

Chapter 66

Bulk Density Measurement in Forest Soils

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66.1 INTRODUCTION

Many of the physical properties important for assessing soils in agricultural systems are the same for forest soils. However, because of the nature of forest soils and terrain associated with forest ecosystems, the most appropriate methods for agricultural soils are not always suitable for forest soils. Coarse fragments, large roots, and steep slopes limit the suitability of some methods for forest soils (Page-Dumroese et al. 1999). In addition, surface organic horizons cover many forest soils and measuring their physical properties such as bulk density requires different sampling methods than mineral soils.

Compaction is one of the key physical processes that is affected by forest management and can influence soil productivity in forest soils (Powers et al. 1998). It has mainly been measured by bulk density but other measurements such as aeration porosity, and soil strength have been used to evaluate the effects of soil compaction. Soil strength can be determined by a cone penetrometer, a device that measures the soil's resistance to penetration by, for example, a root tip (Miller et al. 2001). Determining soil strength by using a cone penetrometer has certain advantages over measuring bulk density, but it is not effective in stony soils (e.g., high variation), a common condition in forest soils (Powers et al. 1998; Miller et al. 2001). Even when a penetrometer is used, bulk density data should be available to provide some interpretation of the readings (e.g., Miller et al. 2001). A recording penetrometer can be very useful in evaluating compaction at depth, such as from forest harvesting equipment traffic. Soil moisture content should be determined each time a penetrometer is used because readings will vary with moisture content, and different soil disturbances will often have different moisture contents (Busscher et al. 1997).

Organic matter plays a dominant role in the bulk density of the soil because of its much lower density than mineral particles and its aggregation effect on soil structure (De Vos et al. 2005). Generally, the higher the organic matter the lower the bulk density. Estimates of bulk density on specific soils have been made from organic matter concentrations using regression equations (e.g., Alexander 1989; Grigal et al. 1989; Huntington et al. 1989; Prevost, 2004). Caution should be used, however, in estimating bulk densities from organic matter content, particularly when applied to soils and environments different than the ones in which the original coefficients were calibrated (De Vos et al. 2005). This technique would only be useful for looking at general trends among soils and would not be appropriate for evaluating the effects of soil disturbance on compaction.

There are a number of factors that need to be considered in determining the most appropriate methods for assessing soil compaction. Quick, less accurate methods may be the most appropriate for field surveys while highly accurate, more expensive, and more time-consuming methods may be needed for research studies (Miller et al. 2001). However, some measure of bulk density is necessary to determine nutrient content (including carbon) on an area basis (kg ha^{-1}).

This chapter presents a bulk density method for surface organic (LFH) and mineral horizons in forest soils. The determination of bulk density on mineral soils is based on the excavation and sand replacement method (Blake and Hartge 1986). This method is particularly relevant to stony forest soils.

66.2 PRINCIPLE

The excavation and volume determination for bulk density is accurate, can be used in forest soils with high coarse fragment contents, and the samples can be used for additional physical and chemical analysis (Page-Dumroese et al. 1999; Maynard and Senyk 2004). The advantages of the excavation method are relative easy of use; it has a low standard error and can give an accurate estimate of coarse fragments (Page-Dumroese et al. 1999). Bulk density is determined on both the total soil and fine fraction (<2 mm). The fine fraction bulk density is critical when converting soil nutrient and carbon data to a mass-per-area basis for nutrient budgets and carbon balance studies in soils with high coarse fragment content, since usually only the fine soil fraction is analyzed for C or N. The main disadvantage of the excavation method is it is more labor-intensive than simple coring or nuclear methods. If sand is used to determine volume, then portability becomes an issue in remote locations; however, this can be partially overcome by using glass beads or polyurethane expanding foam (see Section 66.4.4) rather than sand to determine the volume of the hole.

66.3 SURFACE ORGANIC HORIZON (LFH)

66.3.1 MATERIAL AND SUPPLIES

- 1 Square frame (20×20 cm)
- 2 Knife, machete, clippers
- 3 Tape measure

- 4 Plastic bags
- 5 Forced air-dry oven capable of 105°C

66.3.2 PROCEDURE

- 1 For most forest soils, the bulk density of the LFH is not separated into individual organic layers (e.g., L, F, or H).
- 2 Place the frame (20 × 20 cm) on the surface of the organic material.
- 3 Remove green (live), above-ground plant materials like herbs, grasses, and live moss.
- 4 Cut out the organic material from inside the frame with the knife and put in a labeled plastic bag taking care to avoid contamination from the mineral soil. Small amounts of mineral material can result in large errors in the weight of the material because of the difference in bulk density between organic and mineral soil.
- 5 Take several measurements to determine the depth of the LFH (e.g., every corner and center of each side yields eight measurements).
- 6 At the laboratory, oven-dry the sample at 105°C for 24 h and determine the oven-dry weight. If a portion of the sample is going to be used for chemical analysis that requires field moist or air-dried material, then an intermediate step can be included to determine moisture content on a subsample and incorporate that into the procedure.

66.3.3 CALCULATIONS

$$V_{\text{LFH}} = 400 \text{ cm}^2 \text{ Dep}_{\text{LFH}} \text{ (cm)} \quad (66.1)$$

$$D_{\text{b(LFH)}} = \text{Wt}_{\text{(LFH)}}/V_{\text{LFH}} \quad (66.2)$$

where V_{LFH} is the volume of the hole (cm^3), Dep_{LFH} the depth of the hole, $D_{\text{b(LFH)}}$ the bulk density of the surface organic horizon, and Wt_{LFH} the oven-dry weight of the surface organic material.

66.3.4 COMMENTS

On soils with an Ah horizon under the LFH, distinguishing between the organic and mineral horizon may be difficult. In the field, if any mineral material is detected when a moist sample is smeared between the thumb and forefinger, the sample is likely mineral.

The size of the frame may have to be adjusted depending on the depth of the LFH. For example, if the forest floor is deeper than 20 cm, a smaller frame should be used to limit the volume of organic material collected.

66.4 MINERAL SOILS

66.4.1 MATERIAL AND SUPPLIES

- 1 Sand-funnel apparatus—a metal funnel with a valve on the stem to control the flow of sand when the funnel is inverted. The funnel is 10 cm in diameter matching the size of the hole in the template (commercially available).
- 2 Template is a flat metal plate 30 × 30 cm (ridged) with the 10 cm hole in the center.
- 3 Sand with uniform particle size that is clean, dry, and free flowing. Ottawa sand (mined in Ottawa, Illinois) is often used because the sand particles are relatively uniform in size and spherically shaped.
- 4 Field balance sensitive to 0.1 g.
- 5 Knife, clippers.
- 6 Tape measure.
- 7 Plastic bags.
- 8 Sieves—2 mm.
- 9 Forced air-dry oven capable of 105°C.

66.4.2 PROCEDURE

- 1 Fill a density cone bottle with sand and weigh. The weight of sand held in the cone is predetermined in the laboratory. This will be subtracted from the total weight of sand used to fill a hole.
- 2 When the sampling location is determined, remove moss and other vegetation and any organic horizon material from the surface of the soil.
- 3 Place a density plate over sampling spot using nails (20 cm in length) to hold it down. Place a plastic sheet under each side of the metal plate.
- 4 Using spoons, scissors, knife, and small trowel to remove soil in as close to a cylindrical pattern as possible, to the depth required placing the soil in a tared container.
- 5 Record the depth of the hole (cm). A standard depth of 10 cm is often used but for some conditions and depending on the objectives, sampling may be done by horizon depth.
- 6 Weigh container with the soil.

- 7 Place the soil from the container into a labeled plastic bag.
- 8 Place sand bottle with cone onto metal plate and open stopper to allow the sand to pour into the hole. Ensure a tight fit so that no sand leaks out between the cone and the plate.
- 9 When the sand stops flowing, close the stopper and remove the sand bottle. Reweigh the sand bottle.
- 10 Collect the sand left in the hole for reuse. If the sand is dirty or wet, sieve and dry it, or discard it.
- 11 Refill the sand bottle and weigh it for the next sample.
- 12 At the laboratory, remove the soil from the bags and air-dry the soil. Sieve the soil (breaking up the soil clumps only) to <2 mm fraction.
- 13 Weigh the <2 mm fraction of soil, and the coarse material (>2 mm), organic material (e.g., roots), and rock.
- 14 Oven-dry the <2 mm soil at 105°C for 24 h. If the sample is too large for complete oven-drying, or a portion of the sample is going to be used for chemical analysis that requires field moist or air-dried material, then an intermediate step can be included to determine moisture content on a subsample and incorporate that into the procedure.
- 15 Determine the oven-dry weight of the sample.

66.4.3 CALCULATIONS

The preferred SI unit is Mg m^{-3} , which is numerically equal to g cm^{-3} . Bulk density for fines (<2 mm soil fraction). The volume and weight of large roots may be important and can be determined using the same approach for determining the weight and volume of rock:

$$\text{WSH (g)} = (\text{SWB} - \text{SWA}) - \text{WSC} \quad (66.3)$$

$$\text{VH (cm}^3\text{)} = \text{WSH}/D_{\text{b(sand)}} \quad (66.4)$$

$$\text{VR (cm}^3\text{)} = \text{WR}/D_{\text{p(rock)}} \quad (66.5)$$

$$\text{VF (cm}^3\text{)} = \text{VH} - \text{VR} \quad (66.6)$$

$$\text{BDF (g/cm}^3\text{)} = \text{DWF}/\text{VF} \quad (66.7)$$

where

WSH = weight of sand in the hole,
 SWB = sand weight before inverting in the hole,
 SWA = sand weight after the hole is filled,
 WSC = weight of sand in the cone (predetermined in the laboratory),
 VH = volume of the hole,
 $D_{b(\text{sand})}$ = bulk density of the sand,
 VR = volume of the rock,
 WR = weight of the rock (>2 mm fraction),
 $D_{p(\text{rock})}$ = particle density of the rock (normally 2.65 g cm^{-3}),
 VF = volume of the fines,
 BDF = bulk density of the fines,
 DWF = oven-dry weight of the fines.

Total bulk density

$$TW = DWF + DWC \quad (66.8)$$

$$BDT = TW/VH \quad (66.9)$$

where

TW = total oven-dry weight of material removed from the hole,
 DWF = oven-dry weight of the fines,
 DWC = dry weight of the coarse fragments,
 BDT = total bulk density,
 VH = volume of the hole.

66.4.4 COMMENTS

The volume of the hole can also be determined with glass beads or polyurethane foam. If glass beads are used, a plastic bag is used to line the hole, and the bag is filled flush to the surface with the glass beads. The volume is then determined by pouring the beads into a graduated cylinder. If polyurethane expanding foam is used, foam is added to the excavated hole, covered with a piece of cardboard, and held in place with a rock while the foam dries—usually 2 h with fast-drying foam. Foam volume is determined in the laboratory by submersion in water (Muller and Hamilton 1992).

If more than one depth or horizon is to be sampled for bulk density, then it is necessary to dig a trench or small pit below the desired depth. The density plate is located at the edge of the trench. Once the surface bulk density has been sampled, the soil is removed (area of the plate) to the next depth (bottom of the hole) and a flat surface is prepared for the template.

The diameter of the hole in the density plate is usually 10 cm. Plates with larger diameter holes are available. Large diameter holes can reduce sample variability but collecting large samples particularly from remote locations may not be practical.

If a rock fills more than half of the hole, redo the sample.

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