AN EVALUATION OF VOLUME EXCAVATION AND CORE SAMPLING TECHNIQUES FOR MEASURING SOIL BULK DENSITY

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Abstract. Soil bulk densities were measured at three locations representing a variety of textural classes utilizing two measurement techniques: core sampling and volume excavation. Bulk density values established by the volume excavation method were significantly lower than core sampling values at 2 of 3 locations. The differences in bulk densities generated by the two techniques should be considered when evaluating the severity of compaction on a site relative to an assumed critically limiting bulk density. Core sampling is a simple, fast and common technique, but is not suitable for sampling rocky, dry or wet soils. The volume excavation method requires simple to use and inexpensive tools and was useful for sampling soils of various conditions, but this technique required greater care in sampling technique which increased the time required for sampling.

Key words: Soil compaction, bulk density, volume excavation, core sampling.

Soil compaction is frequently cited as a limitation to the growth and survival of urban trees (5). Compaction often occurs during site construction and continues through the landscape maintenance phase. Several techniques have been used to evaluate compaction: penetrometer resistance, water infiltration, nuclear densitometry, and bulk density measurement. Of these, bulk density is the most direct and reliable method (4). Bulk density measurements typically involve the removal of a volume of soil which is dried for 24 hours in an oven (105°C or 220°F) and weighed. The dry weight of the soil divided by its volume yields bulk density in g/cm^3 or Mg/m^3.

Several methods have been used to measure bulk density: soil clod, core sampling, and volume excavation. The soil clod technique involves excavating a small sample of soil, which is dipped into a saran mixture, and weighed in water and air using Archimedes principle to determine the soil volume (3). This method does not take into account interclod spaces which may be partially responsible for the higher bulk densities generated by this technique (3). In addition, clods may also be difficult to obtain in loose soils (8).

Core sampling is the most common technique for measuring bulk density in agricultural soils. A field core sampling tool (described in 3) is used wherein a cylinder is driven into the soil (Fig. 1) and a sample of known volume is extracted, dried and weighed. The dry weight of the soil is then

Figure 1. Driving the core sampler into the soil.

divided by the cylinder volume providing an estimate of bulk density. This technique provides a relatively simple and rapid estimation of bulk density when compared to the soil clod method. The core sampler has very limited use in dry or wet soils and loses accuracy in gravelly or rocky soils (3,5).

The volume excavation technique is often used by soil engineers to measure bulk density (9). A small hole is dug and all soil collected, dried, and weighed. The volume of the hole is measured by lining it with plastic and pouring sand (of known density), water or oil to grade level and determining the volume of material required to fill the hole (2) (Fig. 2). The dry soil weight divided by the excavated volume yields bulk density.

The objectives of this study were to evaluate the volume excavation and core sampling techniques by comparing bulk density measurements generated by each method in the same soil, using soils of three textures, and to assess the utility of each method for field sampling. Specifically, we were interested in determining whether the apparently simple and inexpensive volume excavation method could be used as a substitute to core sampling for bulk density measurement.

Figure 2. Estimating the volume of the pit for bulk density estimation by the volume excavation method.

Table 1. Description of soils at sampling locations.*

Site	Sat.%	% Sand	% Silt	% Clay	Soil type
EH West	38	42	40	18	Loam
EH East	29	67	21	12	Sandy loam
B-6	51	25	52	23	Silt loam

* Analysis conducted by DANR Analytical Laboratory, University of California.

Methods

Three locations were selected in Yolo County, California for soil bulk density measurement. These sites represented a range of soil textural classes (see Table 1). EH West and EH East soils were located in unpaved roadways. Soils at B-6 were in a fallow, yearly-tilled agricultural field. Soils were sampled at a moisture content approximating field capacity.

At each location, a sampling area of approximately 0.66 m^2 was identified within which eight sampling sites were marked and the soils leveled, removing approximately 2.5 cm of loose surface soil. At four interspersed sampling sites, a core of soil was removed with a standard, hand-driven core sampler (A.M.S., American Falls, Idaho) with removable 4.8 cm diameter by 10.1 cm high sample cylinders (182.8 cm^3 volume). At the remaining four sites, small, smooth-edged pits approximately 15 cm in diameter by 13 cm in depth, were dug, as described by Chancellor (4). Soil excavated from pits was carefully collected in tin cans. A small plastic bag was then inserted into each hole wherein water was poured from a graduated cylinder. The volume of the test pits were estimated by measuring the volume of water required to fill the hole to grade. Extracted soil from all sampling sites was then dried in an oven at 105°C for at least 24 hours.

After drying, soils were weighed. Bulk density by core sampling was determined by dividing the net weight of dry soil by the volume of the sampler cylinder. To evaluate bulk density by the volume excavation method, the dry weight of excavated soil was divided by the estimated volume of the test pit. Statistical analysis of results was conducted as an analysis of variance for a randomized complete block design.

Results and Discussion

Measurements compared. Average bulk densities measured by the volume excavation technique were 3 to 9% lower than those obtained by the core sampling method (Table 2). Differences ranged from 0.05 to 0.14 g/cm^3 and were significant at 2 of the 3 locations studied. The average difference at all three locations was 0.11 g/cm^3. Variation of bulk density values within a technique were generally low and differences between replicates at each site were not significantly different.

It is difficult to determine the specific reasons for the difference in bulk density values generated by the two methods. In considering the sampling procedures, it can be reasoned that core sampling may produce "high" bulk density values, while volume excavation may produce "low" values. It is possible that some compaction of the sample occurs during tool insertion, due to friction between the soil and the cylinder walls thus increasing mass and therefore bulk density. Conversely, in the volume excavation method, if soil volume measured using water and plastic liners was greater than the volume of the soil actually removed, then a lower bulk density would result. Additionally, it is conceivable that some variation in bulk density values between methods could be caused by a difference in sample location. For example, in a soil with cracks resulting from shrinkage, including a crack(s) in the sample volume may result in misleading bulk density values. However, the soils sampled in this study were relatively homogenous due to compaction or tillage and therefore, differences could not be attributed to this phenomenon. Further work will be needed to clearly identify causes for the differences in bulk density values between the two methods.

Ideally, a standard method should be used to determine benchmark bulk densities for soils tested. Unfortunately, previous studies comparing the core sampling and volume excavation techniques to an assumed standard, the soil clod technique, produced conflicting results. Howard and Singer (8) found no differences in bulk density generated by the volume excavation technique and this standard, while Tisdall (11) found significant differences between both volume excavation and core sampling techniques and the soil clod technique.

Table 2. Average bulk density values (g/cm^3) for core sampling and volume excavation sampling methods.*

Site	Texture	Core	Excavation	Dif.
EH West roadway	loam	1.65	1.51**	.14
EH East roadway	sandy loam	1.60	1.46**	.14
B-6	silty loam	1.59	1.54	.05

* Numbers followed by ** are significant at 5% level, ANOVA.

It is important to note that although the difference in bulk density values produced by the two methods is relatively small (3 to 9%), the implications of this difference in terms of soil management and plant performance may be substantial. Critical bulk densities above which plant growth is affected have been developed for various agronomic and forest crops (6,7,10,12,13) and ornamental species (1) growing in different soils. Some adjustment in bulk density values will be needed when comparing on site bulk densities generated by the volume extraction method to critical bulk densities based on the core sampling technique. For example, if a critical bulk density of 1.6 g/cm^3 is assumed for a particular plant/soil combination, on site soil densities of 1.65 g/cm^3 generated by a field core sampler would indicate growth limiting bulk densities, while densities generated by the volume excavation method (1.5 g/cm^3 for a 9% difference) on the same soil would fall below critical levels. Further, core sampler values in this case would indicate a need to reduce bulk densities to sub-critical levels, while volume excavation values suggest that no soil remediation would be necessary.

Technique Characteristics.

Core sampling. Core sampling provides a simple and efficient means for measuring bulk density, as cylinders are simply hammered into the soil and removed. In addition, soil samples are smaller and easier to manage than volume

Table 3. Characteristics of core sampling and volume excavation techniques for measuring soil bulk density.

Where typically used	Agricultural and forestered soils.	Soil engineering.
Equipment needed	Field core sampler, soil sleeves and containers, putty knife, oven, balance.	Shovel, plastic bags or saran wrap, water, measuring container, paper bags, oven, balance.
Ease of operation	Simple to operate, but some older models somewhat bulky and heavy. On many models, sample canister can be very difficult to screw off.	Some care needed in collecting all soil excavated and when estimating volume.
Transportability	Most very portable, althought somewhat heavy. Some older models may require two people to transport to field site.	Tools easily transported. Water may need to be transported to sampling site.
Cost	Approximately $250	Less than $20.
Field factors limiting use	Limited use in wet, dry, rocky or sandy soils. Rocks or roots in sample may affect accuracy.	Can be used in, wet, dry, rocky, or sandy soils (if sides of hole do not cave in). Difficult on slopes or for sampling at depth.

samples. However, the cost of core samplers is substantial (approximately $250).

In using the core sampler, soil type and condition are significant concerns. Encountering gravel was problematic, hindering penetration of the core sampler and altering density readings as gravel caused compaction of portions of the sample and then fell out of the sleeves. Occasionally, clumps of soil would also fall out of the sleeves, necessitating resampling. Additionally, preliminary tests with the core sampler indicated that soil moisture levels near field capacity were critical to obtaining an intact core.

Blake and Hartge (3) have noted that bulk density may increase if the sampling device is overhammered into the soil. In this study, core samples obtained by hammering the core sampler into the soil to varying depths relative to the top of the sleeve produced 6% higher bulk densities on average (data not reported). Therefore, when using a core sampler, the level of the top of the sleeve must be marked on the sampler tip and the sampler must not be hammered into the soil below this level. Most soil samples should slide easily within the cylinder if the sampling is performed correctly and the cutting edge of the cylinder is kept sharp.

Volume excavation. The low cost (less than $20) and availability of tools required make the volume excavation technique an attractive alternative to core sampling. This method allows flexibility in the volume of soil sampled (a large or small hole can be dug), and, by sampling larger volumes, an increase in accuracy would be expected due to the reduced influence of rocks, roots and cracks in the sample. In addition, soil moisture levels and other attributes (e.g. rocks) do not influence the ability to conduct measurements with this technique as long as a shovel can penetrate the soil.

When estimating bulk density through volume excavation, a greater amount of control over technique is necessary for accurate results. Care must be taken to level soil surfaces prior to sampling, collect all soil removed from holes, and estimate volume accurately. Sampling with this technique may not be appropriate on sites where soil disturbance must be minimized. In addition, sampling soils at discrete depths in the soil profile with this method is impractical, due to the need for a relatively large level surface surrounding the test pit. Further comparisons of the two methods are included in Table 3.

Conclusion

The volume excavation and core sampling methods are both useful methods for estimating the bulk density of soil. Each technique has its advantages and disadvantages which need to be considered to select the most appropriate technique for a particular situation. Since the volume excavation technique generates bulk density values 3 to 9% less than the core sampling technique, adjustments need to be made when comparing resultsbetween these two techniques.

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