Understanding Tree Planting in Construction-Damaged Soils

PENNSTATE

College of Agricultural Sciences
Agricultural Research and Cooperative Extension

Understanding Tree Planting in Construction-Damaged Soils

Contents

Made Soils

Soils found in commercial, residential, and other landscapes that have been involved in construction are most likely different from soils found in places that are undeveloped or uncultivated. Some people refer to soils in developed places as fabricated or "made soils." Because of grading (soil fill and removal), equipment movement, cleaning equipment, and other activities in areas that have undergone construction, made soils can be highly mixed and altered. These soils can change in fertility, pH, compaction, and drainage from foot to foot. As a result, soil maps provide little useful information about the characteristics and capacities of construction-damaged soils.

When planting trees and other plants in construction-damaged soils, you most likely are dealing with made soils both horizontally and vertically. These fabricated soils can be heavily compacted, polluted, and unfertile, full of trash and debris, have unhealthy high or low pH ranges, and have strange transition zones (hydrological differentiation) between mixed and crushed layers. These traits can all negatively impact tree establishment (root growth to support plant growth), normal growth and appearance, and plant longevity. There are many examples of construction-damaged soils. Compaction by people or equipment crushes soil structure, impeding air, water, and root movement. Organic soils are often stripped and removed from construction areas, leaving compacted, mostly clay soils. Transition zones, caused by dumping one type of soil on top of another, are often impermeable barriers to water, air, and roots. For successful tree and plant growth, you need to understand the characteristics and capacities of the soil in which you are going to plant, especially soil damaged by construction.

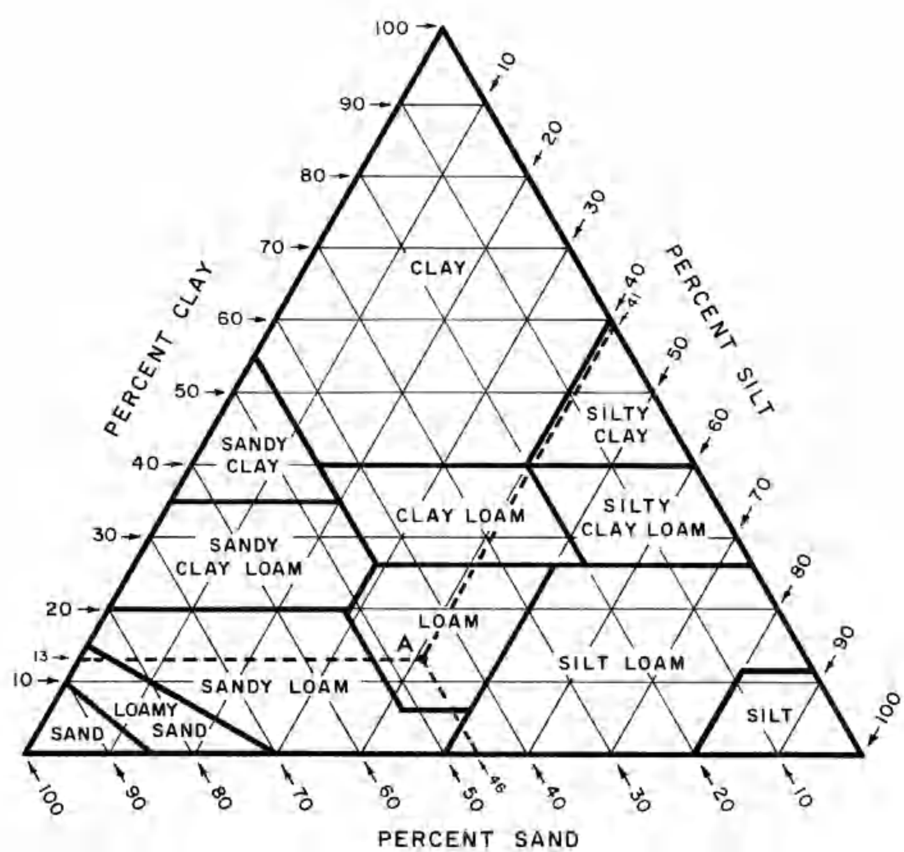
Soils in these developed areas have been stripped of organic material, compacted, and have a certain amount of garbage and debris.

Diameter of Particles				
Millimeters	2.0	0.05	0.002	0
Inches	0.080	0.002	0.00008	0
gravel, stones	sand	silt	clay	
Particles visible with the naked eye		Particles visible under microscope	Particles visible under electron microscope	

Diameters of sand, silt, and clay particles. Sand is the largest soil particle and clay is the smallest.

Soil Texture

Soil texture is the amount of sand (larger soil particle size), silt, and clay (smallest particle size) present in any soil. Texture affects water percolation, water retention, aeration, nutrient capacity and retention, and root and plant growth.



The "soil triangle" shows different soil textures. Most soils of agricultural importance are some type of loam.

In natural soils, soil texture is provided to a great extent by a soil's parent material, the underlying rock, and how this material has interacted with air, water, cold, heat, gravity, and other environmental conditions over time. Because of mixing, dumping, and removing in soils impacted by construction, it can be difficult to determine what the parent material, or basis, for a soil's texture is, and soil texture can change in any given place of a developed landscape.

SANDY TEXTURE

Typically, larger-grained, sandy-textured soils have better water percolation and aeration than smaller-grained, clay-textured soils, but their ability to retain and provide water and plant nutrients is lower. Water and nutrients simply leach through sandy soils quickly. Soils with sandy types of textures are harder to compact but can be extremely droughty and infertile—think of the beach. With large particle sizes, sandy soils have better water and air movement because of more and larger soil pores. Pores are spaces between soil particles that can be filled with and help move water and air. The presence of sand particles also makes any soil more friable or loose and promotes root growth.

SILTY TEXTURE

Silty soils have particles that are intermediate in size between sand and clay. Because of smaller particle size and smaller pore spaces, silty soils have a slower water-intake rate but a higher water- and nutrient-holding capacity than sandy soils. Water does not drain through these soils as quickly, but they are also more easily compacted than sandy soils. Although there are few truly silt soils in Pennsylvania, some portion of silt is an essential part of a desirable soil.

CLAY TEXTURE

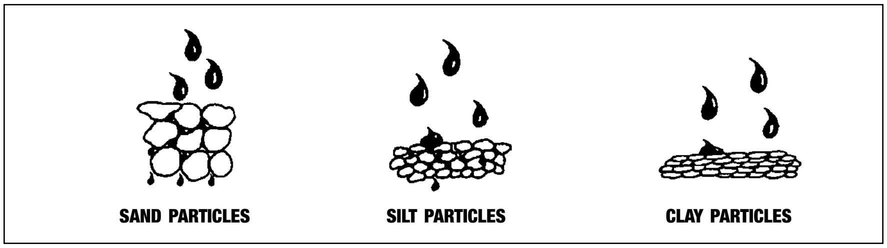
Because of their very small particle size and the associated small size of soil pores, clay soils are much easier to compact, which affects water, air, and root movement. Clay particles are stickier and have the ability to bind both water and soil nutrients. One property of clay is an attraction for positive nutrient ions such as calcium, magnesium, and ammonia. Because of this, clay soils can hold and store large amounts of these plant nutrients. On the other hand, negative plant nutrient ions such as nitrate, phosphate, and sulfate are repelled by clay particles and are only stored for plant use to the extent they are dissolved in any water held in soil pore spaces. Clay is a major ingredient of a healthy soil, but in some cases, clay soils can bind water and nutrients so tightly that they are unavailable to plant roots. As with sand and silt particles, a portion of clay particles is desirable in healthy soils because of high nutrient- and water-binding or holding capacity, which adds to the fertility of a soil.

LOAM TEXTURE

A loam soil has intermediate, approximately equal properties of sand, silt, and clay. Loam soils have good characteristics in terms of water movement and storage, nutrient holding or fertility, and friability for root growth. For many plants, a sandy/loam soil (e.g., topsoil) is the desired soil for good plant growth and survival. This type of soil texture shares all the positive traits that sand, silt, and clay textures provide.

How to Explore Soil Texture

Soil texture can be explored by picking up and gently rubbing a soil sample between your thumb and fingers. It is helpful to dampen the soil to feel the amount of clay—or plasticity. The way a damp soil develops a ribbon as it is rubbed gives a good idea of how much clay is present. Sandy soils feel gritty, and silt has a floury feel to it when



The amount of sand, silt, and clay particles found within a soil make up a soil's texture. Soil structure is how these particles are grouped together.

dry and is smooth and not clayey or sticky when wet. To help you explore through rubbing what type of soils you have, different types of soils are described below. The sources for these descriptions are Phillip J. Craul's *Urban Soils: Applications and Practices* (John Wiley and Sons, 1999) and Nyle C. Brady's *The Nature and Properties of Soils* (Prentice Hall, 2007).

SANDY

Soils where the sand makes up 70 percent or more of the material by weight are classified as sandy. They are not sticky as the heavier clay and loam soils are, but they are loose and single grained. Squeezed in the hand when dry, they will fall apart. Squeezed when dampened, they will form a cast or ribbon that will fall apart if touched.

LOAM

Most soils of agricultural importance are some type of loam. A loam soil has a relatively even mixture of different grades of sand, silt, and clay. They exhibit light or sandy (good drainage) and heavy or clay (nutrient- and water-holding capacity) properties in about equal proportions. Loams are mellow with a somewhat gritty feel yet fairly smooth and slightly plastic or clayey. Squeezed when dry, they will form a ribbon that will bear careful handling, and the cast formed by squeezing the moist soil can be handled quite freely without breaking. They are classified by the amount of sand, silt, and clay they contain: sandy loam, silt loam, and clay loam.

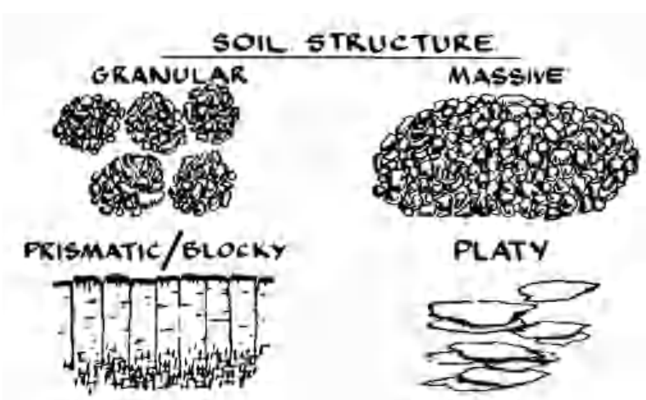
CLAY

Clay soils have between 35 and 40 percent clay. They are fine-textured soils that usually form hard lumps or clods when dry and are quite plastic and sticky when wet. When the moist soil is rolled, it will form a long, flexible ribbon that will not break or fall apart.

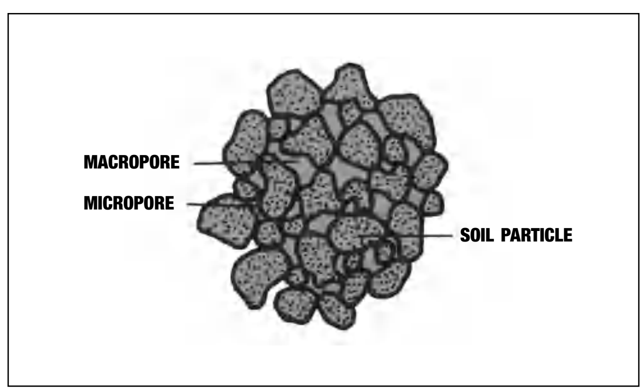
Soil Structure

Soil structure is how the individual soil particles (sand, silt, clay) are arranged, aggregated, held, or come together in peds or clods. Thus, the size and form of soil aggregation is known as soil structure. Good soil structure allows for water and air infiltration and movement, as well as for root growth. Soil structure is developed over time through rain, frost, or other weather impacts. It is also affected by the amount and type of organic material that leaches into a soil over time. Although developed over time in nature, structure can be destroyed quickly by machinery, grazing livestock, cultivation, or other human impacts.

Typical types of soil structure include granular, blocky, prismatic, massive, and platy. Soil texture influences the type of structure a soil can have (e.g., a sandy soil has granular structure and clay soil has blocky structure), and both texture and structure affect the movement of air, water, and roots. Sandy soils often have little or no structure, while clay structures can have very heavy peds or clods (blocky or prismatic structures). It is important to have well-developed structures in heavy clay soils to allow for water, air, and root movement.



Four examples of soil structure. Granular would be related to sandy soils, prismatic and blocky to clay soils.



Compaction smashes a soil's pore spaces, stopping air, water, and root movement.

This soil's structure has been crushed and destroyed by compaction or mashed and destroyed by rough treatment.

Structure is crushed and destroyed by compaction or smashed and destroyed by rough treatment. In soils that have been damaged by construction, structure is often compressed, crushed, or compacted—especially in clay soils. This means soil pore spaces are crushed and a soil becomes layered (platy) and water, air, and roots have a difficult, if not impossible, time moving into and through the soil. Also, compacted soils, because of a lack of pore space, tend to have poor gas exchange and levels of CO_2 produced by root respiration build up in the soil, slowing root respiration and growth. This build-up of CO_2 also happens in soils that are highly saturated for periods of time because of poor drainage or overirrigation.

Soil Structure Is Destroyed by Compaction

Compaction (or destruction of soil structure) is a huge problem when planting trees and other plant materials in developed landscapes and can be measured by soil bulk density. Bulk density is the mass (weight) of a dried soil per unit bulk volume, which includes both solids and the quantity of pore space. Because of the amount of uncompacted pore space, soils that are uncompacted, loose, and porous will have lower weights per volume. Soils that are more compacted will have higher weights per volume because their pore spaces have been destroyed, allowing for more soil in any given volume. Soil compaction, whether surface or subsurface, can also be measured by a penetrometer. A penetrometer is a tool that mimics a plant root. Most plant root growth is restricted at a penetration resistance of 300 pounds per square inch, and a penetrometer measures the resistance in pounds per square inch of a soil to a rod that is driven into it at approximately 1 inch per second.

Soil Horizons and Profiles: Usually Destroyed by Compaction

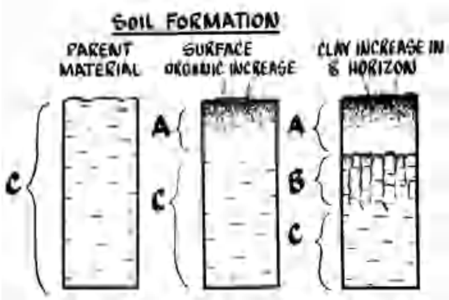
As weathering continues over long periods, a number of changes occur that cause distinctly visible layers in a soil. These layers are called horizons and the sum of horizons for a soil is called its profile. Simple soil horizons are designated by the letters "A," "B," "C," going down from the surface. The first (lowest) horizon in a young soil is the "C" horizon, or the weathered parent material. With more weathering, time, and other forces, other horizons develop. The upper layer of many soils is a dark-colored zone that extends downward a few inches from the surface. This is the "A" horizon and its dark color is due to well-decomposed organic material, or humus. More humus and larger "A" horizons are found in soils (1) in cooler climates than in hot climates; (2) in wetter climates than in dry climates; and (3) under grasslands rather than under forests. The "B" horizons form very slowly in a soil and are an accumulation of clay in a layer beneath the "A" horizon. The "B" horizon builds up as a result of the downward movement of fine particles by percolating water and the formation of clay particles by chemical reactions in a soil over time.

As with soil texture and structure, soil horizons and a soils profile are usually destroyed by construction. As an example, in most developments "A" organic horizons are removed, leaving only the "B" horizon of clay, which forms a barrier to water and air penetration and root growth when compacted.

Soil Problems Found in Construction-Damaged Soils

Soil compaction, high (alkaline) or low (acidic) pH, and simply the amount of fertile soil available for root growth are three serious concerns when planting in constructed landscapes such as parking lots, patios, sidewalks, and compacted yards stripped of their organic horizons. In Pennsylvania, high-pH soils seem to be more abundant than low-pH ones.

Loss of organic material in the "A" horizon, compaction of underlying horizons, and soils containing pollution and debris can be helped by (1) replacing poor soils in the planting area (e.g., use of a high quality topsoil or a prescribed structural or other designed soil); (2) loosely breaking up existing soils that are decent but compacted using a shovel, air spade, or vertical mulching within proper soil moisture content; (3) carefully amending and



Example of very simple soil horizons.

cultivating whole planting areas, not just the planting pit, with composted organic material; and (4) choosing plant materials that are tolerant of compaction, drought, poor aeration, and low fertility.

Breaking Compaction

Air spades and vertical mulching can be used to relieve compaction and help fertility in soils under existing trees. However, when working with soils, you need to pay close attention to the soil moisture content. Working a soil that is too dry can pulverize it, destroying the structure. Working soils that are too wet actually increases compaction. If the soil smears when dug or if water is visible within the soil pores, the soil is too wet.

Vertical mulching is carefully drilling lines of holes (12 to 18 inches deep and 2 feet apart) in concentric patterns beneath a tree and filling them with a composted organic material. This is often combined with irrigation and broadcast fertilization of a nitrogen-based fertilizer in slow-release forms in light to moderate amounts (e.g., 25-14-14). Fertilization amounts should be based on a soil test and the possibility of irrigation. Irrigation amounts should be based on past irrigation and rainfall and recognized standards (e.g., 20 gallons of water per inch of tree diameter at 4.5 feet on the trunk). Air spades can be used to remove or fracture compacted soils in large areas, trenches, or spokes through the root zone. If poor fertility or polluted soils are removed, they

As shown in these three photographs, soil amendments are applied and cultivated thoughout the planting area, not just the planting hole.

should be replaced with a high-quality topsoil. Roots and soils must be protected from the force of the air spade and from weather, such as cold and hot temperatures. Do not expose tree roots on particularly hot or cold days.

When digging larger planting holes and radial trenches to relieve compaction in decent, fertile soils, do not smash soils that you are going to replace as this will destroy structure. Loosely dig these soils and break them apart with a shovel.

Radial trenching can be used to break compaction for new and mature trees.

Structural Soils

Structural soils developed at Cornell University can be used under sidewalks, parking lots, patios, and other confined planting areas that have to be compacted to support the weight of asphalt or cement. The structural soil mix of crushed stone provides both a penetrable, fertile rooting volume and a load-bearing service for asphalt or concrete. The three components of the mix are an angular crushed stone (to provide a skeleton to hold weight), a clay soil (to provide for nutrient- and water-holding capacity), and a small amount of hydrogel (to bind soil and stone together). The actual mix is patented by Cornell University and contractors must be licensed to create these soils at the construction site. A ratio of 80 percent stone, 20 percent clay, and a small amount of hydrogel is recommended. Structural soils must be mixed carefully using the correct gravel size, and they cannot be transported very far because the clay soil will separate from the gravel.

Structural soils can be used under new sidewalks and parking lots, especially those being removed and rebuilt.

Concerns with Structural Soils

As with many recommendations, there are concerns about using structural soils in every planting case. These include (1) proper structural root growth in trees planted only in the gravel of structural soils; (2) proper mixing and the fact that these soils cannot be transported long distances after mixing because the components will separate; (3) the clay and hydrogel components can actually hold water from plant roots and expand; and (4) use of limestone gravel, which drastically increases pH. There are other designed soils besides structural soils. One solution is to have a knowledgeable person involved in selecting the type of soil that will be used when replacing or amending existing soils.

Considering pH

The ability of plants to withdraw and use nutrients from soil is affected by its pH. Most plant materials prefer a slightly acidic pH. Many trees and plants (e.g., pin oak, red oak, red maple, sweet gum) will not grow in high-pH (alkaline) soils, but many soils in the limestone regions of

Air spades (radial trenching) can be used to break compaction under existing trees. Exposed roots must be protected from desiccation.

Pennsylvania and around construction sites (because of the amount of cement and limestone gravel used) are higher in pH. Problems with pH and altering unhealthy pH ranges can be difficult to deal with, especially after trees have been planted. Do not rely on liming to raise pH or sulfuring to lower pH. These are short-term treatments affected by leaching and other forces. They will fail to provide assistance in the long term when pH is a concern. If pH is a concern, plant material should be selected that can handle both high and low pH (e.g., zelcova, Kentucky coffee tree, ginkgo, London plane).

Sidewalk and Other Cutouts

Cutouts for trees in parking lots, sidewalks, and patios should be a minimum of 5 by 5 by 3 feet; 6 by 6 by 3 is a minimum recommended by some, but bigger is better (e.g., a cutout 10–12 feet long, 5–6 feet wide, and 3 feet deep is preferred to support one large growing tree). However, allowing that much space may be impossible in some situations. The depth of the soil available for rooting volume should be at least 3 feet for windfirmness. Structural or other designed soils can be used to expand the rooting area while allowing for the placement of concrete.

Construction debris, gravel, and other waste should be removed from parking lots, sidewalks, and other planters. If structural or other designed soils are not being used, poor soils in planting cutouts should be replaced with a high-quality topsoil. Remember that replacement soils and any amendments must be mixed in with original soils at the bottom and sides of the planting areas to prevent transition zones.

A Note on Soil and Planting Cutout Size

Many people recommend larger cutouts with a minimum available rooting volume of at least 800 cubic feet per tree. These are extremely large areas (10 by 10 by 8 feet) and may not be available in all planting situations, especially when working with older planting areas that will not, or cannot, be redesigned or rebuilt. Again, structural or other designed soils can be used in new construction to increase rooting volumes and allow for concrete placement. But, planting trees in existing sidewalks can be a challenge. Sometimes, in confined places such as existing sidewalks, a decision must be made whether to plant a tree or not. If a tree is planted in less than the minimum planting cutout size recommended in this publication (5 by 5 by 3 feet), problems with hardscape damage should be expected, including issues of tree size, health, and longevity, and the strength of root structure. By providing the largest planting area possible and planting an appropriate tree species, these concerns can be minimized. It is also our opinion that minor hardscape damage, smaller mature tree size, and other problems are offset by the economic and environmental benefits that a reasonably healthy tree will provide a downtown area, a parking lot, or another populated area over time.

Although 5 by 5 by 3 feet to 6 by 6 by 3 feet are the recommended minimum cutouts, larger planters such as 6 by 12 by 3 feet should be used to plant large trees in downtown areas.

Large sidewalk cutouts and innovative planting design should be used for larger trees.

A Note on Organic Materials and Amendments

Although the organic fraction or component of a fertile soil is usually small (1 to 5 percent by weight or around 10 percent by volume), it is important in providing a reservoir of nutrients and water and in improving the friability and structure of soils. Soil microorganisms must break down organic compounds to provide for essential plant nutrients—a process known as mineralization.

Amending soils with organic materials can help improve water-holding capacity and fertility by affecting both texture and structure. Over time, organic materials provide gums that can help bind together smashed soil particles, improving structure. But, as has been pointed out by a number of authors such as Phillip and Tim Craul, the addition of large amounts of organic material is usually necessary to alter the characteristics of highly damaged or modified soils. Adding excessive organic material (usually more than 20 to 30 percent on a volume basis) causes a number of problems such as soil settlement and increase of water-holding capacity to a point where soils stay wet for long periods. Both problems are detrimental to root growth and function, especially in highly clay soils. Undue wetness creates unfavorable aeration conditions, increases carbon dioxide in soils, and can actually impede root function, the breakdown of organic material, and the release and use of plant nutrients.

Soil texture can be modified by the addition of coarse sand or clay, depending on the desired change. Water-holding capacity, bulk density, and drainage are all modified by these amendments, but these modifications are beyond the intent of this publication. If dealing with heavily damaged or modified soils: (1) seek the advice of an expert and do not rely on rule-of-thumb additions of amendments; (2) consider replacing poor soil with a high-quality topsoil or using engineered soil mixes such as a structural or other designed soil under newly constructed or replaced sidewalks and patios; (3) use proper mulching (e.g., 2 to 3 inches of a coarse-ground, well-cured, composted mulch kept away from the tree trunk) and mulch management to provide for vertical amendment of the soil over time. Remember that too much mulch, or mulch that has been compacted by foot or other traffic, can actually impede water and air percolation and movement and cause dry, unhealthy growing conditions.

Do not cover cement and other debris with a few inches of topsoil. All garbage and construction gravel should have been removed from these parking lot and other planting cutouts. These and other planters should be filled with topsoil or a professionally designed soil.

Amending Damaged Soils

When amending compacted planting areas before planting, well-cured composted organic material (mushroom compost, leaves, grass clippings, wood chips) should be incorporated at 25 to 30 percent of the total soil volume of the upper 6 inches or so of the entire planting area (not just the planting hole). Because of high pH and other considerations, well-cured composted sewage sludge is satisfactory but should not be used for more than 25 percent of total soil volume. Additions of composted municipal yard waste can help offset some occurrences of high ammonia content within these biosolids. The composted material must be thoroughly mixed with the native soil and amended together. This includes cultivating soils together at the bottom and sides of the planting area. Abrupt transitions and differences in soils can inhibit water movement and root growth and spread.

Finding out the Problems

When planting trees and other plants in developed landscapes, a shovel, your hand, and a soil test are your best tools to understand the characteristics and capacities of the soil you are using. Dig a small hole to investigate structure, garbage, depth, compaction, and drainage. Squeeze dampened soil between your thumb and fingers to investigate texture. If compaction and drainage are concerns, pour a gallon of water into a 12-inch-wide, 24-inch-deep hole dug with a shovel. If the water does not drain from the hole in eight hours, consider planting in another location. Replacing, cultivating, or amending soil in areas with poor drainage may or may not help drainage, depending on the underlying cause of the problem, such as hardpans, old parking lots, and rock formations. Plantings in these areas may have to be engineered for drainage (e.g., French, PVC, or other drains), planted in mounded beds, or be provided some other special type of planting. Always use a soil test to find out about soil texture, fertility, pollution, and pH. These tests, and the directions for their use, are available through county extension offices.

Final Strategies for Dealing with Construction-Damaged Soils

There are some recommended strategies for planting trees where construction or other activities have altered and damaged soils. Use a shovel and a soil test to find out about compaction, drainage, pH, and other important soil characteristics.

- Plant the easy places first. Plant trees in a front yard rather than a sidewalk cutout or small tree lawn.
- Design and construct bigger planting spaces and make space for roots. Increase the areas of available topsoil and reduce the amount of soil compaction required by designing and constructing large cutouts (5 by 5 by 3 to 6 by 6 by 3 feet minimum). Design tree lawns that are at least 6 feet wide and use structural or other designed soils, continuous planters that run parallel to the curb, and properly designed parking lot planters. Larger cutouts or continuous planters (e.g., to accommodate the growth of two large trees, a cutout/planter 24 feet long, 5 feet wide, and 3 feet deep should be constructed) have been used in Philadelphia and other cities to plant trees in downtown sidewalk areas.
- Preserve and use existing soils. If the soil in which you are planting has a decent texture and is fertile, softly break existing compaction and reuse.
- Improve soil and drainage. Break compaction, amend or replace poor soils, and maintain or create drainage using French drains, plastic piping, or other means.
- Select the right type of tree. Put the right tree in the right place and make the place right for the tree.

For the best results, innovative designs that provide for more fertile soil, rooting areas, and storm water management should be used.

Some Important Soil Terms

Alkaline soil—any soil that has a pH value greater than 7.

Bulk density—the mass of a dried soil per unit bulk volume. A measure of compaction.

Compaction (also called layering)—results when machinery or other pressure breaks soil structure and increases its bulk density. Structure is crushed and disintegrates, causing the collapse of large pore spaces essential for rapid water, air, and root movement.

Fertility—the status of a soil with respect to the amount and availability to plants of nutrients necessary for growth.

Friable—a term pertaining to the ease of crumbling of soils.

Hardpan—a hardened soil layer in the lower A or in the B horizon caused by the cementation of soil particles with organic matter or with materials such as calcium carbonate. Hardpans are also caused by rock formations, old parking lots and street sections, and underlying layers of soil that have been compacted.

Infiltration—the downward entry of water into a soil.

Parent material—the weathered geological material from which topsoil and subsoil have been derived.

Percolation—the downward movement of water through a soil. Unless saturated with water, sandy soils will have much higher infiltration and percolation rates than clay or compacted soils. But clay soils have higher nutrient-holding and provision traits than sandy soils.

Permeability—the ease with which gases, liquids, or plant roots penetrate or pass through a mass of soil.

pH—the degree of acidity (lower pH) or alkalinity (higher pH) of a soil. Most plant materials prefer slightly acidic pH. Neutral is a pH value very close to 7.0; slightly acidic is 6.6–6.0; slightly alkaline is 7.4–8.0; strongly acidic is 5.0–4.0; strongly alkaline is 9.0–10.0; very strongly acidic is 4.0–3.0; and very strongly alkaline is 10.0–11.0.

Surface or topsoil—the top portion of the soil usually moved in cultivation. The top 3 to 10 inches of the soil is presumed to be fertile. A desirable topsoil should contain about 45 percent mineral material, 50 percent pore space, and 5 percent organic material.

Saturation—to fill all the voids or pores between soil particles with a liquid. Soils saturated for longer periods can have poor aeration and high levels of CO_2, both detrimental to root respiration and growth.

Resources

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