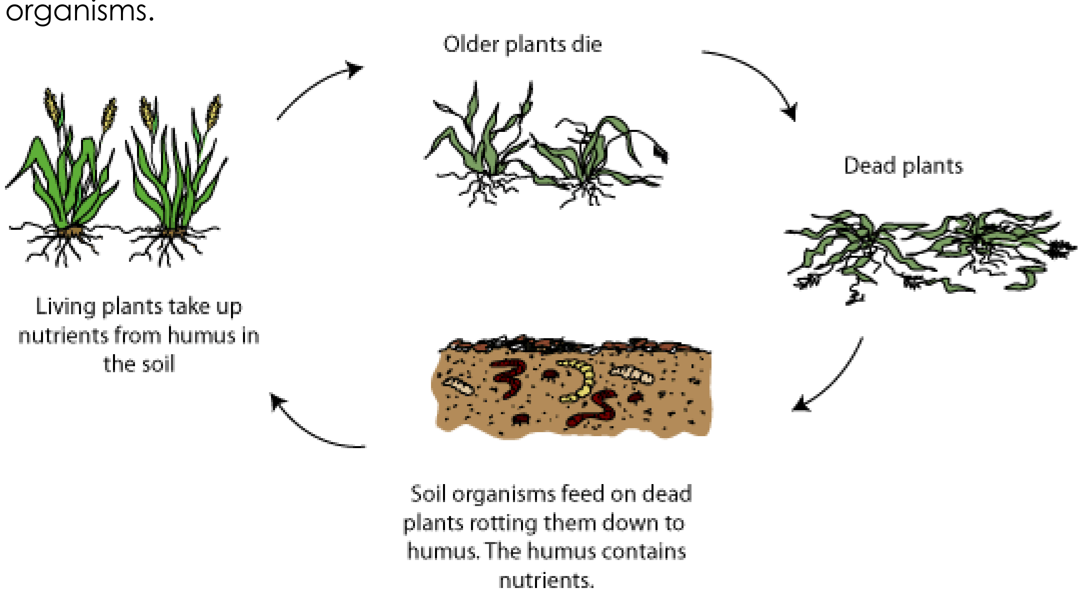
Drainage may be needed in soils that retain high soil moisture levels. Installation of a drain pipe, in conjunction with soil modifications can be useful.

5.9 Soil Management

Soil management is an integral part of land management and may focus on differences in soil types and soil characteristics to define specific interventions that are aimed to enhance the soil quality for the land use selected.

The following soil management strategies are recommended for enhanced soil performance:

- Soil Analysis: In order to follow good practices for sustainable soil management, it's essential that to regularly perform soil analysis. By testing the soil, you can see the exact amount of soil nutrients, humus content, and pH value.
- Soil Fertilization: Organic matter consists of all living soil organisms and the previous living organisms in their various degrees of decomposition. It has a major role in soil management practices carried out before planting. Organic matter improves soil structure, enhances water and nutrient holding capacity, protects the soil from erosion and compaction, and supports a healthy community of soil organisms.



- Biological, Physical and Chemical Soil Protection Measures: In order to manage plant pests, applications of different protection measures are required. These can include tillage, proper planting time, mulching, and chemical/ natural soil and plant treatments.
- Proper Drainage and Irrigation: It is important to ensure good soil drainage as well as optimum humidity for young plants. Soils with less drainage may accumulate higher amounts of water than is needed and thus negatively affect seeds or young plants.

https://content.ces.ncsu.edu/north-carolina-organic-grain-production-guide-contents-1/chapter-6-soil-management

RESOURCES

Water Relations of Plants and Soils, Paul J. Kramer and John S. Boyer, Academic Press, 1995

Soil Compaction & Trees: Causes, Symptoms & Effects, Gr. Kim Coder, University of Georgia, 2000

"The ecological processes which govern tree survival and growth are concentrated around the soil/root interface." ***Soil Compaction & Trees: Causes, Symptoms & Effects, Dr. Kim Coder, University of Georgia, 2000***

Minor Compaction – surface compaction within 8-12" due to contact pressure, axle load > 10tons can compact through root zone, up to 1' deep

"Major Compaction – deep compaction, contact pressure and total load, axle load > 20 tons can compact up to 2' deep (usually large areas compacted to increase strength for paving and foundation with overlap to "lawn" areas)"

"In general, compaction problems occur when airspace drops to 10-15% of total soil volume. Compaction affects the infiltrating and water quality capacity of soils. When soils are compacted, soil particles are pressed together, reducing the pore space necessary to move air and water throughout the soil. "

"Soil amendment and restoration is the process of improving disturbed soils and low organic soils by restoring soil porosity and/or adding a soil amendment, such as compost, for the purpose of reestablishing the soil's long-term capacity for infiltration and pollution removal."

"Existing soil conditions should be evaluated before forming a restoration strategy."

"Physical loosening of the soil, often called subsoiling, or tilling, can treat compaction."

"the combination of subsoiling and soil amendment is often the more effective strategy."

Pennsylvania Stormwater Best Management Practices Manual

Citiations:

Landscape Architecture Graphic Standards Leonard J. Hopper, 2007