EXTENSION

Basics of Soil Bulk Density

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Soil bulk density can be defined as the mass of solid particles in a given volume of soil. These soil solids include mineral particles, such as sand, silt, clay and organic matter. Bulk density measurements are used to determine the compactness of soil. They are also used to determine the stocks of different soil constituents in a layer of soil, such as organic carbon. This is done by multiplying the bulk density with concentration of the element of interest in soil samples from a specific soil layer and multiplying by the thickness of that layer. Therefore, errors in bulk density measurements can result in over- or under estimation of soil carbon or other nutrient stocks. Bulk density values can change at different spots within same field. Also, the values can change overtime within the same field. Variations in bulk density can occur at spatial scale of a few feet as well as over time within a single growing season. Agronomic management, soil moisture level, clay type and accumulation of organic matter can change the bulk density of soil within a short time frame.

Bulk density is typically measured by taking soil core samples and obtaining their dry weight and total volume. Soil cores are collected using cylindrical sampling probes [Figure 1]. In this approach, a cylindrical core or probe with a known cutting-edge diameter is pushed into the soil. The diameter should ideally be 5 cm (2 in) or larger. Moist soil can be prone to compaction during the sampling process, and small diameter probes increase the likelihood of compaction. If there is evidence of compaction during sample collection, the sample should be discarded. Once the core or probe is inserted to the desired depth and removed from the soil, the soil sample is taken out carefully, making sure not to lose any material. If the sample remains intact, it may be divided into sub-samples of desired lengths. The length of each sample and diameter of cutting edge of core or probe are used to calculate the volume of the sample (Equation 2). The samples are then dried at 105 degrees Celsius for at least 24 hours. The dry weight of each sample is then divided by the volume of the sample to obtain the bulk density [Equation 1].

Figure 1. From left to right, Push Probe (diameter 2.26 cm), Giddings Probe (diameter 3.96 cm), and slide hammer soil sampling probe (diameter 4.8 cm).

$$Pb = \frac{Ms}{Vt} \qquad \text{[Eq. 1]}$$

Where, *Pb* is bulk density, Ms is mass of soil solids, and Vt is total volume of the soil core. Bulk density is often expressed in units of g/cm3 or Mg/m3. Also, because of the conversion math, both units have equal magnitudes. Soils with substantial amounts of coarse fragments, which are rocks and gravel >2 mm in size, present special challenges. Inserting the core or probe may be difficult or impossible due to coarse fragments. Coarse fragments are denser than

Bulk Density and Porosity

Texture	Bulk Density for root restriction (g/cm3)
Sandy	>1.80
Silty	>1.65
Clayey	>1.47

Table 1. Bulk density limits for different textured soils. Source: USDA: Soil Quality Indicators.

Any given total volume of soil is the sum of the volume of both soil solids and pore space. The total pore space in the soil is called porosity, which is defined as the pore volume divided by the total volume of soil. Bulk density has an inverse relation with porosity, because soil with high porosity will have lower bulk density than soils with low porosity. Sandy soils typically have a greater amount of macro pores (>75 micrometer) but lower overall porosity than finer textured soils. Finer-textured soils have smaller particle sizes and smaller pores but typically have greater porosity and lower bulk density. A compacted soil will have higher bulk density than a similar textured uncompacted soil. Table 1 shows the bulk density limits for soils, which are usually detrimental for plant growth that restrict root growth. Additionally, compact soil with low porosity is detrimental as it limits water-holding capacity of soil due to low pore space. A sampling study in Oklahoma from 47 fields reported average bulk density of 1.45 g/cm3 up to 30 cm, with a range of 1.23-1.67 g/cm3.

Bulk Density and Organic matter

Organic matter particles are less dense than soil mineral particles. Therefore, a soil with high organic matter will typically have lower bulk density than a soil of same texture but with lower organic matter. Bulk density tends to increase with depth irrespective of the texture (Figure 1), which can be explained by a few reasons. First, the organic matter content as well as the presence of root and macrofauna channels, which add to porosity, are highest at the surface layers. Second, the pressure tends to compact lower layers due to the weight of surface layers. Third, the soil structure tends to change from small granular at the surface to subangular blocky, blocky, prismatic, columnar and massive at the bedrock. The more granular structure at the surface contributes to porosity in the surface soil, resulting in lower bulk density.

Particle Density

Bulk density of soil should not be confused with particle density. Particle density is the density of the soil solids themselves, which is the mass of soil solid particles divided by the volume occupied by these soil particles. This volume does not contain the volume of pores. The relationship between particle density, porosity and bulk density is defined in Equation 2:

$$f = 1 - \frac{Pb}{Ps}$$

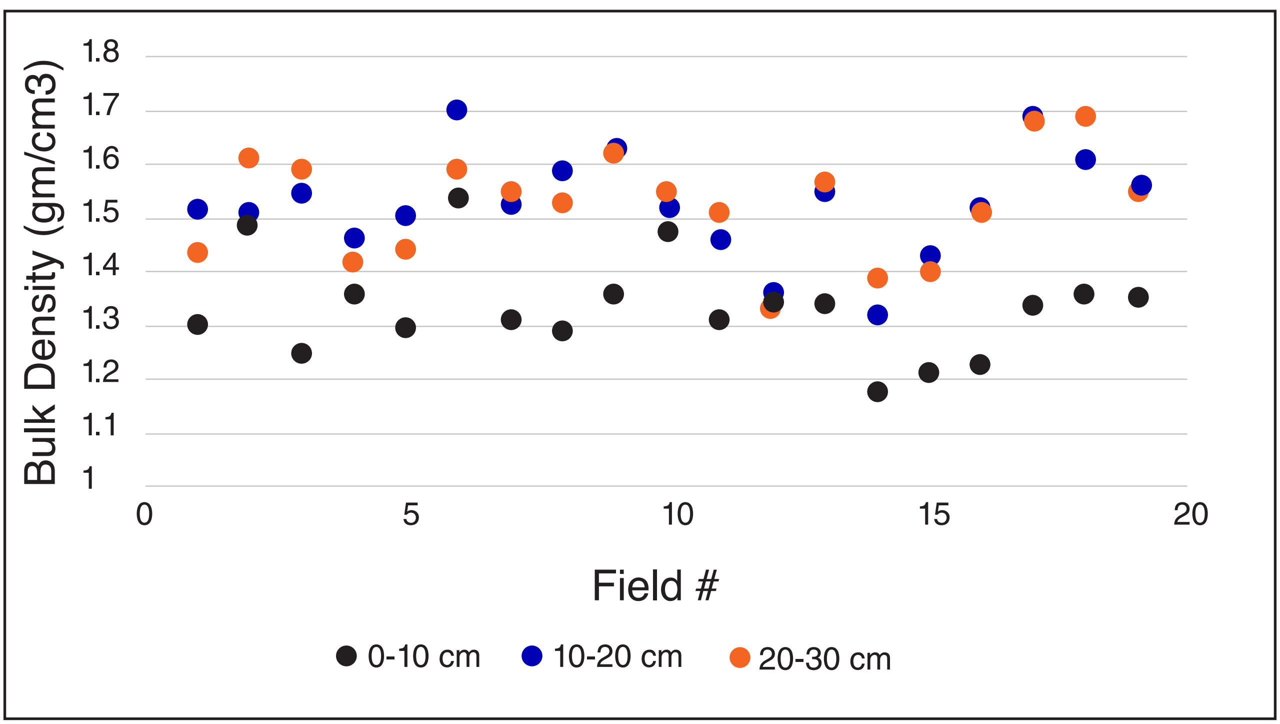

Figure 2. Bulk density measurements in 19 different fields across Oklahoma at 0-10, 10-20 and 20-30 cm depth. These soils include texture classes of fine sand, fine sandy loam, loam, silt loam, silty clay loam and clay loam.

Where f is porosity, *Ps* is particle density, and *Pb* is bulk density. If particle density of a particular soil has not been measured, an approximate value of 2.65 g/cm3 is often assumed.

Dynamic Property

Bulk density is a dynamic property that varies over small distances, as well as within a growing season. Spatial variation can be horizontal and vertical, as shown in Figure 1 where a majority of fields show increases in bulk density with depth, yet a few of the fields show a higher bulk density in the 10-20 cm layer than in the 20-30 cm layer. This could indicate compaction at the 10-20 cm depth, possibly due to tillage, wheel traffic or grazing livestock. Tillage can temporarily reduce the bulk density of the tilled layer, but over time settling and compaction can result in a higher bulk density than was present before the tillage event. No till systems can also be vulnerable to compaction by field equipment or livestock, and no-till systems do not experience the periodic loosening effects of tillage. Strip tillage practices can alter bulk density measurements between tilled and non-tilled strips of field. Changes in bulk density also occur when clay soils shrink and swell due to changes in soil water content. Density increases when these soils dry and shrink. Use of heavy machinery, especially when soil is wet, can compact the soil under the tire footprints of heavy agronomic machines. Therefore, all these factors should be kept in mind when sampling soil for bulk density.

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