URBAN SOILS
Part 2: Measuring Compaction

By James R. Urban

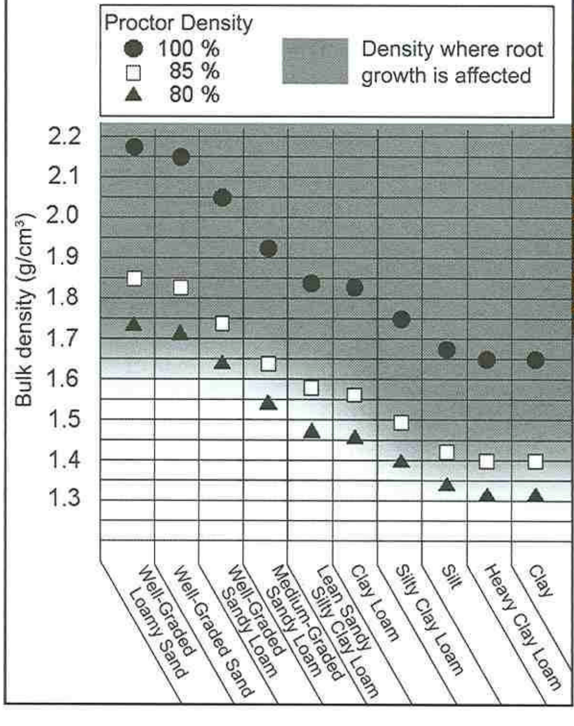
We are pleased to present a three-part series of excerpts from ISA's upcoming book, Up By Roots: Healthy Soils and Trees in the Built Environment, *by noted landscape architect Jim Urban.*

Soil compaction is measured as *bulk density,* which is the soil's dry weight divided by its volume. In agronomic soil science, this is normally expressed in megagrams per cubic meter (Mg/m^3), also expressed as grams per cubic centimeter (g/cm^3). Note: Mg/m^3 and g/cm^3 are the same value—just a different notation. For example, 1.5 Mg/m^3 equals 1.5 g/cm^3.

Different soils have different densities at which they will no longer allow roots to penetrate. Different plants vary in their ability to penetrate dense soil. As soil moisture increases, plants may be able to penetrate a soil that, at lower moisture levels, would be root limiting. This may explain why urban trees can form roots in seemingly root-limiting compacted soil, but only during wet seasons of the year.

Generally, coarse-grained soils may be compacted to a greater degree than fine-grained soils before they become root limiting. This is due to the larger pores that are retained in between larger particles. Table 1 depicts the root-limiting bulk density in different soils. These root-limiting bulk densities are for typical trees and large plants commonly used in landscape applications, but variations of nature provide plenty of exceptions. Note: In the table, root-limiting bulk density levels are depicted as a soft band with an imprecise edge. There is considerable variation among plants, and the same plant may respond differently to minor variations in soil texture.

Table 1. Bulk density and levels affecting rooting compared to several Proctor densities. This table should not be used to evaluate compaction in soil mixes that include organic amendments or lightweight aggregates. (Source: Data adapted from Daddow and Warrington 1983, Lichter and Lindsey 1994, and Brady and Weil 1999).



Compaction Measurement by Proctor Test

Engineers often measure compaction as a percentage of maximum dry density that may be obtained under conditions of optimum moisture content as determined by the *Proctor density test.*

Table 1 illustrates the relationship of Proctor levels to bulk density levels in different soils. Note that compaction rates specified for engineering fills, typically 90 or 95 percent of maximum dry density, are substantially higher than the bulk density that limits root penetration. Depending on the soil type, compaction rates between 80 and 85 percent dry density will begin to restrict root growth. The data in Table 1 suggest that if planting soil compaction is specified in Proctor units, then the maximum compaction should be 80 percent of maximum dry density, except in sandy soils.

To use Proctor measurements in field soils, a geotechnical soils lab must first determine the maximum soil density and its optimum moisture curve. With that information, the soil can then be tested using a nuclear densiometer (Figure 1). The compaction reading on the densiometer is noted as a percentage of the lab-determined Proctor value.

Figure 1. Nuclear densiometer.

The 100 percent density value is expressed in the engineering lab report as bulk density. Often these lab data will be expressed in pounds per cubic foot (lb/ft^3). One Mg/m^3 equals 62.43 lb/ft^3.

A Proctor test is most often used to determine whether a soil is compacted to the minimum level to support structures. Ninety-five percent of maximum dry density is considered adequate for most structures, and 90 percent is a standard for many residential sidewalk applications. Eighty-five percent is often quoted as the density for planting soil, yet research indicates that 85 percent is becoming root limiting for many plants. A percentage lower than 85, more likely lower than 80, is a better standard for planting soil.

The advantage of the Proctor test is that it is precise and accepted industry-wide, but a number of problems are associated with its use:

- Each soil type must be tested by a geotechnical lab before a Proctor test can be conducted.
- Testing equipment is expensive and requires a trained technician.
- Only limited samples can be studied because of set-up time.
- A nuclear densiometer can read soil compaction only to the depth of the probe, or about 6 to 12 inches, and does not give reliable readings in soils with elevated organic content.
- Densiometer readings in organic soil are generally higher by 5 to 15 percent over actual density.
- Maximum and minimum Proctor densities for soil use as a planting medium have not been researched sufficiently.

For those reasons, the Proctor test is an impractical way to analyze soil compaction in existing soil in the site analysis phase. It is a useful tool during the construction phase when the installed planting soils are uniform and a technician skilled in the use of the equipment is available.

Compaction Measurement by Penetration Resistance

The words compaction, bulk density, and penetration resistance are often misused in discussing the level of compression in soil. Remember that all soil has some level of compaction. Compaction is best expressed as the soil's bulk density (weight divided by volume) and is a measurable quality if the proper tools are available. Penetration resistance reflects how hard it is to push an object into the soil; resistance changes with soil type and soil moisture. Soil will have low resistance when it is wet and high when it is dry. A perfectly good garden soil may resist all attempts to insert the penetrometer when dry. Unless soil type and moisture are known, penetration resistance is not a good way to evaluate the level of compaction in a soil.

Penetration resistance is measured by a cone penetrometer (Figure 2). This device can provide instant readings of relative soil resistance to depths of 24 inches or greater. It is pushed slowly through the soil, and resistance is measured on a gauge. A penetrometer is easy to use and relatively inexpensive to purchase. The soil's ability to resist penetration is measured in megapascals (MPa). Moist, sandy loam soil with a resistance lower than 2 MPa is considered appropriate for root penetration. When soil moisture is at about 50 percent of field capacity, penetrometer readings may provide rough data.

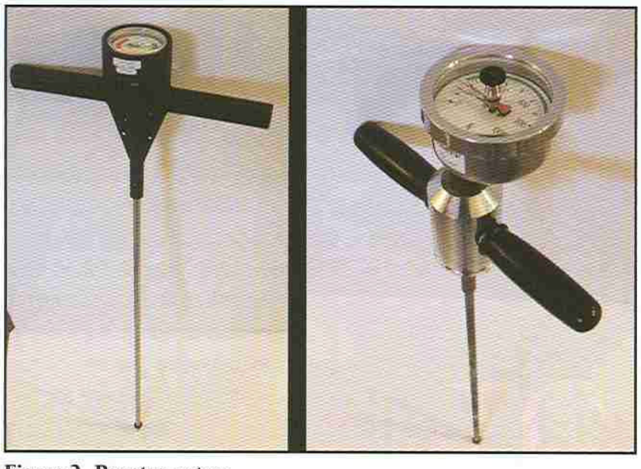


Figure 2. Penetrometers.

To date, there is not sufficient data on the relationships of the two variables of moisture and soil type to make the penetrometer useful in site assessment. With a little practice, a small-bore soil probe can provide about the same level of information about soil compaction as a penetrometer. Penetrometers may have value during the installation of new soil to determine where a contractor has compacted soils to different levels compared to a reference site that is of acceptable compaction and moisture.

Compaction Measurement by Bulk Density

Bulk density of an undisturbed sample is a common measuring standard used by agronomic soil scientists and is the most useful method to measure compaction levels of soil during the analysis phase. Obtaining bulk density is time consuming and requires that samples be taken to a lab, dried, and weighed—a process that takes several days or longer. Special equipment is needed to collect the samples, and special care must be taken in their shipping. Often, the timing of construction does not allow for processing multiple bulk density tests during the soil installation phase.

Despite these problems, this method is still easier than a Proctor test and much more accurate than a penetrometer. Reasonable bulk density measurements can be made by investing in a limited amount of equipment. Approximately $500 will buy a scale, slide hammer, and other sampling tools.

Figure 3 shows the process of measuring bulk density. The length of the sample soil in the liner is measured, removed from the liner tube, and placed in an oven set at 215°F to dry overnight. The sample is then weighed. All measurements should be made in metric units. The measurements and calculations determine the weight, volume, and finally bulk density .

Having the capability to determine bulk density in the office speeds up the process to just one day. Samples can be removed in the afternoon, dried overnight, and a report issued the next morning. This is well within the schedule constraints for most projects. While an office-generated bulk density test is useful, the authority of a test performed by a soil testing laboratory may be required if the results are likely to be challenged or used to defend an action. Several helpful hints to improve the taking of a bulk density test

- Do not screw the sampling core tight to its top piece to make it easier to remove.
- Spray the inside of the plastic liner with silicon lubricant to ease the removal of the soil.
- Clean out all soil from the liner and threads of the tool between tests.
- If the sample is weighed before it is dried, the moisture content of the soil can be calculated.

In their book, *Trees in the Urban Landscape*, Bassuk and Trowbridge (2004) describe a lower-tech method of measuring bulk density that requires less field equipment. Dig a small hole in the soil and fill it with a plastic bag. Pour water into the bag to fill the space and record the amount of water required to fill the hole. It is

Figure 3. Bulk density sampling method.
a. Tools needed in the field:
1. **Shovel to remove organic layer.**
2. **Core sampler and slide hammer.**
3. **Plastic core liners with caps.**
4. **Cleanup tools. Water required for tool cleanup and to make it easier to remove the sampling tool from soil.**

b. Taking an undisturbed sample with a slide hammer and core tube. Note that the cylinder is driven only to the level of the bottom of the cap inside the core, so as to not change the compaction of the sample. Mark this depth on the outside of the tool.

c. After the sample is removed, the length of the sample in the sleeve is measured. The soil may not completely fill the sleeve.

critical that the volume of water be accurately determined, and that the water be filled precisely to the level of soil removal. This gives a reasonably accurate volume of the soil removed. The removed soil can then be dried and weighed to calculate the bulk density, as illustrated in Figure 3.

Each method of assessing soil compaction has advantages and disadvantages. Calculating bulk density is likely the best diagnostic tool for existing soil, while checking Proctor density with a densiometer is often the better tool at a large construction site where a geotechnical soil technician may already be on the site checking engineering conditions. A penetrometer is most useful to check the relative compaction of planting soil installations where the soil type and moisture are relatively consistent.

References

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