Bulk Density Protocol

Purpose

To measure the bulk density of each horizon in a soil profile

Overview

In the field, students collect three soil samples from each horizon in a soil profile using a container with a measured volume. In the classroom, students determine the mass of the samples, dry them, and determine the mass of them again to determine their dry mass and water content. Students then sieve the dry soil samples and measure the mass and volume of any rocks and material with dimensions greater than 2 mm. Students use the *Bulk Density Data Sheet* to calculate the soil bulk density for each sample.

Student Outcomes

Students will be able to collect soil samples from the field and then measure their bulk density. Students will be able to apply mathematical formulas to calculate soil bulk density. Students will be able to relate soil bulk density measurements to soil particle density and porosity. Students will understand that a mixture of solid, liquid and gaseous matter may fill a volume.

Science Concepts

Earth and Space Sciences

- Earth materials are solid rocks, soil, water, biota, and the gases of the atmosphere.
- Soils have properties of color, texture, structure, consistence, density, pH, fertility; they support the growth of many types of plants.
- The surface of Earth changes.
- Soils are often found in layers, with each having a different chemical composition and texture.
- Soils consist of minerals (less than 2 mm), organic material, air and water.
- Water circulates through soil changing the properties of both the soil and the water.

Physical Sciences

- Objects have observable properties.
- Energy is conserved.
- Heat moves from warmer to colder objects.
- Chemical reactions take place in every part of the environment.

Scientific Inquiry Abilities

- Identify answerable questions.
- Design and conduct an investigation.
- Use appropriate tools and techniques including mathematics to gather, analyze and interpret data.
- Develop descriptions and explanations, predictions and models using evidence.
- Communicate procedures and explanations.

Time

2 or 3 (50-minute) class periods

Level

Middle and Secondary

Frequency

Once for a soil profile

Collected and prepared soil samples can be stored for study and analyses at any time during the school year.

Materials and Tools

- Balance
- Metal sampling cans or other containers
- Permanent marker
- Wood block
- Hammer
- Nail
- Pencil or pen
- Trowel, shovel, or other digging device
- Drying oven
- Graduated cylinder
- Water (or possibly alcohol if soil sample contains twigs)
- Sieve
- Latex gloves

Paper or plate to catch sieved soil

Sealable plastic bags to store samples

Bulk Density Data Sheet

Preparation

Collect required equipment.

Calibrate the balance to 0.1 g.

Determine the mass and volume of each can *not including the lid* and mark the value clearly on the can.

Punch a small hole at the bottom of each can using a nail and hammer.

Prerequisites

Soil Characterization Protocol

Bulk Density Protocol – Introduction

Soil bulk density is a measure of how dense and tightly packed a sample of soil is. It is determined by measuring the mass of dry soil per unit of volume (g/mL or g/cm^3). The bulk density of soil depends on the structure (shape) of the soil peds, how tightly they are packed, the number of spaces (pores), and the composition of the soil particles. Soils made of minerals will have a different bulk density than soils made of organic material. In general, soil bulk density can range from 0.5 g/mL or less in organic soils with many pore spaces, to as high as 2.0 g/mL or greater in very compact mineral horizons.

Bulk density is used to convert between mass and volume of a soil sample. The volume of a soil sample can be calculated by dividing the sample mass by the bulk density of the soil. Conversely, the mass of a soil sample can be calculated by multiplying the sample volume by the bulk density of the soil. The fraction of pore space in a soil, its porosity, is calculated as one minus the ratio of bulk density to particle density:

$$\text{Porosity} = 1 - (\text{Bulk Density}/\text{Particle Density})$$

The bulk density of a soil sample should be adjusted for any rocks or coarse fragments it contains. The bulk density measurement is a valuable tool for understanding soil processes such as heat, water and nutrient exchange, but only if measured for soil material less than 2 mm in size. The following equation helps to correct the bulk density for rocks in a soil sample:

$$\frac{\text{Mass of dry soil (g)} - \text{Mass of Rocks (g)}}{\text{Volume of dry soil (mL)} - \text{Volume of Rocks (mL)}} = \text{Bulk Density (g/mL or g/cm}^3\text{)}$$

Teacher Support

Preparation

Students should review the *Bulk Density Field and Lab Protocol* prior to collecting samples in the field.

Students should have a basic understanding of the concepts of mass and volume and density calculation before they begin this protocol.

Teachers should demonstrate the various methods that can be used to determine volume before students measure the volume of their sampling containers.

Holes need to be punched into the bottoms of the sample cans or containers before they are used in the field. This allows air to escape so that the soil completely fills the container. Students will know that the volume of the container has been completely filled when soil begins to appear through the hole.

As an alternative method, pipes can be used instead of cans to sample bulk density.

Measurement Procedures

In the field, metal cans or other containers are pushed into the soil horizons to obtain samples with specific volumes.

After bringing the soil samples back from the field, students measure the wet mass of the soil before drying. Although this information is not used in the bulk density calculation, it helps students make connections to soil moisture content.

Bulk density is calculated from the mass of a given volume of dry soil, including the air spaces, but excluding materials larger than soil, such as rocks or materials with dimensions greater than 2.0 mm.

In the lab, soil samples are dried in order to obtain the dry mass of the soil. After determining the mass of the dry samples, the samples are sieved and rocks or other material with dimensions greater than 2 mm are separated. The mass of all the material with dimensions greater than 2 mm is determined, and its volume is determined for the amount of water that it displaces.

The cans or pipes that were used for collecting the soil samples must be massed and their volumes measured. For a can, the first step in measuring volume is filling the can with water. The water is then poured from the can into a graduated cylinder and the volume is measured in mL. For a pipe, the volume of the pipe will have to be determined using the equation:

$$\text{Volume of a pipe} = \text{Pi} \times r^2 \times h \times 1 \text{ mL}/1 \text{ cm}^3$$

Where:

Pi is the mathematical constant approximately equal to 3.141592654

r is the radius of the base of the pipe (cm)

h is the height of the pipe (cm)

There are many potential sources of error for the measurements described in this protocol. Taking three replicate samples for each horizon helps to minimize the overall error. Errors may occur if the sampling containers are not completely filled with soil, if the sides of the sampling container are too thick and compress the soil, if the sampling container becomes badly deformed being pushed into the soil, if the soil is not completely dried, or if all rocks are not removed.

Sometimes, after sieving a soil sample, small twigs are left. When these twigs are put in water to measure their volume, they float. To measure their volume, a lower density liquid, such as alcohol, is used instead of water.

Managing Materials

Metal sampling cans, such as those used in the *Gravimetric and Volumetric Soil Moisture Protocol* can be used for bulk density sampling. Containers other than sample cans may also be used to obtain soil samples. These should be thin walled (so as not to compress the soil), and have a known volume. Possible materials may include thin walled pvc pipe or other pipe or pipes, and other types of metal cans with thick sides, such as those used for tuna fish or cat food. Do not use glass or other materials that may break or be easily deformed. As long as volume can be calculated for the container, and it can be completely filled with soil, it is acceptable to have both ends open (such as would occur if using a pvc pipe or pipe). In this case, however, the formula Pi x radius^2

x height must be used to calculate the pipe volume (see above).

Supporting Activities

Particle density is similar to bulk density, but it includes only the mass of the solid (mineral and organic) portion of the soil and the volume does not include the pore spaces where air and water are found. Bulk density and particle density data are used to determine the porosity of a soil. If your class is interested in porosity, have students measure particle density and calculate porosity (See *Particle Density Protocol*).

Students remove rocks and materials from the soil samples as part of the bulk density measurement. Have students follow the *Particle Size Distribution Protocol* to gain a better understanding of the distribution of different sizes of soil particles in each horizon of a soil profile.

Have students compare their bulk density data with the soil characterization data to determine whether there are correlations between the physical and chemical properties of each horizon and its bulk density.

Latex gloves are used to avoid contaminating the soil sample with acids from your skin.

Questions for Further Investigation

What human activities could change the bulk density of the soil?

What natural changes could alter the bulk density of a horizon?

How does bulk density affect the types of vegetation that can grow on a soil?

How does bulk density affect root growth and distribution?

How are soil texture and bulk density related?

How are soil structure and bulk density related?

How does bulk density affect the flow of water or heat in soil?

Soil Bulk Density

Field and Lab Guide

Task

To obtain three bulk density measurements for a given soil horizon in a soil profile

What You Need

- ❑ Balance
- ❑ Sampling cans or other containers or pipes (enough for three per horizon plus a few extra, in case some of the cans bend)
- ❑ Permanent marker
- ❑ Wood block
- ❑ Hammer
- ❑ Nail
- ❑ Pencil or pen
- ❑ Sealable plastic bags, jars, or other containers to store samples and extra soil
- ❑ Drying oven
- ❑ Graduated cylinder
- ❑ Water (or possibly alcohol if soil samples contain twigs)
- ❑ #10 Sieve (2 mm mesh openings)
- ❑ Latex gloves
- ❑ Paper to catch sieved soil
- ❑ Rolling pin, hammer, or other utensil for crushing peds and separating particles
- ❑ Trowel, shovel, or other digging device
- ❑ One copy of the *Bulk Density Data Sheet* per horizon
- ❑ paper or cloth wipe towel

In the Classroom Before Sampling

1. Collect required equipment. You will need 3 cans or pipes for each horizon that you identified at your *Soil Characterization Site*. If you think that the cans may bend as they are hammered into the soil at your site, you should prepare extra cans to bring to the field.

2. Punch a small hole into the bottom of each can using the nail and hammer. (**Note:** this is not necessary if using a pipe with two open ends).

In the Field

1. Go to your *Soil Characterization Study Site*. For each horizon in your soil profile, push a can or pipe into the side of the horizon (images 1a and 1b). If necessary, wet the soil first in order to ease the can into the soil. Stop when soil pokes through the small hole in the bottom of the can (or has reached the edge of the pipe, so that the pipe is full of soil). If it is difficult to push the can into the soil, place a piece of wood over the can and hit the wood with a hammer (image 2). This spreads the force of the hammer blow to all edges of the can at once and minimizes bending the can sides. If the sides of the can become bent, this will change the volume of the can and may compact the soil sample, affecting the measurement results. If the sides of a can bend beyond perpendicular, discard that can and use another.

   Note: If you do not have a pit or other exposed soil profile you can measure the bulk density of the soil surface as follows:

   a. Choose three locations close to the site where you performed the *Soil Characterization Protocol*. Remove vegetation and other material from the soil surface.
   b. At each of the three locations, push a can or pipe into the surface of the soil. If necessary, wet the soil first in order to ease the can into the soil. Stop when soil pokes through the small hole in the bottom of the can (or has reached the edge of the pipe, so that the pipe is full of soil).

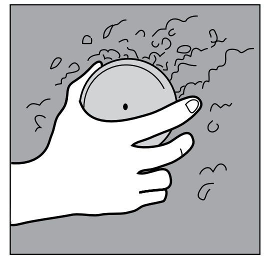


Image 1a, pushing sample can into soil

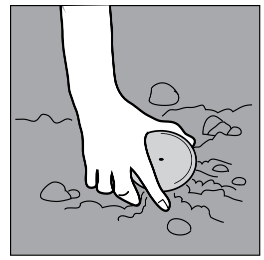


Image 1b, pushing sample can into soil

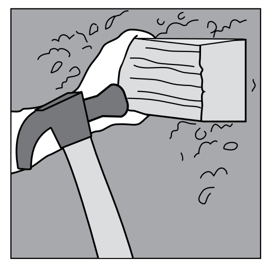


Image 2, pushing sample can into soil

2. Using a trowel or shovel, dig around the can or pipe to remove it and the surrounding soil. Trim the soil from the top of the can (and bottom for a pipe) and around the edges of the can so that the volume of the soil is the same as the volume of the can or pipe.

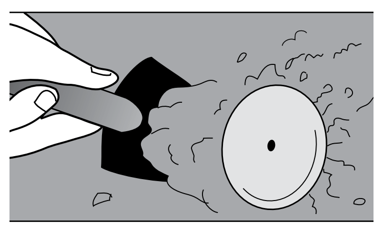


Image 3, use trowel to dig up sample can

3. Cover the can with its lid or other cover. Label the can with a container number (image 4) and record this number on your *Data Sheet*. If using a pipe, label it with a container number, record this number on your *Data Sheet*, and place the pipe in a plastic bag.

4. Repeat this procedure so that you have three bulk density samples for each horizon in your profile (image 5).

Image 4, label the sample cans

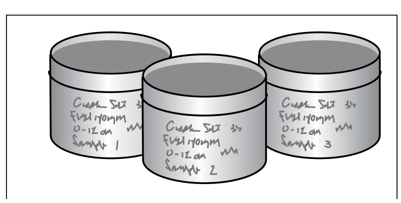


Image 5, repeat procedures for three samples per horizon

In the Classroom After Sampling

1. Calibrate the balance to 0.1 g.

2. Remove the lid off the sample can. Measure the mass of each sample in its can (image 6), and record this as the wet mass on the *Bulk Density Data Sheet*. If you used a pipe instead of a can, remove the pipe filled with soil from the plastic bag and weigh it to determine the wet mass, which should then be recorded on the *Bulk Density Data Sheet*.

Image 6, weigh wet mass sample and can

3. Dry the samples in a soil-drying oven (image 7). See the *Gravimetric and Volumetric Soil Moisture Protocol* for instructions on drying soils.

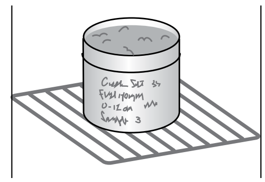


Image 7, dry sample without lid in oven

4. After the soils have dried, determine the mass of each sample and its container (image 8) and record this as the dry mass on the *Bulk Density Data Sheet*.

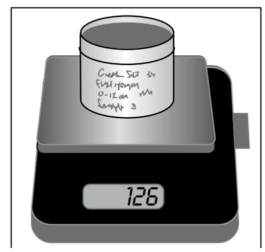


Image 8, weigh dry mass sample and can

5. Place a sieve (#10, 2 mm mesh) on a paper plate or large piece of paper (such as newspaper) and pour one sample onto the sieve (image 9).

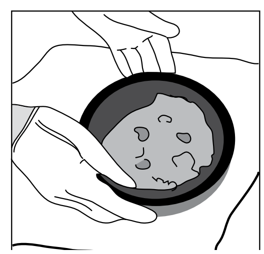


Image 9, pour sample through sieve

6. Wipe the inside of the can or pipe with a wipe towel (image 10). Measure the mass of the can or pipe without the lid on and record this mass on the *Data Sheet*.

Image 10, wipe inside of sample can

7. To measure the volume of the clean, dry container, fill the 500 mL graduated cylinder with water. Record the initial volume (Vi) of water in milliliters. Pour water from the cylinder into the container filling it to the brim (Image 11). Record the volume of water remaining in the graduated cylinder (Vf). To obtain the volume of the container, subtract the remaining volume of the water in the graduated cylinder (Vf) from the initial volume (Vi) of water. This calculation, (Vi) - (Vf), will provide you with the volume of the container.
   For pipes, measure the mass and calculate the volume using the following equation:

   $$\text{Volume pipe} = \text{Pi} \times r^2 \times h \times 1\ \text{mL}/1\ \text{cm}^3$$

   where Pi is the mathematical constant approximately equal to 3.141592654
   r is the radius of the base of the pipe (cm)
   h is the height of the pipe (cm)

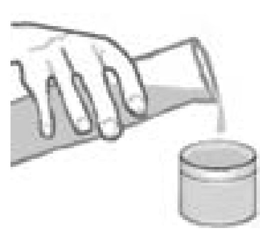


Image 11, measure volume of sample can

8. Put on latex gloves to avoid contaminating your sample with acids from your skin, and pick up the sieve full of soil.

Image 12, Push dry soil through sieve

9. Carefully push the dried soil material through the mesh onto the paper plate. Be careful not to bend the wire mesh by forcing the soil through. Rocks will stay on top of the sieve. If no sieve is available, carefully remove the rocks by hand. Save the sieved soil from each sample for other lab analyses.

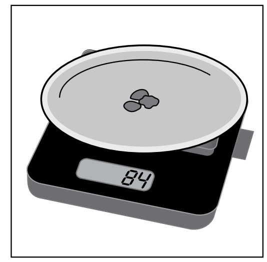
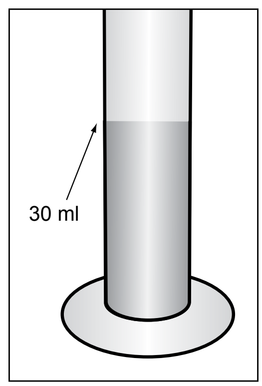


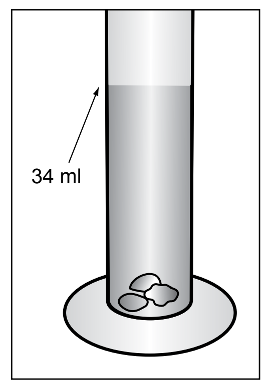
Image 13, determine mass of rocks

10. If rocks are present, use the following procedure to determine the mass and volume of the rocks.
    a. Measure the mass of these rocks (image 13) and record on the *Bulk Density Data Sheet*.
    b. Place 30 mL of water in a 100 mL graduated cylinder. Record this volume of water on the *Bulk Density Data Sheet*. Gently place the rocks in the water. Read the level of the water after all the rocks have been added. Record this volume of water on the *Bulk Density Data Sheet*.

Note: As you add the rocks, if the volume of water and rocks in the cylinder comes close to 100 mL, record the increase in volume, empty the cylinder and repeat the procedure for the remaining rocks. In this case, you must record the sum of the water volumes with the rocks and the sum of the water volumes without the rocks.

If you have sticks or other organic debris, substitute alcohol for water, and follow the same procedure.





Images 14a and 14b, measure volume of rocks by water displacement

11. Transfer the rock-free dry soil from the paper under the sieve to clean dry plastic bags or containers (image 15). Seal the containers, and label them with horizon number, top and bottom depth, date, site name, and site location. This soil can now be used for other lab analyses. Store these samples in a safe, dry place until they are used.

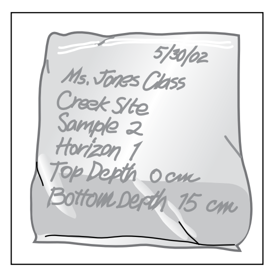


Image 15, place sieved soil in labeled bags

Bulk Density Protocol – Looking at the Data

Are the data reasonable?

Typical bulk density values for soils average around 1.3 g/mL (g/cm^3) for soils composed mostly of mineral particles. However, they can be as high as 2.0 g/mL (g/cm^3) for very dense horizons, and as low as 0.5 g/mL (g/cm^3) or lower for organic soils.

To calculate the bulk density of a soil sample complete the calculations on the *Soil Bulk Density Data Sheet*.

What were the results of your data?

If the bulk density for a soil sample is <1.0, it has a very low density and may have a high organic matter content. In order to identify organic matter, look for a dark color and the presence of roots. Many times, soil horizons on the surface are high in organic matter.

If the bulk density for a soil sample is near 2.0 or greater, it is a very dense soil. Soils become dense if they have been compacted and do not have a high organic matter content. This is common in surface soils on which people walk or where machinery has compressed the soil. Soils with massive or single grained structure will have higher densities than soils with granular or blocky structure. The texture of the soil can also affect the bulk density. In general, sandy soils have a higher bulk density than clayey or silty soils, because the porosity is lower although the size of the pores is larger in sandy soils.

If the bulk densities of soil samples do not seem to be consistent with the other properties of the same horizon (color, structure, texture, depth in the profile, root content), then there may be an error in the measurement. The methodology and calculations should be checked for errors.

What do scientists look for in these data?

Many different scientists use information about soil bulk density, particle density, and porosity. They use bulk density to estimate how tightly packed the soil components are in each horizon.