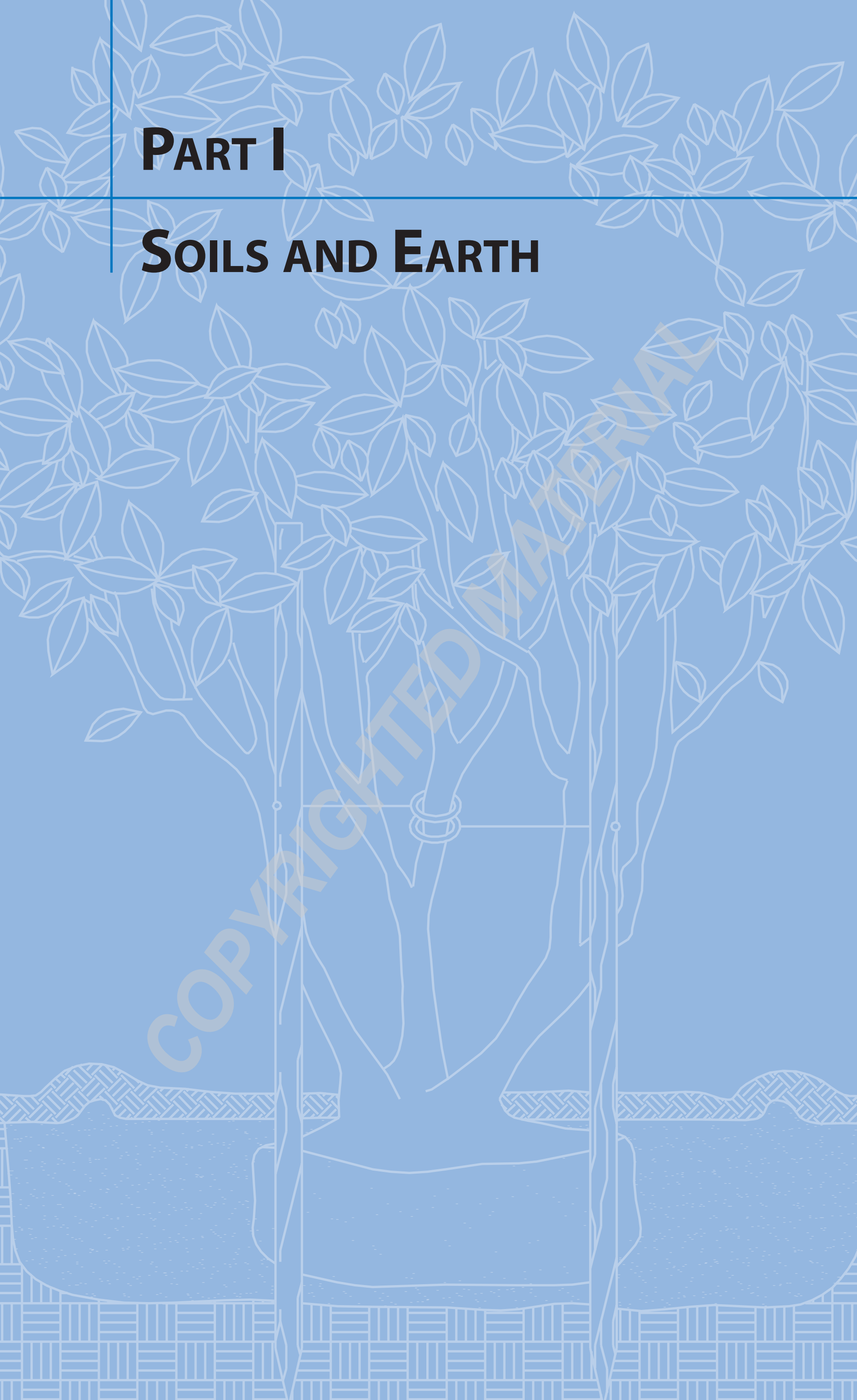
Part I

Soils and Earth



Chapter 1

Soils

Soil Overview

Soil Assessment

Designed Soil Mixes

Soil Overview

Description

Soil as a growing medium may be defined as a natural system, composed of mineral particles, organic matter, water, and air, all supporting growing plants. The "soil profile" consists of horizons, and there exist important interrelationships among the horizons, as they are interdependent and necessary for the entire profile to fulfill its function as a rooting medium, both in nature and in the designed landscape project (Craul and Craul 2006). The ideal soil has about 45 percent mineral solids, 5 percent organic matter solids, and 25 percent each water and air.

Understanding the functional relationships within the general form of the natural soil profile (Craul 1992, 1999) is necessary to make a reasonable estimate of the degree of limitations present in the existing project soil materials, which is essential to formulating a soil design plan.

Assessing Site Conditions

As shown in Figure 1.1, the major horizons of the ideal natural soil profile include:

- *O horizon (organic)* — This horizon functions as a mulch that reduces evaporative water losses, lowers daytime and maintains nighttime surface soil temperatures, and contributes organic matter for soil tilth and acts as a source of energy for soil organisms.
- *A horizon (topsoil)* — This horizon contains incorporated organic matter and a large and diverse organism population, and serves as the major rooting medium for most of the plant roots.
- *B horizon (subsoil)* — This horizon provides added necessary rooting volume for plant stability and nutrient and water storage, to supplement the topsoil.
- *C horizon (substratum or parent material)* — The C horizon contributes deep rooting and drainage volume. It becomes more important to good plant growth in relatively shallow soils.

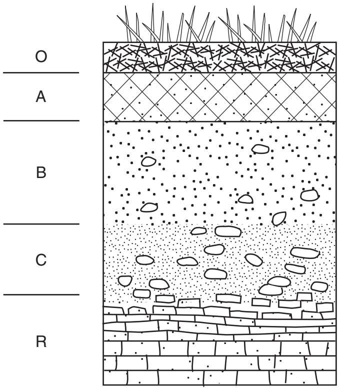


Figure 1.1 Ideal natural soil profile.
Source: Hopper, *Landscape Architecture Graphic Standards*. Copyright John Wiley & Sons, Inc., 2007.

- *R horizon (bedrock)* — The R horizon comprises the consolidated material from which the soil profile may or may not have been derived. Some soil materials have been transported by various agents of erosion and deposited on other existing bedrock.

In the context of urban soils and those on most landscape projects, it is useful to distinguish soils that have been intensively altered from those that retain most of their natural characteristics (with perhaps alteration only to the surface), appearing nearly like the soil profile shown in Figure 1.2. In contrast, the profile of a highly disturbed soil would appear as shown in the figure "Complex Urban Soil," with characteristics that would decrease its capability to sustain the plant palette. In this case, typically, alteration or replacement is required, and installation of a specially designed soil becomes a viable alternative on many projects.

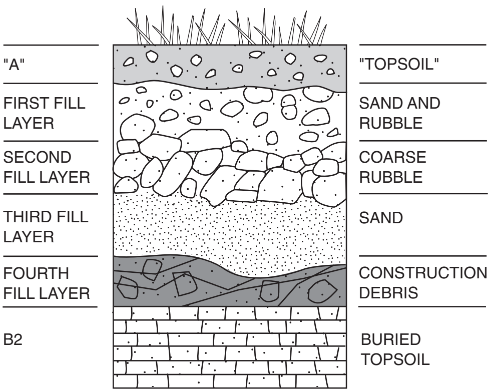


Figure 1.2 Complex urban soil.
Source: Hopper, *Landscape Architecture Graphic Standards*. Copyright John Wiley & Sons, Inc., 2007.

Acceptable Practices

Particle Size Distribution (Texture)

The soil texture or particle size distribution is the most influential physical characteristics of many other soil characteristics, including density and susceptibility to compaction, structure formation, drainage and aeration, and relative fertility. Its overall effects are modified by the presence of organic matter. Therefore, it is the first property of concern in examining existing soils.

Texture is defined and described by the proportion of sand (2 to 0.05 mm), silt (0.05 to 0.002 mm), and clay (< 0.002 mm) particles in the soil. The complete particle size classes are given in Table 1.1, and these form the basis of texture description.

These different soil particles in varying percentages join together to form small clumps of soil called peds. The arrangement of these peds contributes to the soil's structure.

Sand is the largest particle size in soil. Sand is broken down into sub-categories from very coarse to very fine. Sand has an impact on the drainage quality of soils and its resistance to compaction. Soils that contain mostly very fine sands may not drain well, whereas soils that contain mostly very coarse sand may drain so quickly that they can't support the development of a healthy root system. Although sand particles do not bond together, they do combine with silt and clay to

Table 1.1 USDA Size Classes of Soil Mineral Particles

Size Class (Separate)	Diameter Range (mm)	U.S. Standard Sieve Size (No.)
Coarse fragments	> 2.00	—
Very coarse sand	2.00 to 1.00	10
Coarse sand	1.00 to 0.50	18
Medium sand	0.50 to 0.25	35
Fine sand	0.25 to 0.10	60
Very fine sand	0.10 to 0.05	140
Silt	0.05 to 0.002	300
Clay	< 0.002	—*

NOTE
*Determined by sedimentation test rather than sieving.

Source: Craul 1999.

form the soil's structure as well as improve water and nutrient retention important for root development.

Silt particles are the next-largest size particles in soil. Their primary role is to hold water and, to a lesser extent, nutrients and to make them available to plant roots. Silt particles do not bond easily.

Clay particles are the smallest particle size in soils. Clay particles bond easily with nutrients that are made available to the roots and promote plant growth. They also bond with sand and silt to form larger soil particles that together provide good drainage, as well as good water and nutrient retention. Although clay particles alone can retain a significant amount of water, it is not readily accessible to plant roots. Soils that contain 10–30 percent clay are considered desirable for plant growth. The bond between clay peds is not very strong and is easily broken when wet, which can increase the soil's bulk density. Therefore, grading or any moving with heavy equipment of soils containing a significant percentage of clay should not be permitted when the soil is wet.

The USDA-NRCS classification system (see Figure 1.3) categorizes different soil textures according to the percentages of clay, silt, and

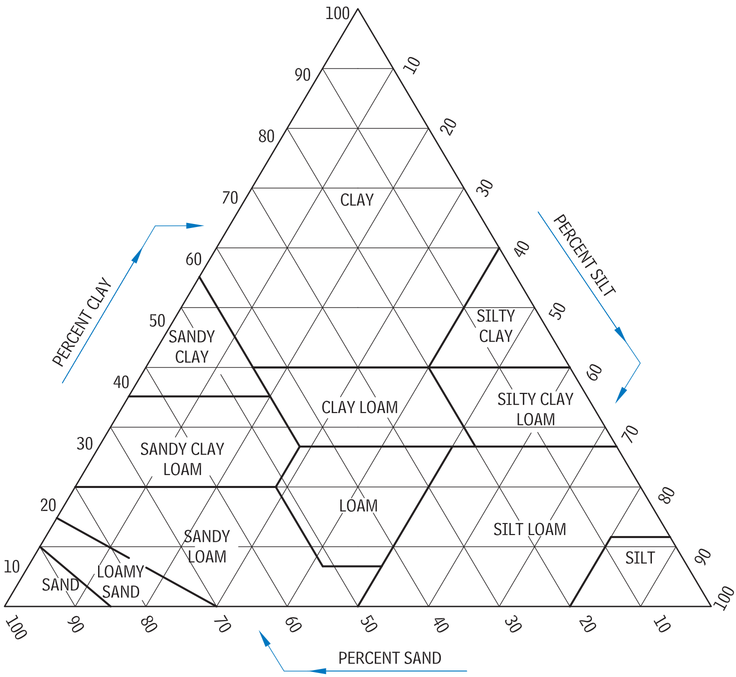


Figure 1.3 USDA's texture classes.
Source: Hopper, *Landscape Architecture Graphic Standards*. Copyright John Wiley & Sons, Inc., 2007.

sand. The name and texture of a specific soil are based on the USDA Soil Texture Classification Triangle. Soils are named based on their texture, such as "sandy loam," "silty clay," or "silt loam." Soils made up of 20 percent or more clay often have "clay" in their names, soils that have 50 percent or more sand have "sand" in their names, and soils that have 40 percent or more silt have "silt" in the their names. Soils that contain all three textures are described as "loam."

The designation "loam" is a texture description and does not necessarily reflect the quality of the soil, as is sometimes thought.

Soils in the lower central area of the triangle are generally considered better agronomic soils. Soils that fall closer to the corners or edges of the triangle have less proportional mixture of all three types of soil textures and are considered less desirable as a growing medium.

Soil Structure

Aided by microorganisms and insects within the soil, the clay, silt, and sand soil particles bond together into larger aggregate particles called peds. The arrangement of the peds and the spaces between them contributes to a soil's structure.

There are five primary types of soil structure:

- *Granular* — Less than 0.5 cm in diameter, these particles resemble cookie crumbs. Generally found in the surface horizons of the soil. These soils provide good drainage and aeration. See Figure 1.4.
- *Blocky* — Between 1.5 and 5.0 cm in diameter, these particles are generally found in subsoil but can sometimes be found in the surface horizons. See Figure 1.5.
- *Prismatic* — Vertical columns several cm long, typically found in the B horizon. The vertical cracks are caused by water and roots moving downward as well as by freeze/thaw and wet/dry conditions. See Figure 1.6.
- *Columnar* — Vertical columns similar to prismatic, but with a distinct cap at the top of the column. These caps, caused by sodium-affected soils or swelling clays, are very dense and are not conducive to root system development. Columnar soils can often be found in the subsoils of arid climates. See Figure 1.7.
- *Platy* — Thin, flat plates that are generally oriented horizontally. Generally found in subsurface soils that have been subject to compaction. This type of soil structure does not allow water to move through easily, and is not conducive to root system development. See Figure 1.8.

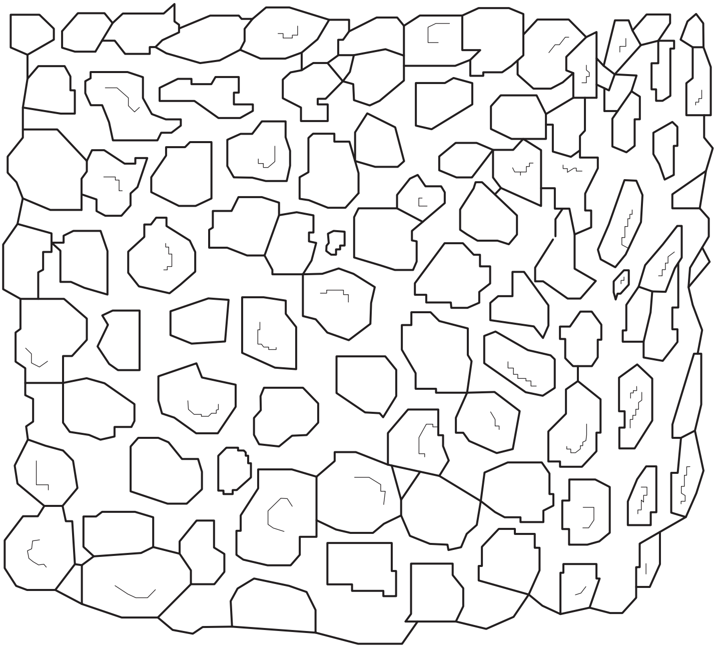


Figure 1.4 Granular Soil Structure.

Figure 1.5 Blocky Soil Structure.

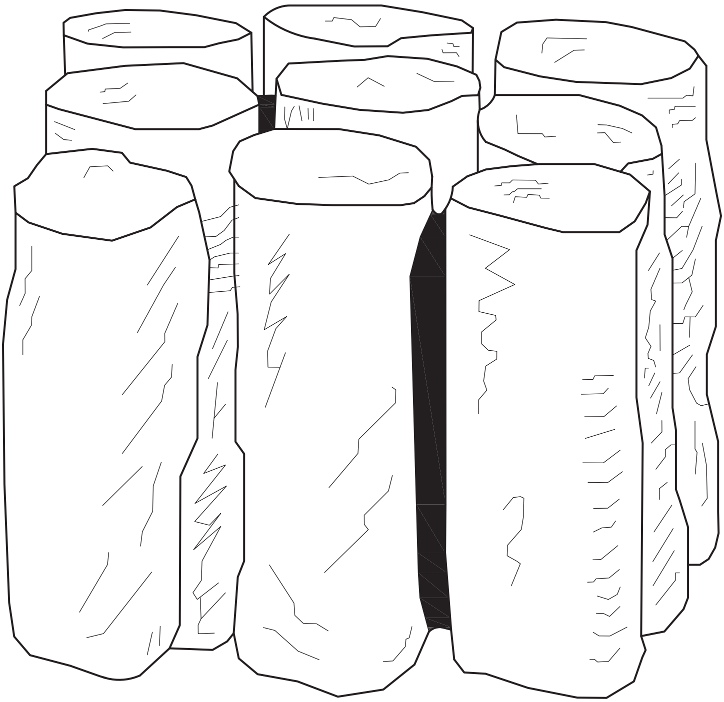


Figure 1.6 Prismatic Soil Structure.

Peds occur naturally in the soil and maintain their structure through cycles of wetting and drying. Soil clods are soil aggregates that are broken into shapes on the surface by actions such as tilling or frost action, and are not considered peds.

There are two soil types that are described as lacking structure. They are:

- *Single grained* — The individual soil particles do not bond together and have a very loose consistency. Most common in sandy soils. See Figure 1.9.
- *Massive* — Soil with no visible structure. One blocklike mass with no aggregation of smaller peds. Often caused by overcompaction that has destroyed the original soil's structure. See Figure 1.10.

Soil Texture and Structure

The combination of texture and structure contributes to soil characteristics that are important to good root system development and plant growth.

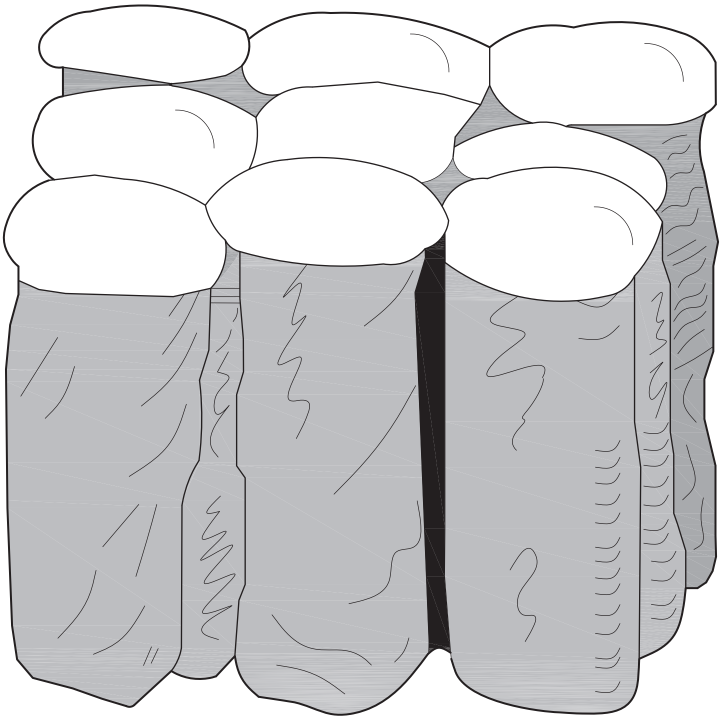


Figure 1.7 Columnar Soil Structure.

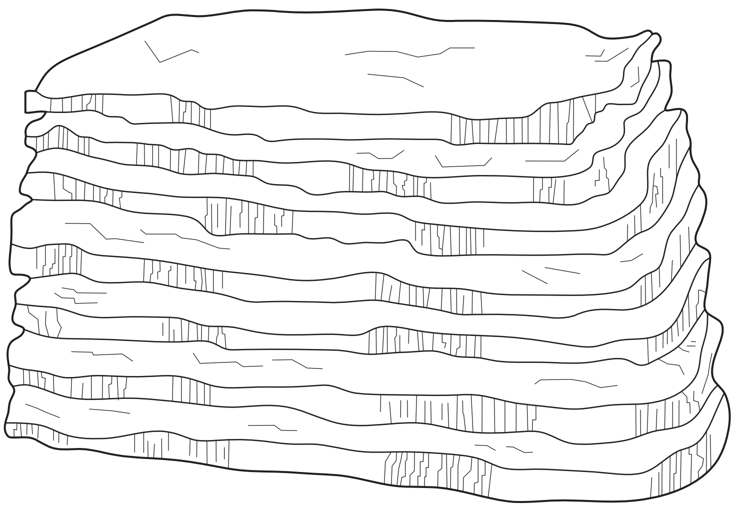


Figure 1.8 Platy Soil Structure.

Figure 1.9 Single-Grained Soil.

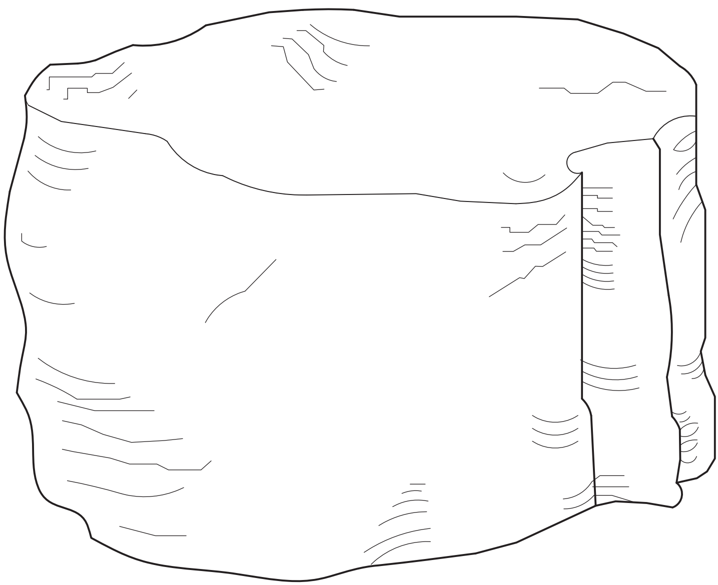


Figure 1.10 Massive Soil.

- Granular soil structures with a loamy texture provide good drainage and aeration, hold water and nutrients, and make them available to a plant's root system.
- Single-grained soils allow water to drain through quickly and lack the ability to hold nutrients necessary for plant growth.
- Dense soil structures, such as platy soils, impede the flow of water and air through the soil and make root system development difficult.

Soils can be amended to improve drainage, aeration, and water- and nutrient-retaining characteristics that would be desirable for root system development and plant growth. (Refer to the "Soil Amendments" section in Chapter 4.)

Macropores and Micropores

In good-quality soil, the peds combine to create void space that accounts for approximately 50 percent of a soil's volume. These voids are classified as either macropores or micropores.

- Macropores are the relatively large interconnected spaces between the peds that allow excess water to drain through freely, with air being drawn in to fill these voids after water has passed through. Soils with large macropores are well drained and have good aeration.
- Micropores are the smaller spaces within the peds that hold water through the forces of adhesion (attraction of water to a solid surface) and cohesion (attraction of water to itself), offsetting the force of gravity that would pull it away.

As pores increase in size, the force of adhesion is weakened and gravity exerts a greater force, drawing the water downward. As pores decrease in size, the force of adhesion becomes greater than the force of gravity, and the water is held within the ped and made available to a plant's root system. When little water remains on the surface of the soil particles, the force of adhesion can be strong enough to prevent the plant roots from drawing the water away.

Ideally, the system of macropores and micropores is balanced so that soil is well drained and aerated as well as retaining water necessary for the plant's root system.

When soils become *saturated*, as in a heavy or extended period of rain, their macropores and micropores are entirely filled with water. As the water drains from the macropores, the remaining water in the micropores makes up the maximum amount of water the soil can hold, which is referred to as the soil's *field capacity*. With the soil at field capacity, water is taken up by the roots through osmosis, and some water at the surface is lost to the atmosphere by evaporation. At the point where the surface tension or adhesion is stronger than the ability of the water to pass through to the roots, the soil has reached its *wilting point*. After the wilting point, no water is made available to the plant's root system, and if this condition remains for an extended period of time, the plant will begin to show signs of drought stress.

The water held between field capacity and wilting point is referred to as *plant available water*.

Different types of soil structures hold different amounts of water at field capacity and wilting point. Larger-particle sandy soils contain a large number of macropores but few micropores, making their ability to provide plant available water very small. Smaller-particle clay soils have few macropores and many micropores. Having fewer macropores results in poor drainage and less oxygen available to the plant roots. The micropores are very small and adhesion force very great, and even when a clay soil contains a significant amount of water, the water is not plant available.

Practices to Avoid

- Do not ignore the importance of soil texture and structure during site assessment. (Refer to the "Soil Assessment" section.)
- Do not allow soil structure to be destroyed during construction. (Refer to the section "Construction Damage to Existing Trees" in Chapter 3.)
- Do not lose the opportunity to improve a soil's ability to sustain healthy plant growth and root system development. (Refer to "Soil Amendments" section in Chapter 4.)

Soil Assessment

Description

It is widely held that the majority of a plant's problems come from the soil where it is planted, and indeed there is a strong consensus among urban horticulturists that soil largely determines the success of a landscape planting. Soil assessment is the most critical part of the site assessment process and is the part that requires the most time.

It is important to understand the physical properties of the soil because they are key to allowing roots to grow and to that all-important balance between air and water in the soil. We also need to understand the depth and usable volume of the soil that is present, as well as its chemical properties. The focus for soils is, then, on volume, physical properties, and chemical properties. The importance of understanding soil, the medium in which all landscape plants grow, even in wetlands, cannot be overestimated.

Assessing Site Conditions

A soil site assessment should include:

- Identifying good soil and integrating approaches to save it for use or reuse. Areas with good soil will be naturally suitable areas for planting. In areas that will be paved, the good soil should be stripped, preserved, and redistributed to planted areas after construction. Do not allow valuable topsoil to be mixed with poor soil or be buried.
- Preventing soil compaction in areas that will be planted. If construction has not yet taken place, planted areas should be marked off and protected from compaction by heavy equipment.
- Identification of other vegetation growing on the site. Every plant has specific soil requirements for good growth. Plants that are thriving can be a good indicator of subsurface soil conditions.
- Collecting soil samples for testing. Soil samples should be taken from different areas of the site to test for soil properties. Samples

should be taken wherever there is reason to believe soil properties are different. More locations should be taken in urban areas, as the soil properties can differ greatly over a site depending on previous development.

Acceptable Practices

Texture

It is possible to test for soil texture in the field. There are a couple of approaches, both that involve taking a soil sample, adding some water, forming the soil into a ball, and then pressing forward between the thumb and forefinger to create a soil ribbon. See Figures 1.11 through 1.16. These field tests are predicated on the fact that soils that contain more silt and clay can be made into a longer, more flexible ribbon than soils with a higher percentage of sand. Soils with a higher percentage of sand will tend to flake rather than form a ribbon.

These tests are relatively easy to perform but do require a bit of practice to master, particularly the squeezing of the soil into a ribbon.

Clayey soils tend to drain poorly; particular attention should be paid to drainage, and generally wet-tolerant plants should be chosen for these types of soils. Sandy soils tend to drain quickly, and if irrigation will not be provided, more drought-tolerant plants should be considered, especially for trees planted within paved areas. Water-soluble nutrients leach quickly in sandy soils; if a fertilization program is not likely to be included in the management of the landscape, species more tolerant of lower nutrient levels and sandy soils should be considered.

Percolation

The tree roots require oxygen to develop and grow. In poorly drained soils, pooling water fills the voids in the soil structure, preventing oxygen from reaching the roots. If information on percolation is not otherwise available, an informal percolation test can be performed as follows:

- Dig a 12″ diameter hole, 12″ deep. Scarify the sides and bottom. See Figure 1.17.
- Cover the bottom of the hole with an inch or two of fine gravel to prevent clogging of the bottom soil.

- If possible, fill the hole with water 24 hours before the test, to saturate the soil (if the soil is dry and that is not possible, fill the hole several times with water before the test).

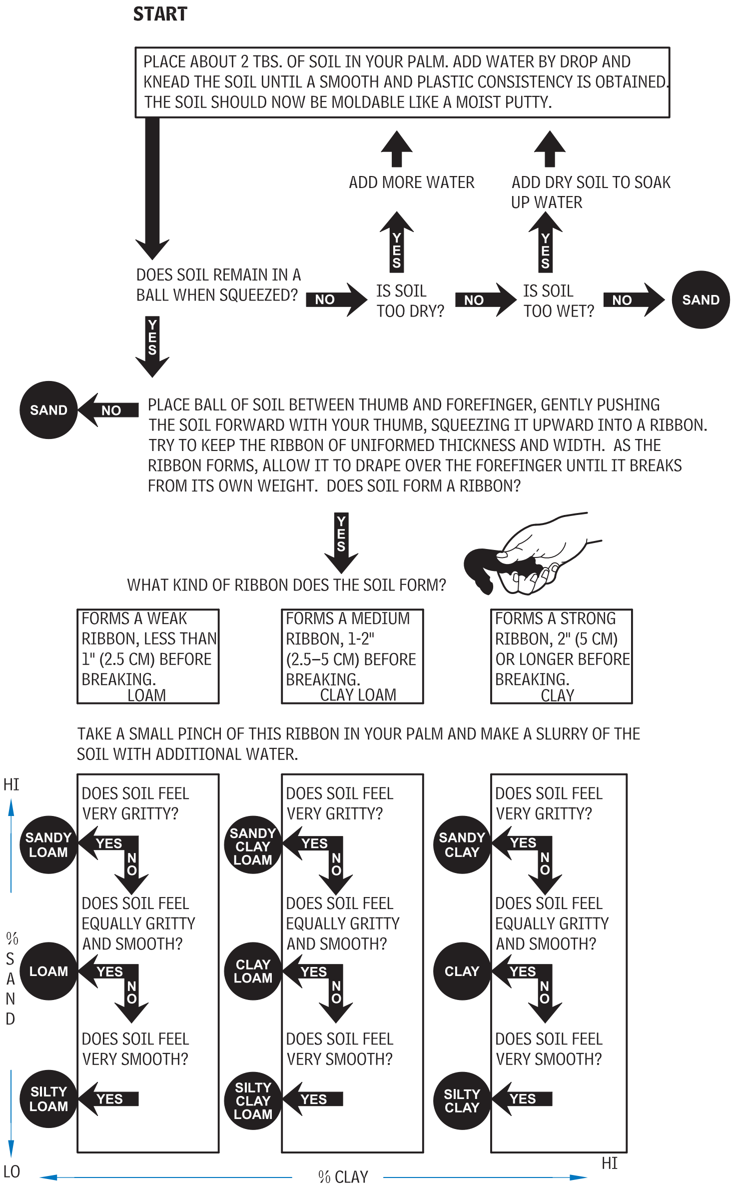


Figure 1.11 Guide to soil texture by feel.

Source: Trowbridge and Bassuk, *Trees in the Urban Landscape*. Copyright John Wiley & Sons, Inc., 2004.

- Wet the area around the hole.
- Fill the hole to the top with water. See Figure 1.18.
- For the test, fill the hole with water and measure the change in level on an hourly basis to determine the percolation rate. See Figure 1.19.

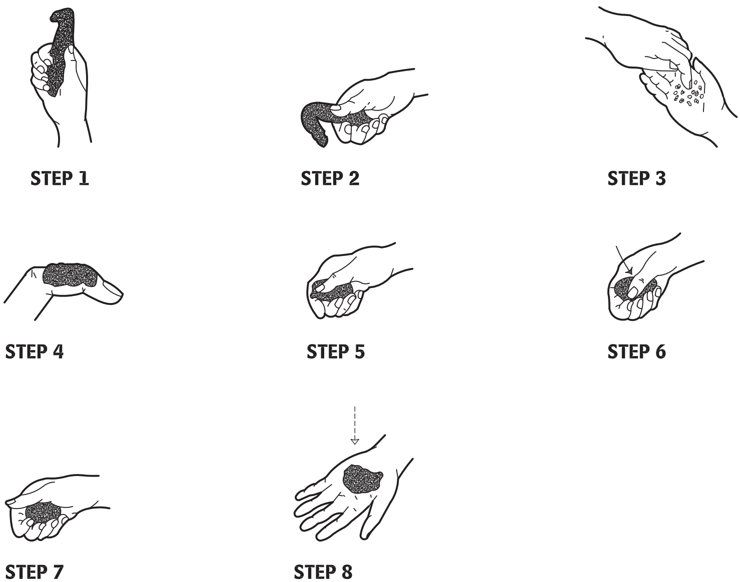


Figure 1.12 Step 1 – After preparing a baseball-sized handful of soil by moistening similar to Figure 1.11, make the thickest ribbon possible straight up in the air (about 1/2 to 3/4 inch thick). Measure length when it falls over.

Step 2 – Make a thick ribbon with your hand pointed sideways. Measure the length when it falls. Take the average of both lengths. For every inch of ribbon assume an 8% clay content.

Step 3 – Feel for sand percentage by smearing a thin layer in your palm and rubbing hard. Estimate sand content to be 10% or less; about 25%; about 50%; about 75%; or about 90%. Reference the textural triangle to identify the texture of the soil.

Step 4 – Examine the ribbon. A smooth shiny surface with no skips or gaps means about 30 percent clay or more.

Steps 5 and 6 – If you can push your thumb into the ball and it feels like pizza dough, it is probably a silty loam.

Steps 7 and 8 – If it is very sandy, make a ball and drop it into your other hand. If it breaks, it is a loamy sand. If it holds together, it is a sandy loam.
Source: Trowbridge and Bassuk, *Trees in the Urban Landscape*. Copyright John Wiley & Sons, Inc., 2004.

Figure 1.13 To start the soil ribbon test, first grab a hand full of soil. Moisten the soil enough so that it will hold together, but not so much that it becomes muddy or runny.

Figure 1.14 Squeeze the soil tightly so that it forms an egg-sized ball.

Figure 1.15 Begin to squeeze the soil out between your thumb and forefinger, forming a ribbon.

Figure 1.16 Try to make a ribbon as long as possible, and check the length at the point where it breaks. Compare the length to the chart.

Figure 1.17 A hole is dug 12 inches in diameter by 12 inches deep, and the sides are scarified.

Figure 1.18 After covering the bottom of the hole with an inch or so of fine gravel, add water to the top of the hole.

Figure 1.19 Check the depth of the water in the hole on an hourly basis, and record the drop in level in inches.

As a general rule of thumb, adequate drainage should register a minimum of a 2-inch drop in water level per hour; a drop of 2–8 inches per hour represents moderate drainage, and a drop of over 8 inches per hour is excessive drainage. If the rate is less than 2 inches, the soil should be amended to improve its drainage characteristics, or a subsurface drainage system will need to be considered. Excessively draining soils should be amended to improve drainage characteristics.

Trees generally do well when planted in well-drained loamy soil. Although some tree species will tolerate wet conditions, trees will not survive in tree pits filled with standing water.

Poorly draining soils often have a foul smell and gray color that can be very noticeable while digging the hole for the percolation test.

In urban or suburban areas, site disruption and the tendency for construction to mix debris, different subsoil types, and good topsoil all together in various compacted layers on the site can impact percolation. These various layers can sometimes be made visible by digging test pits and looking for distinctly different soil layer colors or textures. The separate layer boundaries should be broken down by tilling deep enough to integrate the different layers.

A more formal percolation test can be conducted by using a double-ring infiltrometer (see Figure 1.20). It consists of two open-ended

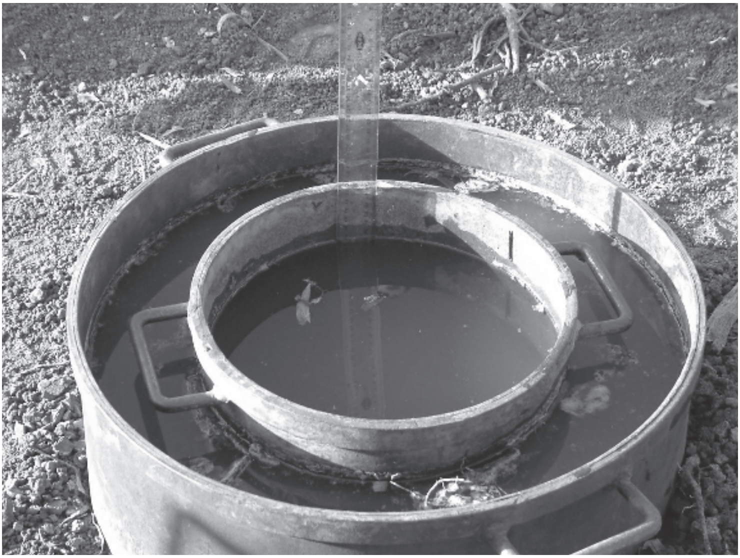


Figure 1.20 Double-Ring Infiltrometer.

metal cylinders that are driven concentrically into the ground and then filled with water (the outside ring should be filled first). The outer ring is 24 inches in diameter, and the inner ring is 12 inches in diameter. The outer ring prevents horizontal flow and encourages only vertical flow from the inner ring. As water drains into the soils, water is added to the cylinders to keep the liquid level constant. Measuring the amounts of water added to the center cylinder over a specified time period allows the infiltration rate of the soil to be calculated. The data collected are plotted on a graph to identify the steady state infiltration rate reached after the soil has become saturated.

Bulk Density

The bulk density of soil is a good indicator of the level of soil compaction. An easy method to determine bulk density is to:

- Weigh a bucket or container large enough to hold a cubic foot of soil.
- Dig an 8-10″-deep by 8-10″ diameter hole with a shovel, placing all the excavated soil in the container. Take care to keep the sides relatively smooth and not disturb the adjacent soil.
- Line the hole with a plastic bag and fill the hole level to the top with water. Measure the volume of water in the bag. See Figure 1.21.
- Completely dry the excavated soil in an oven for a minimum of 8 hours at 200–220 degrees F (or for a quicker result, dry in a microwave for about 4 minutes, then let cool for a minute).

Figure 1.21 Hole is lined with a plastic bag. After the bag has been filled to the top with water, the volume of the water is measured and compared with the weight of the dried soil.
Source: Trowbridge and Bassuk, *Trees in the Urban Landscape*. Copyright John Wiley & Sons, Inc., 2004.

- Calculate the weight of the dried soil by weighing the soil and container together and then subtracting the weight of the container alone.
- Soil Bulk Density = Soil Dry Weight (g)/Soil Volume (cubic cm or ml) Note: The volume of 1 cubic centimeter equals the volume of one milliliter.

Table 1.2 can be used to determine if bulk density indicates that soil compaction levels are too high to promote proper root development and tree growth.

If bulk densities exceed the values in the table, the soil should be amended. See "Soil Amendments."

Soil pH Testing

A pH test is very simple and inexpensive. Kits are available that allow quick tests in the field to be made, providing preliminary pH level data. See Figure 1.22.

Samples should be taken by digging a small hole or using a soil-coring device to about a depth of 12 inches. Mix the soil sample in a clean container before testing or taking it to a lab.

Soil-testing laboratories will often include measures for adjusting pH levels with the test results.

Table 1.2 Critical Bulk Density Values for Different Soil Textures

Soil Texture	Critical Bulk Density[1] Range g/cc[2]
Clay, silt loam	1.4–1.55
Silty clay, silty clay loam, silt	1.4–1.45
Clay loam	1.45–1.55
Loam	1.55–1.65
Sandy clay loam	1.55–1.75
Sandy loam	1.55–1.75
Loamy sand, sand	> 1.75

Notes
1. Bulk densities greater than these values could restrict root growth.
2. Grams per cubic centimeter
* This technique can underestimate bulk density by 3 to 9 percent.

Source: Adapted from Trowbridge and Bassuk, *Trees in the Urban Landscape*. Copyright John Wiley & Sons, Inc., 2004.

Figure 1.22 A field pH test kit allows preliminary data to be determined.

A critical component of the testing is to take enough samples from areas where trees will be planted to account for any differences in soil types. Results can vary over a site, especially where soil color or texture appears different and in developed areas that have been disturbed by construction.

Construction debris can affect pH levels (e.g., concrete left in the soil raises pH levels) and should be removed from the planting site.

Soil Elements

There are three categories of soil elements found in soils:

- Basic nonmineral elements
- Macronutrients
- Micronutrients

These are the three basic nonmineral elements:

- Oxygen (O)
- Hydrogen (H)
- Carbon (C)

Carbon and oxygen are extracted from the air by the breaking down of carbon dioxide (CO_2), and hydrogen is found in the water (H_2O) in the soil. Through photosynthesis, these basic elements are used in large quantities to make starches and sugars for plant structure (most of a tree's weight is made up of carbon atoms).

Macronutrients are dissolved in water and absorbed by the roots to be used for general plant functions. They include the elements most often found in fertilizers (nitrogen, phosphorus, potassium), and they are the first to get the call to correct soil deficiencies, because the plants use large amounts for growth. The application of a fertilizer might provide some short-term benefits, but longer term, adding organic material will address these nutrient deficiencies and improve other qualities of the soil as well. The macronutrients required by plants are:

- *Nitrogen (N)* — Necessary part of all proteins, enzymes, and metabolic processes involved in the synthesis and transfer of energy; part of chlorophyll, the green pigment of the plant that is responsible for photosynthesis; helps with plant growth.
- *Phosphorus (P)* — Essential component in the process of photosynthesis; helps formation of all oils, sugars, starches; helps transform solar energy into chemical energy; encourages blooming and root growth.
- *Potassium (K)* — Absorbed by plants in larger amounts than any other mineral except nitrogen, and sometimes calcium; helps build protein; helps in photosynthesis, fruit quality, and reduction of diseases.
- *Calcium (Ca)* — Essential part of plant cell wall structure; provides for normal transport and retention of other elements, and strengthens the plant as well; mitigates the effects of alkali salts and organic acids.
- *Magnesium (Mg)* — Part of chlorophyll in all green plants and essential for photosynthesis; activates plant enzymes needed for growth.

- *Sulfur (S)* — Essential for protein production; promotes activity and development of enzymes and vitamins; helps in chlorophyll formation; improves root growth; improves plant's resistance to cold.

Micronutrients are used by plants for specialized functions. They are required in relatively small quantities, and therefore are not usually added to soils. Some of these elements can be present in high enough concentrations to be detrimental in urban areas, where there are remnants of previous industrial activity on the site. If previous industrial activity is known or suspected, the soil should be tested to ensure that this is not the case (and that no other hazardous materials are present). Micronutrients required by plants are:

- *Boron (B)* — Aids in the use and regulation of other nutrients; helps in production of sugar and carbohydrates; essential for seed and fruit development.
- *Chlorine (Cl)* — Helps in metabolism.
- *Cobalt (Co)* — Aids in shoot development and growth.
- *Copper (Cu)* — Important for reproductive growth; helps root metabolism and utilization of proteins.
- *Iron (Fe)* — Essential for formation of chlorophyll.
- *Manganese (Mn)* — Functions with enzyme systems involved in breakdown of carbohydrates and in nitrogen metabolism.
- *Molybdenum (Mo)* — Helps in the use of nitrogen.

Fertility

Fertility is the soil's ability to store nutrients and make them available to the plant's root system. Soils hold elements and nutrients by a process called cation exchange. Cation exchange is the attraction of positively charged elements to the negatively charged soil particles. The number of these soil particles and their ability to attract and hold these elements is referred to as cation exchange capacity (CEC).

The quantity of positively charged elements the soil can hold is based on the surface area of the soil particle. Clay particles are the smallest soil particles with the greatest surface area compared to their volume. Therefore, clay soils provide the best nutrient-holding capacity. Well-decayed organic matter particles, with their irregular, complex surface characteristics, provide good nutrient-holding capacity. The larger, smoother silt particles hold less, and sand particles have very little nutrient-holding capacity.

Clay and organic matter have the highest CEC and are therefore considered good components of a fertile soil. Soils with large percentages of sand, which have a low CEC, are considered less fertile. Because it is difficult to mix clay into a soil, mixing organic material into a soil to improve fertility is the preferred approach. Soil should be tested for percentages of clay and humus—the more of each, the more fertile the soil.

Organic material should be replenished regularly, to keep the fertility level high.

Plants are sensitive to changes in soil nutrient levels. Even small changes can affect plant health and manifest themselves in visible distortions of leaves, color, and branches. If fertilization or other regular amending of the soil is discontinued, soils have a tendency to revert back to their original nutrient levels. Therefore, it is always best to choose plants that are matched to the original soil characteristics.

The soil's pH level also affects a plant's ability to absorb nutrients (see Figure 1.23). Soil tests may show that nutrients are present in the soil, but that the plants are unable to absorb them because of the soil's pH level. Most plants are somewhat tolerant of a soil with a higher pH—as opposed to a lower pH—than that preferred by the plant. A soil's pH is a product of its parent material, surrounding environment, and

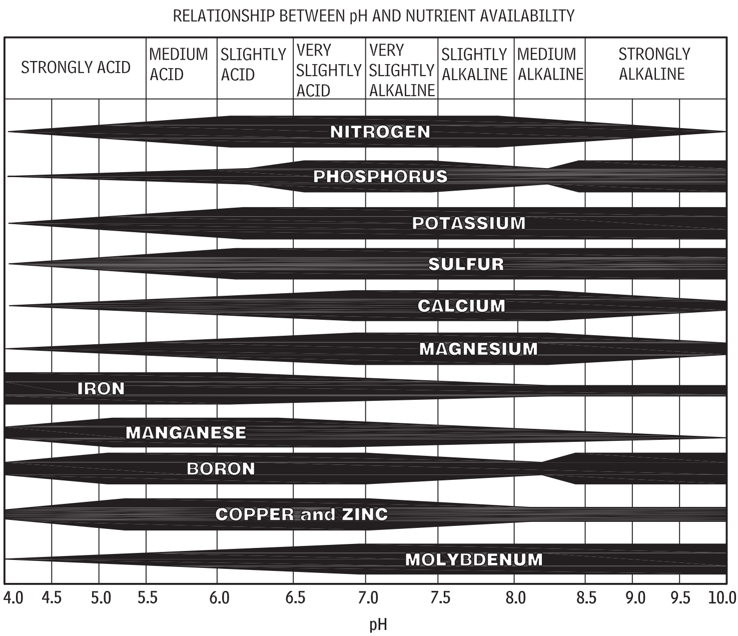


Figure 1.23 Specific nutrients' availability to a plant is dependent on the pH of the soil.

Source: Trowbridge and Bassuk, *Trees in the Urban Landscape*. Copyright John Wiley & Sons, Inc., 2004.

precipitation rate. It is difficult to effect long-term change in pH; therefore, it is always better to choose plants whose preferred pH range is a match to the soil's original pH level.

See the sections "Soil Amendments" and "Site Considerations and Tree Selection" in Chapter 4.

Organic Matter and Humus

Humus is produced by the decomposition of organic material that accumulates on the soil surface, such as leaves, branches, and lawn clippings. As this material decomposes, it is integrated into the top layer of soil by water, insects, and earthworms. The soil's humus content affects soil structure, porosity, moisture, and drainage.

Humus is often added to sandy soils to improve texture, water storage, and nutrient retention. Added to clayey soils, it can improve aeration and drainage. However, humus will need to be replenished as the existing material continues to decompose. If this is not likely as part of a maintenance plan, then selection of plants that are matched to the soil's existing organic content level should be considered.

In the field, digging a test pit about a foot or so deep to expose the "A" soil horizon can give a good indication of a soil's humus content. Soils with high organic content look rich and dark. In contrast, compacted soils or lighter sandy soils contain less organic material and are therefore considered less fertile.

Soil Salinity

High salt levels in soil dry out tree roots, making it difficult for a tree to grow or even survive. Trees may be subjected to high soil salt levels if planted in coastal areas (airborne salt spray) or adjacent to pavements likely to receive deicing salts (sidewalks, roadways, parking lots), or irrigated with well water that may have high salt levels. Soils in these areas should be tested for sodium levels and sodium absorption ratios. (See "Site Considerations and Tree Selection" for more information.) If conditions exist that represent potential salt problems, have the soil tested.

Electrical conductivity (EC) is used to measure salt content. The typical unit of measurement of how well electricity is conducted is micromhos per centimeter (mmhos/cm). This unit is derived from the typical unit of resistance, the ohm. Because conductivity is the opposite of resistance, the name of this unit is based on ohm spelled backward. A reading of zero indicates no electrical conductivity. There are many different kinds of salt, and the electrical conductivity test will provide the levels of salinity but not the type of salts present.

Soil salinity level test results per centimeter affect plant consideration as follows:

- *0–2 mmhos* — Low level, not a consideration in plant selection.
- *2–4 mmhos* — Plants sensitive to salt conditions will be affected.
- *4–8 mmhos* — Moderate salt levels that will affect many plants.
- *8–16 mmhos* — High salt levels; only salt tolerant plants should be considered.
- *Over 16 mmhos* — Indicates very high soil salinity that few plants will tolerate.

If well water is used for irrigation, have it tested. If the irrigation water conductivity is above 1 mmhos per cm, it may be contributing to poor plant growth and salt buildup in the soil.

Soil salinity levels can change significantly throughout the year. In areas where deicing salts have been used, salt levels can be extremely high in early spring. These levels can be significantly reduced if taken after a rainy spring when the soil has leached to lower levels. It would therefore be advisable to test for soil salinity in the early spring before salt levels are affected by spring rains.

Moisture

Some plants tolerate a broad range of moisture levels in the soil, while others prefer very specific moisture conditions. Although irrigation can help plants that require more moisture than conditions can provide, it is advisable to select plants that match the existing soil moisture condition.

If possible, try to make field visits at different times of the year and during different weather conditions, to note where drainage appears poor or where soil seems to drain well. Take particular note of low-lying areas or areas that are at the base of a slope; they tend to be wetter than areas that are at higher elevations. Look for plant species that like wet conditions or those that prefer dry conditions; they can be a good indicator of soil moisture. Be guided accordingly in your planting location and species selection.

Soil Life

The presence of a broad spectrum of organisms in the soil indicates a healthy soil environment. Bacteria help decompose organic matter, earthworms integrate humus from the surface into the top layer of soil, and mycorrhizal fungi form symbiotic relationships with roots to help them absorb water and nutrients, to mention just a few of the beneficial qualities of soil life.

In the field, dig down and look for earthworms, insects, or white threadlike strands of fungi that would indicate a healthy soil. If none is found, investigate other possible causes of poor soil quality. In some soils, such as sandy soils, there may be beneficial microorganisms that cannot be seen.

Distance to Water Table

If a site has a shallow water table, trees that tolerate wet conditions should be considered. The distance to the water table often varies during the year. It might be several inches below the surface in the cooler season and drop several feet in the growing season because transpiration pulls it from the soil. If possible, test holes should be dug at different times of the year to avoid drawing incorrect conclusions.

Test pits or auger holes should be dug down to three feet. If any water appears in the hole over a three- to four-hour period, only trees that tolerate wet conditions should be considered. If water fills the hole to within 18 inches of the surface, moderate-sized trees should be considered, as larger trees will not be able to develop the deep anchoring roots to make them stable. See Figure 1.24.

In some cases, it may be possible to add a layer of stone beneath the root ball to keep it elevated above the water level (see Figures 1.25 and 1.26). This can keep water draining away from the root ball and allow root development in the soil above.

Depth to Bedrock

Minimum depth to bedrock, impervious horizon, or infrastructure surface such as an underground rooftop, should be at least 24 to 30 inches for most planting designs. A depth of 36 inches is nearly ideal for most situations.

Hazardous Materials

No known contaminants should be present anywhere within the profile or within the subbase below; otherwise, HAZMAT cleanup is required, unless the Environmental Protection Agency (EPA) and the appropriate state office have issued certificates of cleanup or isolation, and acceptance.

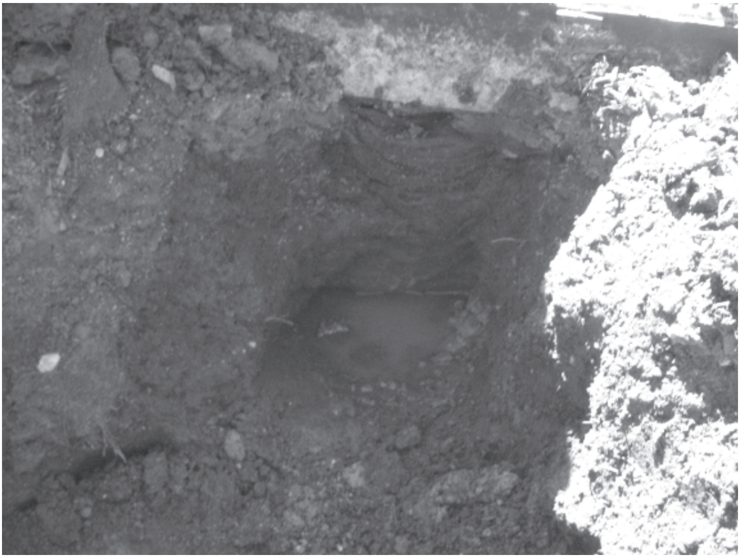


Figure 1.24 This tree pit fills with water as it is being dug, indicating a high water table and/or poorly drained soil.

Figure 1.25 After determining the water level, place a layer of stone on a geotextile fabric to elevate the root ball so that it is sitting above the water level.

Figure 1.26 The root ball is set on the stone with the tree flare slightly above the surrounding grade, keeping the root ball as high as possible.

Practices to Avoid

Avoid soils with coarse fragments (stones and/or building rubble). If present, they should be less than 2 inches in diameter and less than 25 percent by volume within 24 inches of the soil surface. Coarse fragments may increase with depth but should not exceed the limit. Remove excess coarse fragments by employing a rock rake after the stony soil has been loosened with a chisel plow or a spade tiller; adding sufficient stoneless, specified soil to the surface to provide an adequate depth of planting medium for the desired plants is another alternative, and is probably the least expensive. However, in extremely stony situations, the interface between the nonstony and stony material may create restricted rooting. For very stony areas, a planting design of simple scattered plants would require the removal of stones only in the planting pits. This technique is commonly employed in stony desert regions; usually, soil must be supplemented in the planting pits.

Designed Soil Mixes

Description

On sites that have very poor soil or damaged soil structure, or that have been disturbed by previous development, designed soil mixes can be used to restore the soil's ability to support healthy plants. Designed soil mixes can improve soil aeration, water storage, nutrient-holding capacity, and drainage.

Importing topsoil from undeveloped sites to be used on a project is discouraged and is not considered a sustainable approach. The Sustainable Sites Initiative's Guidelines and Performance Benchmarks further state:

- Imported topsoils or soil blends designed to serve as topsoil may not be mined from:
  - Soils defined by the Natural Resources Conservation Service as prime farmland, unique farmland or farmland of statewide importance
  - Other Greenfield sites, unless those soils are a byproduct of a construction process
- Soils must be reused for functions comparable to their original function (i.e. topsoil is used as topsoil, subsoil as subsoil, or subsoil is amended to become functional topsoil).

Proper design emulation of an appropriate local natural soil suitable for the desired plant palette ensures sustainability to the plant palette and the overall landscape design. Components of a designed soil may be recycled by-products such as composted organic materials, waste sand or ground glass as a sand substitute, tailings from stone quarry washers as silt and clay substitutes, and many others yet to be devised.

Designed soil mixes can be uniquely developed for very specific landscape uses such as high-use turf areas, steep slopes, wetlands, bioretention, planting over structure or on roofs, and meeting the soil requirements for planting beds.

Assessing Site Conditions

Designed soil mixes can be considered on projects where the site's existing soil cannot perform the functions that are required for the proposed design. Some of the most common (and interrelated) existing soil conditions that can be modified with a designed soil mix are:

- *Compaction* — One of the most common and difficult existing soil conditions that require modification if vegetation is to thrive. Compacted soils usually have poor drainage characteristics, reduced aeration capacity, and densities that inhibit root growth.
- *Bulk density* — Inhibits root growth into the denser soils immediately outside the planting pit.
- *Damaged soil structure* — Damage to soil peds, macropores, and micropores results in poor drainage and aeration, and prevents root growth.
- *Poor drainage* — Excessively wet or saturated soils deprive plant roots of necessary oxygen.

The soil texture or particle size distribution is the physical property that has the greatest influence on many other soil properties, including density and susceptibility to compaction, structure formation, drainage and aeration, and relative fertility. Its overall effects are modified by the presence of organic matter. Therefore, it is the first property of concern in examining existing soils, or the first criterion considered for designing a soil.

See the sections "Soil Overview" and "Soil Assessment" in this chapter for additional information.

Acceptable Practices

When the existing soil material has been drastically altered or is totally unsuitable, then a designed soil mix should be considered for restoration. The overall goal is to return the soil to a condition that enables it to perform desired functions suitable for one or more land uses.

Design of a General Soil Profile

Designed soils are not necessarily natural soils, nor do they yet fit into the accepted USDA Soil Taxonomy; therefore, the following specifications are given to provide an arbitrary horizon designation system (Craul 1999):

- *S1: topsoil* — A medium loamy sand amended with mature composted organic matter to a content of 10 percent by weight.

Table 1.3 Range in Percent Passing Sieve Sizes for S2 Subsoil and Organic Amended S1

Sieve Size	Percent Finer
#10	100
#18	88–100
#35	70–80
#60	40–50
#140	29–39
#300	25–35
Silt range	10–30
Clay range	5–15

Source: Craul 1999.

- *S2: subsoil* — A medium loamy sand (USDA) conforming to the following specifications, which may contain 1 to 2 percent organic matter by weight (refer to Table 1.3). The range of silt should be within 10 to 30 percent, and the range of clay should be within 5 to 15 percent.
- *S3: drainage layer* — A gravelly sand (AASHTO #4) that provides a high rate of water flow from the bottom of the soil profile to the underdrainage system.

The table of percent passing for the stack of sieve sizes (Table 1.1) and the particle size envelope (see Figure 1.27) for each designed soil or for each separate horizon, where distinct horizons are required for a unique soil profile (for example, the S3 layer in the horizon designation system in Table 1.4), should always be provided in the specifications, for clarity and to ensure that the testing laboratory and landscape contractor receive the necessary information. It is also valuable and necessary data for such applications as rooftop projects and those involving slope stability and the like. Estimates of bulk density are also necessary, although not graphically represented.

Organic Matter

Organic matter is a very important component of soil, whether natural or designed. Design guidelines are as follows:

- The organic matter in natural soil is formed there as the result of soil formation and evolution, and the content may be determined by ASTM tests.
- Organic matter content and type must be specified as a component for designed soil.

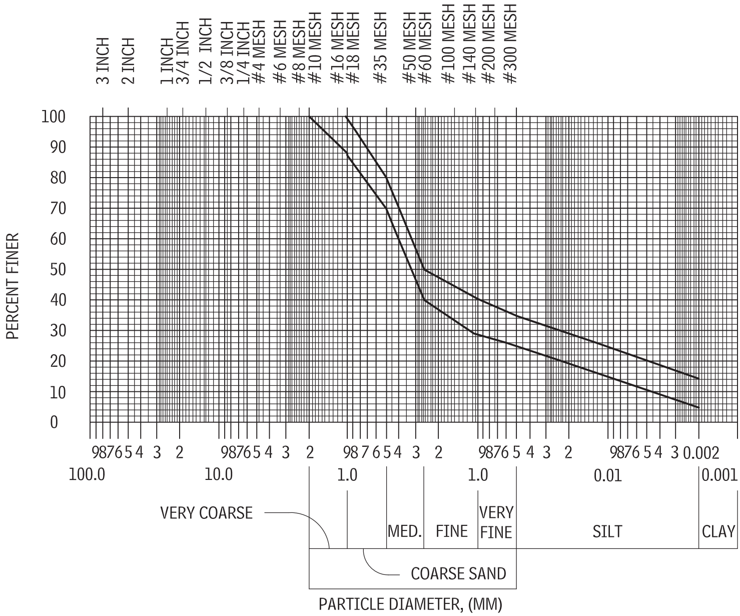


Figure 1.27 Particle size distribution envelope for the S2 subsoil loamy sand. *Source:* Hopper, *Landscape Architecture Graphic Standards*. Copyright John Wiley & Sons, Inc., 2007.

- Peat moss is no longer recommended as a soil amendment, in light of LEED and Sustainable Site Initiative Guidelines and provisions.
- Composted biosolids have become a preferred source of organic matter amendment. Problems of uniformity in processing and

Table 1.4 Range in Percent Passing for AASHTO Aggregate #4 *Frequently Used as S3 Drainage Layer

Particle Size Class	Sieve Size	Percent Passing
Medium gravel	3/8″	100
Fine gravel	#4	95–100
Very fine gravel	#8	80–100
Very coarse sand	#16	50–85
Coarse sand	#30	25–60
Medium sand	#50	10–30
Fine sand	#100	2–10
Silt + clay**	—	1–2

Notes
*Sometimes called "highway sand."
**Determined by hydrometer method in ASTM F-1632.

meeting specifications have been overcome, and formulations are now more or less standardized. Availability is no longer a problem.

Experience has shown biosolids to be a very good source of organic matter, with reliable and acceptable field results when properly composted and installed. That said, problems have been encountered with excessively high pH values of alkaline-slaked biosolids, which should therefore be avoided.

Specifications for composted biosolids are as follows:

- *Carbon: nitrogen (C:N) ratio* — This should be in the range 10:1 to 25:1.
- *Stability* — The three tests for stability are:
  - Dewar self-heating test: Maximum heat rise <20°C above room temperature (of 20–25°C)
  - CO_2 evolution test: <1.5% carbon/day
  - O_2 respiration test: <0.8 mg/g VS/hr

Thus, per Table 1.5, only Classes IV and V are acceptable for mixing. The larger the number, the greater the degree of stability. Too often, contractors have delivered composted biosolids at a stability level of III or less.

- *Odor* — Compost has no unpleasant odor. Any odor of ammonia indicates that the compost is immature (Class III or less) and should not be applied until cured to mature (Class IV or V) stage.
- *Mineral/organic content and fineness* — Compost must contain more than 40 percent organic matter (dry weight), and 100 percent should pass a half-inch (13 mm) or smaller sieve. Debris (metal, glass,

Table 1.5 Four Levels of Stability/ Maturity by the Dewar Test

Stability Evolved Class	Stability Description	Temperature Rise	O_2 Evolved CO_2	
			MG/G VS/HR	Percent Carbon/Day
V	Very mature compost	0–10°C	< 0.5	< 0.8
IV	Maturing, curing compost	10–20°C	0.5–0.8	0.8–1.5
III	Material still decomposing	20–30°C	0.8–1.2	1.5–2.0
II	Immature, active compost	30–40°C	1.2–1.5	2.0–2.5
I	Fresh, very raw compost	40–50°C	> 1.5	2.5–3.0

Source: Switzenbaum, Craul, and Ryan 1996. Stability classes originally developed by Woods End Research Laboratory 1995.

plastic, wood other than residual chips) content should not exceed 1 percent dry weight.

- *Reaction (pH)* — This must be in the range of 5.5 to 8.0.
- *Salinity* — Soluble salts should not exceed 4.0 mmhos/cm (dS/m) or 2,560 ppm salt.
- *Nutrient content* — Nutrient content should be stated, giving: nitrogen, phosphorus, potassium, calcium, magnesium, sodium, and micronutrients, including iron, copper, boron, manganese, and molybdenum.
- *Heavy metals/pathogens/vector attraction reduction* — All these must meet the provisions of the 40 CFR Part 503 rule (EPA CFR, Part 503 Regulations, Table 3, page 9392, Vol. 58, No. 32, Friday, Feb. 19, 1993, *Federal Register*).

For a general topsoil specification, organic matter content may be 5 to 10 percent dry weight; for a subsoil, it should be from 1 to 3 percent dry weight. The values given here may appear to be low; however, these are weight basis. Approximate volume values are obtained by multiplying the dry weight by 2.2. It must be kept in mind that these values are to be used in mixes for landscape soils. Most people confuse the values with those for potting mixes, which always contain greater amounts of organic matter.

Blended Soils

Blended soils use natural topsoil as one component in the mix, which serves to limit the amount of topsoil used and conserve this valuable natural resource. Blended soils are composed of varying proportions of:

- *Natural topsoil* — Contributes silt, clay, and organic matter to the blended mix.
- *Uniform particle sand* — Contributes to the soil structure of the blended mix, including resistance to compaction.
- *Compost* — Provides organic matter to the blended mix.

Blended soil mixes for some typical uses include:

- *High-use lawn soils* — 3 parts sand; 1.5 parts topsoil; 1 part compost.
- *Passive lawn soils* — 2 parts sand; 1.5 parts topsoil; 1 part compost.
- *Planting beds* — Top layer of equal parts sand, topsoil, and compost; subsoil layer of equal parts sand and topsoil.

Overview of Mixing Procedures

At first, mixing the components in large quantities and ensuring a complete mix can be overwhelming (see Table 1.6). Fortunately, equipment and techniques are available on- or off-site to accomplish mixing

Table 1.6 Guide for Mixing Soil Components

Mixing Method	Comments and Cautions
Machine mixing	The most efficient method is by ball mill or tub mixer for large volumes. May be processed on- or off-site. Problem is variation among batches: Close inspection and frequent sampling is required. Usually not weather-dependent.
Windrowing	Appropriate for medium to small volumes. May be done on- or off-site but requires a large, dry, flat, solid surface; not on gravel or loose soil. Dry, compacted soil may suffice on approval by the landscape architect or the project soil scientist. Uniformity of mixing depends on the skill of the windrow equipment operator. Not recommended for large quantities, as it is very difficult to achieve thorough mixing as required in the specifications. Frequent inspection required. Weather-dependent and should be done when the materials are moist, not wet or dusty.
Spreading and mixing on-site	This method depends on the location (access), slope gradient, and general configuration of the site. Should not be used on slopes greater than 2:1. Cannot be used in very confined sites. Primary mixing machine is the tractor-mounted rototiller; the hand rototiller is too light for most applications. Weather-dependent and should be done when the materials are moist, not wet or dusty.

in an appropriate manner for any mixing volume (Switzenbaum, Craul, and Ryan 1996).

Testing

To ensure proper soil design function it is imperative that each soil component be clearly specified and tested before installation, and further tested as a system after installation for conformance and proper function. Close scrutiny throughout the entire project process is always required, as many contractors are not yet familiar with detailed soil specifications and the required testing for landscape projects.

ASTM standard tests and interpretation of results include the following:

- F-1632-03: Standard Method for Particle Size Analysis
- F-1815-97: Standard Method for Saturated Hydraulic Conductivity, Water Retention, Porosity, Particle Density, and Bulk Density
- F-1647-02a: Standard Method for Organic Matter Content of Putting Green and Sports Turf Root Zone Mixes
- D-3385-03: Standard Method for Infiltration of Soils in the Field Using Double Ring Infiltrometer

- D-4221-99: Standard Method for Dispersive Characteristics of Clay Soil by Double Hydrometer

Method F-1815-97 is the most appropriate general all-around test for the major physical characteristics of soil.

For composted biosolids, if used as the organic matter source, the maturity test showing "mature" or "maturing" is absolutely necessary; "immature" is unacceptable (see the "Organic Matter" section earlier in this chapter for further details).

For the chemical properties of pH, nutrient content, soluble salts, and organic matter content, the tests and interpretations performed by the appropriate state agricultural experiment station are valid and should be used. If the existing or designed soil does not exhibit the appropriate chemical characteristics for the plant palette, then amendments are required to adjust them accordingly.

The landscape architect should always confirm that the soil materials delivered to the site are the same on which the tests were performed; thus, samples must be obtained from the bulk deliveries and tested again. Most laboratories can provide quick turnaround service (at extra charge) to facilitate installation.

Overview of Installation

Soil placement during installation requires following the appropriate soil mechanics procedures with respect to compaction of the soil. Close supervision of the soil installation process by the landscape architect or the soil scientist, if one is retained for the project, is absolutely necessary. See Chapter 3, "Earthworks," for more information.

Installation activities include:

- Proper inspection and sampling for tests of delivered soil materials.
- Supervision of soil placement in lifts to the proper degree of compaction.
- Prevention of excessive traffic over the placed soil.
- Proper sequencing of planting with soil placement, to greatly reduce disturbance to the placed soil.

The best practice is simultaneous placement of the topsoil and plants, if feasible. Contractors have stated that this practice has saved them time—hence, money. It also eliminates unwanted traffic over the topsoil final grade.

Practices to Avoid

Some contractors attempt to bypass adhering to the specifications by inflating the estimated costs of the specified soils and then offering the client the contractor's own lower-cost materials. Be aware that substitutions of this type can lead to soil design mixes that do not meet the requirements of the project.

References

ALSO IN THIS BOOK

"Topsoil Preservation, Stripping, and Stockpiling"; "Construction Damage to Existing Trees"; and "Spreading and Grading Topsoil".

OTHER RESOURCES

American Society of Landscape Architects, the Lady Bird Johnson Wildflower Center and the United States Botanic Garden. *The Sustainable Sites Initiative-Guidelines and Performance Benchmarks 2009*. www.sustainablesites.org.

Craul, P. J. *Urban Soil in Landscape Design*. New York: John Wiley & Sons, Inc., 1992.

Craul, P. J. *Urban Soils: Applications and Practices*. New York: John Wiley & Sons, Inc., 1999.

Craul, T. A., and P. J. Craul. *Soil Design Protocols for Landscape Architects and Contractors*. Hoboken, NJ: John Wiley & Sons, Inc., 2006.

Hopper, Leonard. *Landscape Architectural Graphic Standards*. Hoboken, NJ: John Wiley & Sons, Inc., 2007.

Pine, Robert. *Specifying Soils for Complex Landscapes*. PowerPoint Presentation. ASLA, Chicago 2009.

Switzenbaum, M.S., P.J. Craul and T. Ryan. "Manufactured Loam Using Compost Material Phase 1: Feasibility." Final Report. Amherst, MA: University of Massachusetts Transportation Center, 1996.

Trowbridge and Bassuk. *Trees in the Urban Landscape*. Hoboken, NJ: John Wiley & Sons, Inc., 2004.

"Soil Science Education Home Page." Soil Structure and Images. 15 December 2010. NASA. 22 April 2011. http://soil.gsfc.nasa.gov/pvg/prop1.htm.

Urban, James. *Up By Roots*. International Society of Arboriculture, Champaign, IL, 2008.