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The question is compaction: is bulk density the answer?

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Bottom line: Compacted (excessively dense) soils pose a serious threat to turf growth, health and quality. When soils are compacted, critical hurdles are placed in the way of root growth, air and water movement and the venting of toxic gasses such as carbon dioxide. Understanding and measuring soil compaction is therefore an important procedure in the selection of golf course green construction materials, and in the development of aerification and topdressing management programs that are designed to alleviate compaction. Although bulk density measurements are frequently used to predict and measure compaction, the values obtained can be misleading, and do not provide sufficient information to accurately assess soil compaction. For on-site testing, we have found that the relatively simple process of measuring soil strength with a cone penetrometer provides a quick and realistic look at the state of soil compaction.

"The bulk density has been used as a parameter in assessing root zone mixes since the original (USGA) specifications. Several studies, however, have found it an irrelevant number in predicting performance . . . It is questionable if it should be reported and that there be a required range that must be met. Thus, it has been proposed that the required bulk density range be dropped from the specifications." (Hummel, 1993)

Technical articles on greens construction and management deal with a wide, and complex variety of physical measurements – porosity, particle density, bulk density, particle shape and size, soil strength, conductivity and others. One of these measurements – bulk density – consistently raises questions and causes some confusion. What does bulk density actually measure? Can it predict the performance of root zone mixes? Does it provide some measurement of compaction on older greens? Should superintendents be making regular bulk density measurements on their greens, or are there better ways to evaluate performance? And finally, since the USGA no longer considers bulk density a valuable enough measurement to utilize it in the root zone recommendations, why do so many technical and research articles continue to use bulk density measurements?

These are important questions for many reasons. Selection of products such as sands, soil amendments, and organic matter are frequently based on physical parameters, including bulk density, without a full understanding of the significance (or lack thereof) of this measurement. Deciphering research articles and product technical literature is difficult because there isn't a consensus among researchers about the value of the bulk density measurement. And development of programs to monitor and evaluate greens performance can be greatly improved if it's clear which physical measurements are most valuable in different situations. At PACE Consulting, we get several calls each year from superintendents who want to know if they should be taking bulk density measurements on their greens, and/or with questions about how to interpret bulk density data.

In this issue of *PACE Insights*, we'll respond to these concerns, and hopefully give you some guidance in navigating the somewhat murky issue of bulk density.

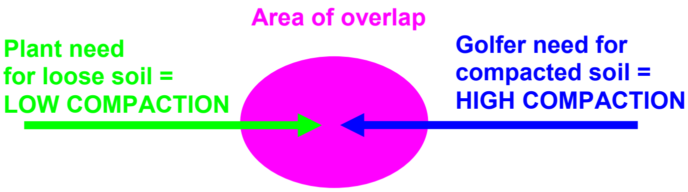
The problem of compaction

Simply put, heavily compacted soils spell trouble for plants. When soil particles are compacted, or packed tightly together, there are few spaces (pores) left in between the soil particles, which means that there is limited room for root growth. In addition, air movement, water movement, water drainage and venting of toxic gasses such as carbon dioxide into the atmosphere is also restricted.

Alleviating compaction: By "loosening up" compacted soil, root growth is improved. The long roots in the photo below are growing only in the sand-filled (lighter colored) aeration holes. Root growth is more stunted in the dark, compacted soil that surrounds the aeration holes.

On the other hand, some level of compaction must be maintained in order to provide an even, consistent and firm surface for the game of golf itself, as well as for foot and vehicle traffic Thus, there is a basic conflict between the needs of the game for a firm surface, and the needs of the plant for a looser, less compacted soil. Identifying the small window where the needs of the game and the needs of the plant overlap is therefore a very important process that influences not only the selection of root zone mixes and soil amendments, but also management practices such as aerification and top dressing.

It is to find (and then to stay within) this area of overlap that we go to great lengths to select the right root zone mixes and the best soil amendments, and to design the right management programs. And it is for this reason that it's so important to confirm the accuracy of any measurement that is used to estimate compaction.



Bulk density: a definition

Bulk density is a measurement of soil weight that takes two components into account: the particle weight (weight of soil solids such as sand, silt, clay and organic matter), as well as the air trapped in the soil's pore spaces.

Bulk density measurements are usually expressed in grams per cubic centimeter (g/cc) which reflects the fact that we are measuring the weight (in grams) of a given volume of soil (in cubic centimeters). Soil bulk density measurements fall into a relatively narrow range – usually between 1.0 and 2.0. g/cc.

Bulk density and compaction: are they related?

The answer to the question above is "Yes". And also "No". And sometimes, "It depends." Here's why it's hard to get a straight answer.

In the world of turf management, bulk densities are frequently used to determine soil compaction levels. The assumption is that because the total volume of air filled pores is included in its calculation, bulk density should provide a good estimate of soil compaction. Compacted soils with few air filled pores have high bulk densities, whereas looser, more porous soils have more air filled pores, and therefore have lower bulk densities. As bulk density increases, it should become more difficult for roots to penetrate and grow through the soil. In addition, air, gas and water movement should also be significantly slowed down. Some typical bulk densities are listed in Table 1.

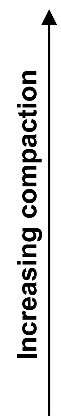
So far, so good. But the reality is that bulk density measurements taken on golf courses have been inconsistent and typically do not accurately represent the level of compaction present. And when the USGA evaluated the use of bulk density measurements as a tool for selecting root zone mixes, they decided that the measurement wasn't useful in predicting performance (Hummel, 1993) and as a result dropped bulk density as a parameter for accepting or rejecting root zone mixes. There are several reasons why bulk densities don't necessarily reflect reality when it comes to golf course greens, as described below.

Not all pores are alike

Just to review, bulk density measures the weight of soil particles PLUS any air trapped between particles in spaces known as **pores.** High bulk densities are thought to indicate potential compaction problems because the number of air filled pores is low. This suggests that roots, air and water will have trouble growing and moving. In contrast, low bulk densities are thought to indicate a more optimal soil, because the number of air filled pores is higher.

Table 1. Typical bulk densities for different soils and soil components (from Brady and Weil, 1999). Values in red usually indicate a soil that will severely restrict root growth. Values in green are considered optimal for satisfying turf plant growth needs and golfer satisfaction.

Soil or particle type	Bulk density (g/cc)
Pure quartz crystals	**2.6 - 2.7**
Concrete	**2.4 – 2.5**
Pure sands	**1.7 – 1.8**
Sandy loams	1.6
Silt loams	1.5
Clays	1.4
Typical greens root zone mixture	**1.2 – 1.6**
Typical arable soil for agricultural crops	1.3
Uncultivated forest and grassland soils	0.8 – 1.2



If the majority of pores were always **macropores** (greater than 75 microns in diameter), then the above statement might be accurate. But as you might have guessed when you saw the term "macropores" introduced, there also exists a type of air-filled soil space known as **micropores.** These pores, which are less than 75 microns in diameter, can be small enough to actually prevent root growth, since roots themselves range in size from 60 – 250 microns, or even more. And a prevalence of micropores not only restricts root growth, but also impedes water and air movement so that the soil is poorly aerated, has poor microbial activity, and slow gas and water movement.

Unfortunately, bulk density measurements make no distinction between the air held in macropores and the air in micropores. Bulk density simply quantifies the combined volume of all air filled pore spaces. And this can be misleading. For example, there are sands that, despite a high bulk density reading, sustain good root growth and good water and air movement because the majority of pores are macropores. In contrast, there are clay soils that, because they have a multitude of micropores, have low bulk densities, but are nevertheless waterlogged, compacted and have poor root growth.

Comparing apples and oranges

Another problem making bulk density data difficult to interpret is that golf course soils are mixtures -- a combination of several very different materials (sands of different shapes and sizes, organic matter and in some cases, soil), each with their own characteristic bulk density. When these components are mixed together, their complex interaction (will the particles interlock and form macropores between them? Will fine particles plug up macropores?) is not accurately measured by bulk density.

Measuring bulk density: It is necessary to obtain a soil sample of known volume without changing the compaction or any other feature of the soil structure. To do this, thatch and turf are removed from the area to be sampled, and a drop hammer sampler (photo 1) is driven into the soil (2). This allows an enclosed metal cylinder of known volume to become filled with soil. The cylinder is then removed from the sampler (3) and capped (4) to allow transport back to the laboratory. Back at the lab, the soil is removed from the cylinders and is placed in a drying oven to remove all water. Following this, the soil is weighed. Bulk density is then calculated by dividing the weight (in grams) over the known volume of the metal core-sampling cylinder.

Who uses bulk density and why?

Bulk density measurements were originally developed to help estimate the weight of a given volume of soil. Because the procedure for obtaining measurements did not require excessive time or expensive and sophisticated equipment, the procedure was widely adopted. In the absence of today's high precision analytical equipment, bulk density became a valuable tool years ago for soil scientists, farmers and the construction industry to mention only a few. For example:

<u>Fertility rates:</u> Years ago, soil weight (as estimated by bulk density) was used by soil scientists and farmers to help calculate fertilizer rates. Today, a large number of good analytical labs and their vast array of equipment makes determination of soil nutritional levels and other parameters much easier, and more precise than in the past. For this reason, bulk density is rarely, if ever used for this purpose today.

<u>Estimating soil weight in construction projects:</u> Probably the group that relies most on bulk density measurements these days includes engineers, architects and landscapers involved in large construction projects. Because bulk density is a measure of soil weight, this value allows contractors to determine what type of equipment is needed to move large masses of soil. High precision isn't necessary in this application, which explains its continued popularity.

<u>The turf industry:</u> Despite the evidence that bulk density measurements do not provide useful measurements on golf course soils, they continue to appear in technical literature. The reasons why aren't clear, but our guess is that we're suffering partly from a holdover from the past, and partly from a matter of inertia. Many turf scientists were trained as soil scientists and agronomists -- disciplines where bulk densities regularly appear in textbooks and research papers. And it's a relatively simple procedure that produces a treasure trove of data -- albeit possibly meaningless data! And because research papers continue to use bulk density measurements, new scientists believe that they too must accumulate bulk density data, even if the results are difficult to interpret. We feel that the USGA took a constructive step when they omitted this confusing measurement from their specifications. We hope that in the future more researchers will consider alternative physical measurements such as soil strength, capillary and air filled porosity, and even soil gas percentages, to predict and characterize soil compaction.

An on-site alternative for measuring compaction

If bulk densities are not useful in measuring soil compaction, how can superintendents monitor this important parameter? We have found that using a cone penetrometer to measure soil strength can provide valuable information on soil compaction levels.

The **cone penetrometer** (see photo to the right) was originally developed by US Army Corps of Engineers for predicting the ability of soils to withstand the weight of army vehicles in off road military operations. Today, this handy tool is used extensively to evaluate compaction, evaluate root growth in compacted soils, and to characterize soil physically.

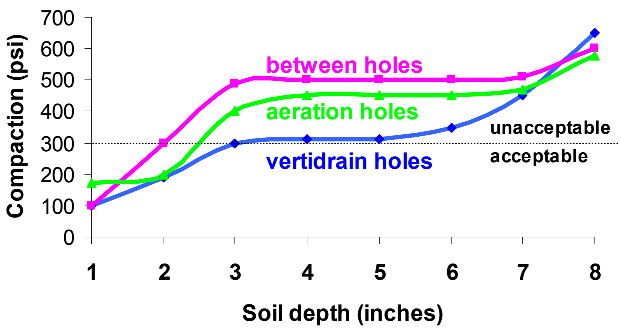
It works on the principle that the pressure needed to force a rod (the stainless steel probe of the penetrometer) into the soil is indicative of the level of compaction. In crop agriculture, a reading of more than 300 psi (pounds per square inch) is considered to be so severely compacted that plant roots will have great difficulty in penetrating the soil.

To investigate the usefulness of the cone penetrometer as a tool for measuring compaction, the PACE Turfgrass Research Institute conducted a study several years ago with the cooperation of Mike Caranci, superintendent at Candlewood Country Club. We were interested in learning how two different aerification procedures affected soil compaction on putting greens.

1. Shallow (3" deep) core aerification (with cores removed) with 5/8" tines.
2. Deep vertidraining (9 inches deep) with ¾" tines.

In both cases, the holes were filled with 20-30 silica sand. One day later, we took penetrometer readings at 8 different soil depths, and from three locations: the sand-filled aerification holes, the sand-filled vertidrain holes, and the non-aerified area between holes.

Figure 1. The effect of aerification procedures on soil compaction, when readings were taken with a cone penetrometer, 1 day after aerification, topdressing and irrigation. Candlewood Country Club, Whittier, CA. Compaction values higher than 300 psi are considered unacceptable for optimum plant growth.



To summarize what we found:

- The cone penetrometer provided a good estimate of soil compaction. However, if the area to be sampled is too narrow or too shallow, readings may not be accurate (see below).
- As expected, the areas between aerification holes were the most compacted, with acceptably low compaction readings only at the 1 and 2 inch soil depths. At depths of 3 inches and higher, the soil is sufficiently compacted to interfere with root growth.
- The vertidrain holes were the least compacted, with acceptable (less than 300 psi) compaction levels at depths up to 5 inches. This is why longer roots are able to grow in these holes, as illustrated in the photo on page 1.
- Aeration holes were surprisingly compacted. This may be due to the fact that the penetrometer probe doesn't provide accurate readings in these relatively narrow and shallow holes.
- As you probe deeper and deeper into the soil profile, compaction readings will get higher. This is an expected result, because the weight of the soil on top exerts a great deal of pressure on the soil below, which results in compaction.

Taking your own compaction readings

Knowing just how compacted your greens are can be useful in several contexts.

Timing of aerifications/peace of mind: If soils show an increasing trend towards compaction, you can schedule an aerification with the comfort of knowing that it truly is worth the time, effort and disruption.

Measuring the impact of management programs: If you have ever wondered how effectively soil amendments, topdressing sands or aerification procedures decrease compaction, you are not alone. Taking compaction readings can help you determine the value of these practices at your own location.

Communicating with golfers: Penetrometer readings are hard data that can be used to educate golfers, greens committees and managers about the value of aerification.

Taking readings is a relatively simple procedure:

- Obtain a soil compaction tester (cone penetrometer) from a company such as Spectrum Technologies (800-248-8873 or www.specmeters.com) for $199.00 If your soils are very compacted, you may need to purchase a gauge that reads higher than the 300 - 500 psi limit on most penetrometers (a 2 ½" liquid filled pressure gauge that reads up to 1,000 psi is available for $30 from Grainger's [model # 5A044] [www.grainger.com or 1-800-225-5994].
- Take your readings within a few hours after irrigation, when the soil is at, or near field capacity. This will ensure that moisture levels are consistent from one sampling date to the next.
- Using the ½ inch tip provided with the penetrometer, push down on the handles, with a slow but constant speed.
- Take note of the pressure readings at each of the soil depths marked on the stainless steel probe (most penetrometers have markings at 3 inch intervals). If feasible, take along a helper and have them record the numbers for you.

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