USDA Natural Resources Conservation Service

Indicator	Test	Function
P	L/O	W/S

Soil Quality Indicators

Bulk Density


A three inch diameter ring is hammered into the soil to collect bulk density samples.

Bulk density is an indicator of soil compaction. It is calculated as the dry weight of soil divided by its volume. This volume includes the volume of soil particles and the volume of pores among soil particles. Bulk density is typically expressed in g/cm^3.

Factors Affecting

Inherent - Bulk density is dependent on soil texture and the densities of soil mineral (sand, silt, and clay) and organic matter particles, as well as their packing arrangement. As a rule of thumb, most rocks have a bulk density of 2.65 g/cm^3 so ideally, a medium textured soil with about 50 percent pore space will have a bulk density of 1.33 g/cm^3. Generally, loose, porous soils and those rich in organic matter have lower bulk density. Sandy soils have relatively high bulk density since total pore space in sands is less than that of silt or clay soils. Finer-textured soils, such as silt and clay loams, that have good structure have higher pore space and lower bulk density compared to sandy soils.

Bulk density typically increases with soil depth since subsurface layers have reduced organic matter, aggregation, and root penetration compared to surface layers and therefore, contain less pore space. Subsurface layers are also subject to the compacting weight of the soil above them.

The wetting and drying and freeze/thaw cycles that occur in soils naturally, generally do very little to alter soil bulk density.

Dynamic - Bulk density is changed by crop and land management practices that affect soil cover, organic matter, soil structure, and/or porosity. Plant and residue cover protects soil from the harmful effects of raindrops and soil erosion. Cultivation destroys soil organic matter and weakens the natural stability of soil aggregates making them susceptible to damage caused by water and wind. When eroded soil particles fill pore space, porosity is reduced and bulk density increases. Cultivation can result in compacted soil layers with increased bulk density, most notably a “plow pan” (see Figure 1). Livestock and agricultural and construction equipment exert pressure that compacts the soil and reduces porosity, especially on wet soils.

Relationship to Soil Function

Bulk density reflects the soil’s ability to function for structural support, water and solute movement, and soil aeration. Bulk densities above thresholds in Table 1 indicate impaired function. Bulk density is also used to convert between weight and volume of soil. It is used to express soil physical, chemical and biological measurements on a volumetric basis for soil quality assessment and comparisons between management systems. This increases the validity of comparisons by removing error associated with differences in soil density at time of sampling.

Problems with Poor Function

High bulk density is an indicator of low soil porosity and soil compaction. It may cause restrictions to root growth, and poor movement of air and water through the soil. Compaction can result in shallow plant rooting and poor plant growth, influencing crop yield and reducing vegetative cover available to protect soil from erosion. By reducing water infiltration into the soil, compaction can lead to increased runoff and erosion from sloping land or waterlogged soils in flatter areas. In general, some soil compaction to restrict water movement through the soil profile is beneficial under arid conditions, but under humid conditions compaction decreases yields.

Table 1. General relationship of soil bulk density to root growth based on soil texture.

Soil Texture	Ideal bulk densities for plant growth (g/cm³)	Bulk densities that restrict root growth (g/cm³)
Sandy	< 1.60	> 1.80
Silty	< 1.40	> 1.65
Clayey	< 1.10	> 1.47

The following practices can lead to poor bulk density:

- Consistently plowing or disking to the same depth,
- Allowing equipment traffic, especially on wet soil,
- Using a limited crop rotation without variability in root structure or rooting depth,
- Incorporating, burning, or removing crop residues,
- Overgrazing forage plants, and allowing development of livestock loafing areas and trails, and
- Using heavy equipment for building site preparation or land smoothing and leveling.

Improving Bulk Density

Any practice that improves soil structure decreases bulk density; however, in some cases these improvements may only be temporary. For example, tillage at the beginning of the growing season temporarily decreases bulk density and disturbs compacted soil layers, but subsequent trips across the field by farm equipment, rainfall events, animals, and other disturbance activities can recompact soil.

On cropland, long-term solutions to bulk density and soil compaction problems revolve around decreasing soil disturbance and increasing soil organic matter. A system that uses cover crops, crop residues, perennial sod, and/or reduced tillage results in increased soil organic matter, less disturbance and reduced bulk density. Additionally, the use of multi-crop systems involving plants with different rooting depths can help break up compacted soil layers.

To reduce the likelihood of high bulk density and compaction:

- Minimize soil disturbance and production activities when soils are wet,
- Use designated field roads or rows for equipment traffic,
- Reduce the number of trips across the area,
- Subsoil to disrupt existing compacted layers, and
- Use practices that maintain or increase soil organic matter.

Grazing systems that minimize livestock traffic and loafing, provide protected heavy use areas, and adhere to recommended minimum grazing heights reduce bulk density by preventing compaction and providing soil cover.

Conservation practices resulting in bulk density favorable to soil function include:

- Conservation Crop Rotation
- Cover Crop
- Deep Tillage
- Prescribed Grazing
- Residue and Tillage Management

Measuring Bulk Density

The Cylindrical Core Method is described in the Soil Quality Test Kit Guide, Section I, Chapter 4, pp. 9 - 13. See Section II, Chapter 3, pp. 57 - 58 for interpretation of results.

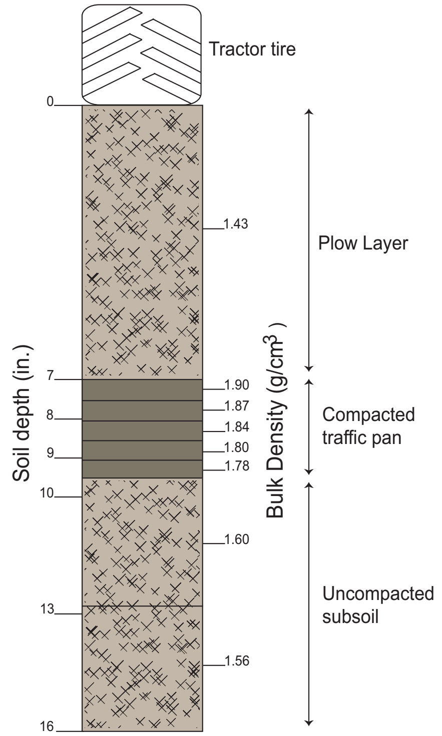
Reference: Arshad MA, Lowery B, and Grossman B. 1996. Physical Tests for Monitoring Soil Quality. In: Doran JW, Jones AJ, editors. Methods for assessing soil quality. Madison, WI. p 123-41.

Specialized equipment, shortcuts, tips:

A microwave or drying oven is required to process samples and a weighing scale is needed to determine the mass of the sample.

Time needed: 30 minutes

Figure 1. Tillage and heavy equipment traffic compacted soil below the plow layer of an Udult soil (Norfolk), inhibiting root penetration and water movement through the soil profile.



Adapted from: The Nature and Properties of Soils, 10th Edition, Nyle C. Brady, Macmillan Publishing Company.