

URBAN SOILS

Part 1: Understanding Compaction



By James R. Urban

We are pleased to present a three-part series of excerpts from ISA's upcoming book, *Up By Roots: Healthy Soils and Trees in the Built Environment* by noted landscape architect Jim Urban.

This excerpt discusses soil compaction.

The natural soil-forming process tends to create soil that is at suitable levels of compaction (or, to use the scientific term, bulk density) for ground stability and the growth of some kind of plants. Few natural places exist where the soil bulk density is so high that plants will not grow.

Human activity tends to change the compaction level in the soil, most often making it more compact, but sometimes reducing its compaction. Identifying compaction levels in the soil and when they need to be modified is a critical step in creating good growing conditions.

As soil becomes mechanically compacted, the organic bonds that were holding the soil structure are broken, and soil particles are pushed together, filling the pore space. Think of what would happen if you stepped on a bag of popcorn. Your foot would crush the fluffy kernels together, and the spaces between them would be difficult to re-create.

The same goes for soil. As pore space is eliminated, space for air and water is lost, and roots must push harder to get through the soil. The plant has access to less water and grows fewer roots in the more difficult conditions.

Pore Space

In a good-quality natural soil, the minerals normally make up about 50 percent of soil volume. An additional portion, less than 5 percent, is organic matter ranging from bacteria and insects and their excretions to roots and pieces of decaying plants.

The remaining soil volume, almost half, is pore space within the soil structure. The pore space is filled with a combination of air and water, with the proportion dependent on current weather. The pore space devoted to the interchange of air and water in the soil is critical to plant growth. Figure 1 shows the relationship of the various components of natural soils and how changes in compaction can change this balance.

Soil Types and Compaction Response

Soil texture has a significant impact on the ability of a soil to become compacted to the point where it limits water and/or

root penetration. Because there are infinite variations on soil texture, it may be easier to look at soil from the perspective of a soil engineer rather than an agronomic soil scientist. In this less complicated view, soil textures can be divided into just four basic types based on their different compaction responses in constructed landscapes (Figure 2):

- **Coarse-grained soil:** Mostly large sand particles. May retain significant pore space even when compacted.
- **Fine-grained soil:** Mostly clay silt and fine sands. May have very few usable pore spaces when compacted.
- **Fine-graded or even-graded soil:** Even distribution of particles across most of the particle size range from coarse to fine. There is a particle size to fill every size pore. These soils may be self-compacting or at least are easily compacted. Engineers treasure fine-graded soils for their ability to be easily compacted, and they often import them onto a construction site for controlled fills.
- **Gap-graded or poorly graded soil:** Contains both fine and coarse particles but without some of the intermediate-sized particles. These soils tend to be compaction resistant and may retain large pores. They may not become root limiting, even at fairly high compaction rates. Gap-graded soils are not prevalent in nature and usually are manufactured.

Compacting Forces

Soil compaction starts with the first person who walks on the soil. One person walking on a path once a day for 100 days adds the same amount of compaction to the path as 100 people walking on the path on the same day, assuming the water content in the soil is the same each day. Water lubricates the soil particles and makes

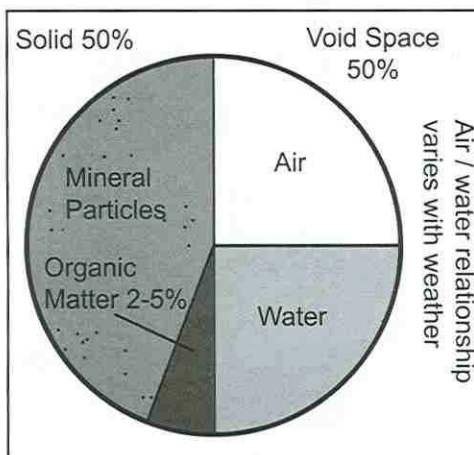


Figure 1a. Composition of ideal forest soils.

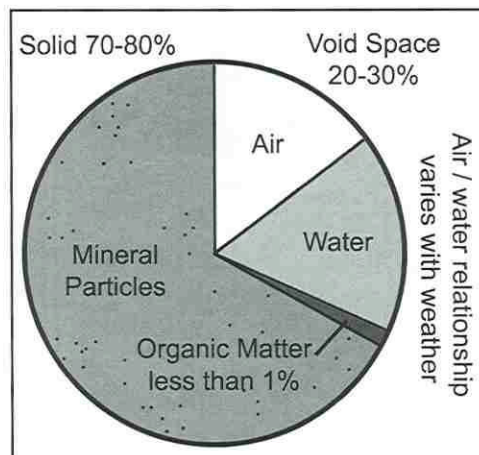


Figure 1b. Composition of urban soils.

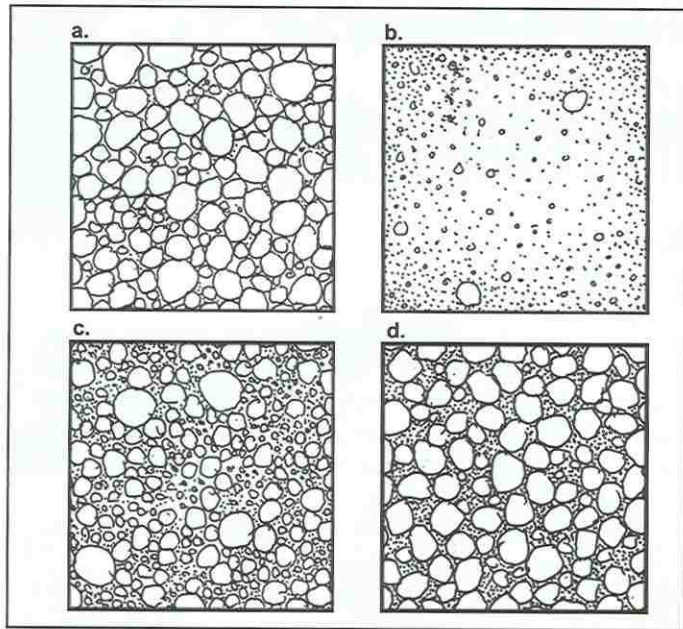


Figure 2. Soil textures. (a) coarse-grained. (b) fine-grained. (c) fine-graded or even-graded. (d) gap-graded or poorly graded.

them easier to push together. So, one person walking on a path on 100 rainy days will cause more compaction than 100 people walking on the path on a dry day.

Compaction levels from surface traffic decrease with depth. As compacting loads are transferred downward, they are spread out laterally through most soil types at an approximate angle of 45 degrees from the point of impact. This reduces the compacting force dramatically in just a short distance below the impact level. A force of 1 pound per square foot applied at the surface of the soil equates to a force of only 0.11 pound per square foot 1 foot below the surface of the soil and 0.01 pound (or less) per square foot at a depth of 2 feet.

To obtain a consistent compaction rate in an installed soil, engineers specify soil compaction to be performed by the contractor, in thin layers called lifts, as the soil is

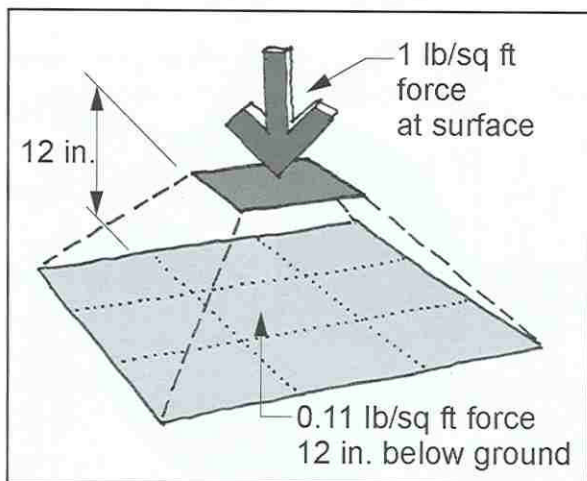


Figure 3. Load transfer in soil and its impact on compaction. Compacting force dissipates with depth.

being placed. For example, compaction for a road bed may be specified in 6- to 8-inch lifts. For general soils, lifts may be 12 inches thick. Planting soil compaction will vary from 12- to 24-inch lifts, depending on the sensitivity of the project to tolerate settlement.

Figure 3 shows the transfer of loads in soils.

Vibrating the soil while applying the compacting force helps the particles fit more tightly together. The vibration can also break the bonds between clay soil particles, helping to increase compaction levels. As noted previously, adding water to a soil helps lubricate the particles so they slide together, but too much water causes the particles to flow, transferring the force without compacting the particles. Some of this force is transferred upward toward the surface, causing the soil next to the compacting force to bulge up. This is called pumping, and it indicates that the soil is not being effectively compacted. The right combination of soil water level and vibration can create serious compaction in a soil, pleasing the engineer, but causing anxious moments for the designer if the soil is intended to support tree roots.

The weight of the soil is also a compacting force, and in natural soil with a consistent texture, bulk density normally increases with depth. Conversely, when urban soils are compacted solely by surface loading, compaction decreases with depth due to the lateral transfer of the compacting force. This decreasing compaction continues until it reaches the level that would have resulted from the weight of the soil above. At this point, the compaction rate begins to increase.

Time also increases bulk density in lower soil levels. The weight of the soil continues to compress the soil below it until equilibrium is reached between the weight of the upper soil and the lower soil's ability to resist that weight. Natural soils may be quite stable, while graded soil continues to settle for periods that can last years. Engineers use this principle to prepare subgrades in sites with deep areas of soil that are insufficient to hold the structure planned for the surface. Fill soil is mounded on top of the final grade for a specified period. Both the depth of the mound and the length of time are factored

into estimating the compaction rate.

The compaction force is a function of both the weight of an object and the surface area over which the weight is distributed. Track vehicles and low-inflation rubber tire vehicles have a much lower compacting force than a standard car or truck. Note that pedestrians, with their small footprint-to-mass ratio, can cause more compaction than a track-grading machine.

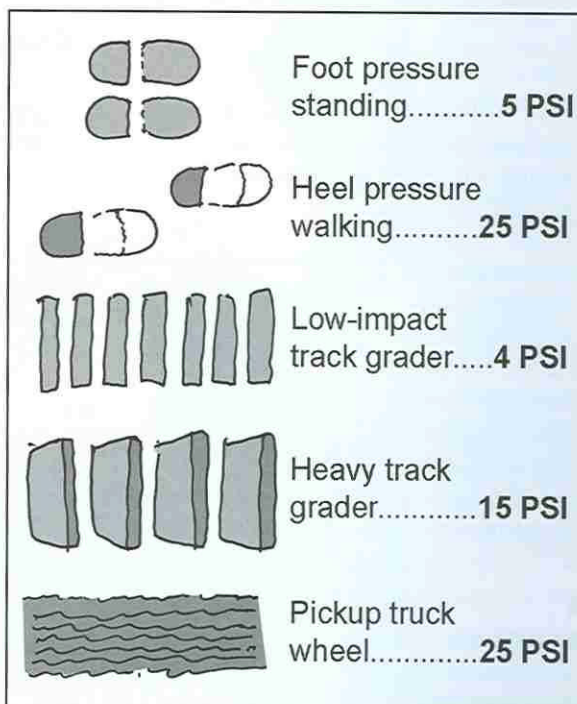


Figure 4. Compaction forces of vehicles and pedestrians.

Caliches, Claypans, Fragipans, Hardpans, and Plow Layers

Naturally and human-degraded soil may contain dense layers that make it difficult for water or roots to penetrate. These layers may result in high water levels, mechanical compaction, or a sharp change in soil type between layers. Such conditions may create soil interfaces (boundaries between horizons). The names for these soil conditions as used in the industry can overlap somewhat, and definitions can change slightly by region.

- **Caliches**, often found in the western United States, are layers that were formed as soil particles became cemented together by compounds that include calcium or magnesium.
- **Claypans** are layers that were formed by the accumulation of clay particles.
- **Fragipans** are layers that were formed by compaction.
- **Hardpans** are almost any type of hard layer in the soil. This general term is sometimes used to refer to layers formed by soil particles becoming cemented together with compounds of calcium, silica, or organic matter.
- **Plow layers** are layers that were formed by repeated compaction by the bottom of a plow pushing down by the weight of the soil.

Soil Interface

A soil interface (vernacular term), or abrupt boundary (scientific term), is a sharp or distinct joint between two different horizons and is the result of a dramatic change during soil formation. Roots and water may have difficulty crossing layers where there is a dramatic difference in porosity across the interface. Minerals and/or clay particles may collect along interfaces, resulting in caliches,

claypans, fragipans, or hardpan layers. If water sits on top of the interface, it is called a perched water table. ▶

Settlement of Mineral Soil vs. Loss of Organic Matter

Mineral soil settles as particles fill in voids. Except for high-sand-content soils, it may be impossible for a contractor to compact a planting soil to the point where it will not settle and still support root growth. Settlement of the mineral portion of the soil can usually be contained to less than 10 percent of the soil depth.

Large amounts of organic soil amendments are often added to planting soil mixes. This organic amendment will continue to decompose in the soil, significantly reducing its volume and causing a reduction in soil volume. Most of this lost volume leaves the soil as CO₂ into the atmosphere. Increasing bulk density cannot control soil settlement from loss of organic matter.

Soil settlement roughly equal to 50 to 75 percent by volume of organic amendment should be anticipated in addition to the normal mineral settlement. If 20 percent by volume of compost is added to the soil, the shrinkage will be between 10 and 15 percent of the installed soil depth.

Add only small amounts of organic amendments (10 percent by volume) to planting soil mixes to reduce shrinkage. Greater amounts of organic amendments (up to 50 percent by volume) should be added to the top 6-inch layer of planting soil where soil shrinkage is not as critical.

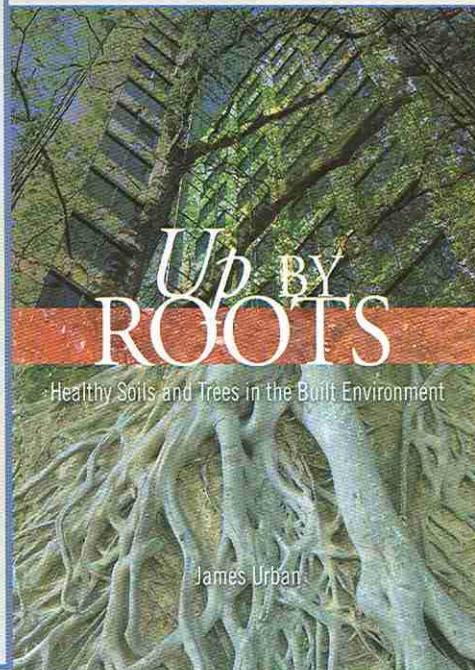
Healthy soil and other essential requirements are critical to the success of trees but are often missing in the design concepts of contemporary urban landscapes.

UP BY ROOTS is a manual for landscape architects, architects, urban foresters, and planners who design, specify, install, and manage trees in the built environment.

Author **James Urban** provides an overview of basic soil science and tree biology and how they interact and then explains the process of designing and implementing landscapes to ensure healthy trees that can contribute to healthy places for people to live, work, and play.

Coming in 2008!

UP BY ROOTS Healthy Soils and Trees in the Built Environment



The two-part, seventeen-chapter book contains hundreds of illustrations and data in graphic form to guide the design of soils and trees.

James Urban is a recipient of the ASLA Medal of Excellence for his work to improve trees in urban environments. He has been instrumental in changing the approach to trees by landscape architects and has helped to develop many innovative concepts including tree soil trenches, structural soil, and structural cells. He is a frequent contributor to *Landscape Architecture* magazine and other publications.



Urban Soils (continued)

Changes to Soil Compaction

The forces of freeze/thaw and swelling/shrinking in the soil tend to slowly reduce surface layer compaction, especially when combined with high levels of surface biological activity. This process is slightly more rapid in colder and wetter climates, but many winters are needed to allow a compacted soil to begin to recover even in the northeastern United States.

Mulch layers to stimulate biological activity and retain moisture also help soils recover from compaction. Lightly compacted soil

and soil where the compaction is only on the surface few inches will recover more quickly if mulch is added to the soil.

In warm or dry climates, the soil may stay compacted. Once the soil reaches a point where root penetration and soil biology is severely restricted, time and the addition of mulch have a diminishing impact on reducing compaction. For example, portions of the compacted tracks of the Oregon Trail through the high desert are still visible after more than 100 years of rest.

Part 2 of this series continues in the June issue and addresses the topic of measuring compaction. **AN**