Soil Particle Density Protocol

Purpose

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

Overview

Students weigh a sample of dry, sieved soil from a horizon, mix it with distilled water and then boil the mixture to remove any air. The mixture cools for a day and then students add water until the volume of the mixture is 100 mL. Students measure the temperature and mass of the final mixture and use the *Soil Particle Density Data Sheet* to calculate the soil particle density. Three samples should be measured for each horizon.

Student Outcomes

Students will be able to apply laboratory tests for particle density to soil samples. Students will be able to calculate soil particle density and porosity using mathematical formulas. Students will be able to relate soil particle density to bulk density and porosity.

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.

Soils consist of minerals (less than 2 mm), organic material, air, and water.

Physical Sciences

Objects have observable properties.

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

Two 45-minute class periods

Level

Middle and Secondary

Frequency

Three times for each horizon in 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

Oven-dried, sieved soil

100-ml volumetric or Erlenmeyer flask(s) with cap(s) or stopper(s)

Distilled water

Pencil or pen

Small funnel

Thermometer

Balance accurate to within 0.1 g

Squirt bottle for washing soil out of beaker

Hot plate or Bunsen burner or other heat source

Oven mitts or tongs

Soil Particle Density Data Sheet

Preparation

Dry and sieve soil samples; store them in sealed containers.

Collect required equipment.

Calibrate the balance to 0.1 g.

Prerequisites

Soil Characterization Protocol

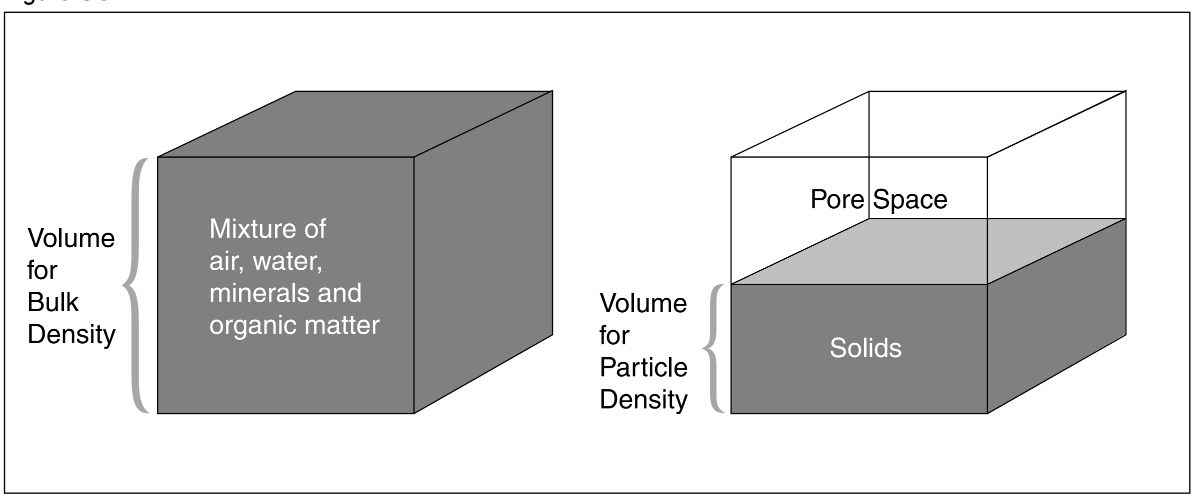
Soil Particle Density Protocol – Introduction

The particle density of a soil measures the mass of a soil sample in a given volume of particles (mass divided by volume). Particle density focuses on just the soil particles and not the total volume that the soil particles and pore spaces occupy in the soil. Particle density differs from bulk density because bulk density includes the volume of the solid (mineral and organic) portion of the soil along with the spaces where air and water are found. The density of soil particles is a result of the chemical composition and structure of the minerals in the soil. See Figure SO-DE-1.

Particle density data are used to better understand the physical and chemical properties of the soil. For example, the particle density indicates the relative amounts of organic matter and mineral particles in a soil sample. The chemical composition and structure of minerals in a soil sample can be deduced by comparing the soil's particle density to the known densities of minerals such as quartz, feldspar, micas, magnetite, garnet, or zircon.

Particle density data are also used with bulk density data to calculate the pore space (porosity) occupied by air and water in a soil sample. With this knowledge about the properties of a soil, students and scientists gain a better understanding of the soil's function within the ecosystem of an area and can better interpret soil moisture measurements.

Figure SO-DE-1



Teacher Support

Preparation

Have students conduct the *Bulk Density Protocol* in order to gain a better understanding of density as a measure of the amount of mass in a given volume. Students also need to measure bulk density in order to calculate soil porosity.

Measurement Procedures

To calculate soil particle density, students measure the mass and the volume of *only the solid particles* in a soil sample, not the air and water found within the pore spaces between the particles.

Students carry out this measurement by putting a soil sample in a flask with distilled water. The soil/water mixture is boiled to remove all air from the sample. After the mixture has cooled, water is added to the mixture to obtain a specified volume. The mass of this mixture is then measured. The mass of the water is then subtracted from the mass of the soil and water. The particle density is calculated from the mass of the solid particles in a specified volume.

Safety Precautions

Students need to know how to safely use Bunsen burners or other heating elements for boiling the soil/water mixtures.

Students should practice using tongs or oven mitts to lift the volumetric or Erlenmeyer flasks that hold the soil/water mixtures.

Students can boil practice mixtures of soil and water to ensure they do not let the actual soil samples boil over.

Supporting Activities

Have students compare their soil characterization data with soil particle density data to see if they can correlate the horizons' physical and chemical properties with their soil particle densities.

Questions for Further Investigation

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

How does parent material affect the particle density of a horizon?

How does particle density affect soil temperature?

What is the relationship between particle density and plant growth?

How can particle density affect the way water moves through the soil?

Does particle density relate to soil color? If so, how?

Does particle density relate to the presence of carbonates? If so, how?

How does particle density relate to the uses of a soil?

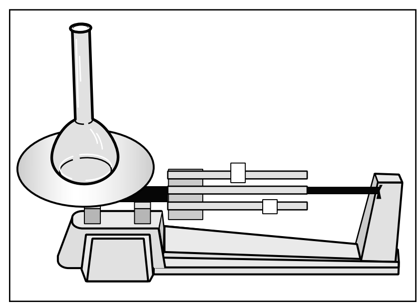
Does particle density relate to particle size distribution? If so, how?

Soil Particle Density
Lab Guide

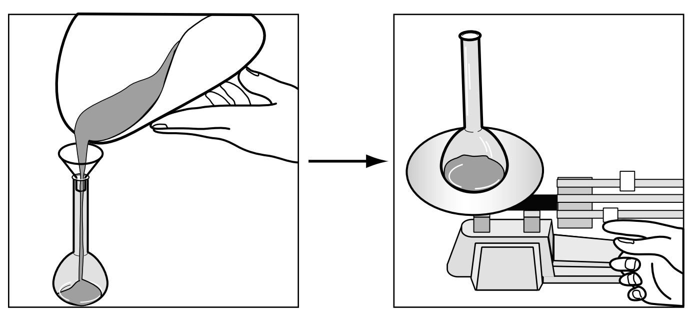
Task
To measure the particle density of a soil sample

What You Need
- ❑ Oven-dried, sieved soil
- ❑ Distilled water
- ❑ Small funnel
- ❑ Balance accurate to 0.1 g
- ❑ Squirt bottle
- ❑ Oven mitts or tongs
- ❑ Three 100 ml volumetric or Erlenmeyer flasks with caps or stoppers
- ❑ Pencil or pen
- ❑ Thermometer
- ❑ Squirt bottle for washing soil out of beaker
- ❑ Hot plate or Bunsen burner or other heatsource
- ❑ *Soil Particle Density Data Sheet*

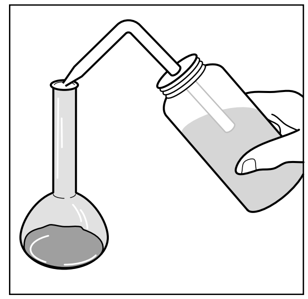
In the Lab
1. Place distilled water in squirt bottle.
2. At the top of the *Data Sheet,* note the length of time since the soil was dried in an oven, and how the soil has been stored (e.g. in plastic bag, air tight container, other).



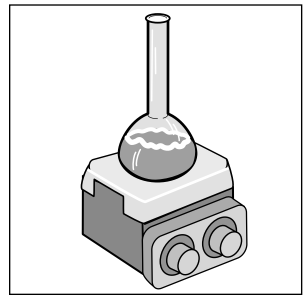
3. Measure the mass of the empty flask without its cap. Record the mass on the *Soil Particle Density Data Sheet*.
4. Measure 25 g of dried, sieved soil. Place soil in the flask using the funnel. Since it is important to have all 25 g of soil in the flask, be careful to transfer all the soil into the flask and not to spill any soil outside the flask (**Note:** if soil is spilled outside the flask, repeat this step with another 25 g sample).



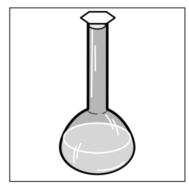
5. Measure the mass of the flask containing the soil (without the stopper/cap). Record the mass on the *Soil Particle Density Data Sheet*.



6. Use the squirt bottle to wash any soil sticking to the neck of the flask down to the bottom of the flask. Add about 50 ml of distilled water to the soil in the flask.



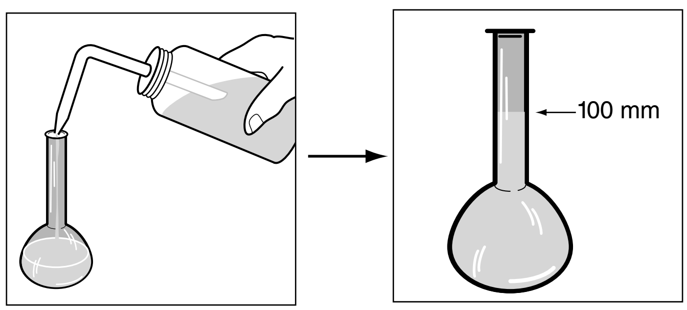
7. Bring the soil/water mixture to a gentle boil by placing the flask on a hot plate or holding it over a Bunsen burner. Gently swirl the flask for 10 seconds once every minute to keep the soil/water mixture from foaming over. Boil for 10 minutes to remove air bubbles.

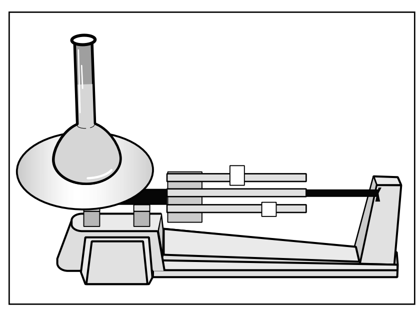


8. Remove the flask from the heat and allow the mixture to cool.

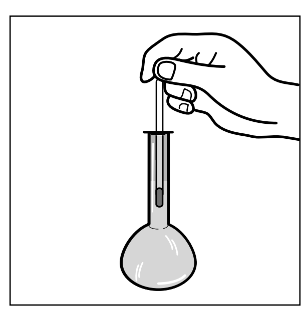
9. Once the flask has cooled, cap the flask and let it sit for 24 hours.

10. After 24 hours, remove the stopper/cap and fill the flask with distilled water so that the bottom of the meniscus is at the 100 mL line.





11. Weigh the 100 mL-soil/water mixture in the flask (without the stopper/cap). Record the mass of the mixture on the *Soil Particle Density Data Sheet*.



12. Place the bulb of the thermometer in the flask for 2-3 minutes. When the temperature has stabilized, record the temperature of the mixture on the *Soil Particle Density Data Sheet*.

Particle Density Protocol–Looking at the Data

Are the data reasonable?

Typical particle densities for soils range from 2.60 to 2.75 g/cm^3 for mineral particles. However, they can be as high as 3.0 g/cm^3 for very dense particles and as low as 0.9 g/cm^3 for organic particles. In order to calculate the soil particle density for your sample, use the information from the *Soil Particle Density Data Sheet* and follow the steps given in the *Calculation Work Sheet*.

What do scientists look for in these data?

Particle density measurements provide information about the kinds of material present in a soil. If the particle density is high, we know that the parent material of the soil consists of minerals that have a high density. This information provides insight into the geologic history of the soil. A low particle density (<1.0 g/cm^3) indicates high organic matter content. It also provides information about the potential release of carbon from the soil into the atmosphere as the organic matter decomposes over time.

Scientists are also interested in knowing how much space is in the soil (porosity). This information tells them how much air and water can be stored in the soil profile. It also tells them the rate at which air, water and heat will move through the soil profile. By knowing this they can better understand the behavior of the soil, predict flooding, verify the types of life the soil can support, identify how the soil may change, and determine how the soil may be best used for human activities.

Calculating Soil Porosity

The amount of pore space, or porosity, of the soil is calculated according to the following equation:

$$\text{Porosity} = 1 - \left(\frac{\text{Bulk Density}}{\text{Particle Density}}\right) \times 100\%$$

Bulk Density = mass of dry soil / total volume of soil and air (g/cm^3)

Particle Density = mass of dry soil / volume of soil particles only (air removed) (g/cm^3)

$$\frac{\text{Bulk Density}}{\text{Particle Density}} = \frac{\text{Volume of dry soil}}{\text{Volume of dry soil and pore space}}$$

This value will always be less than or equal to 1. So the value (1 - Bulk Density/Particle Density) will be between 0 and 1. This value is then multiplied by 100 to calculate the percent porosity.

For example, students take three soil samples for bulk density and soil particle density for each horizon at the soil pit at their Land Cover Sample Site. After performing the *Bulk Density* and *Soil Particle Density Protocols*, they determine:

Bulk Density:

Mass of dry soil = 395 g

Total soil volume = 300 cm^3

Bulk density (mass of dry soil/total soil volume):
395 g/300 cm^3 = 1.32 g/cm^3

Particle Density:

Mass of dry soil = 25.1 g

Volume of dry soil = 9.5 mL (cm^3)

To calculate particle density (mass of dry soil/volume of particles only):

25.1 g/9.5 cm^3 = 2.64 g/cm^3

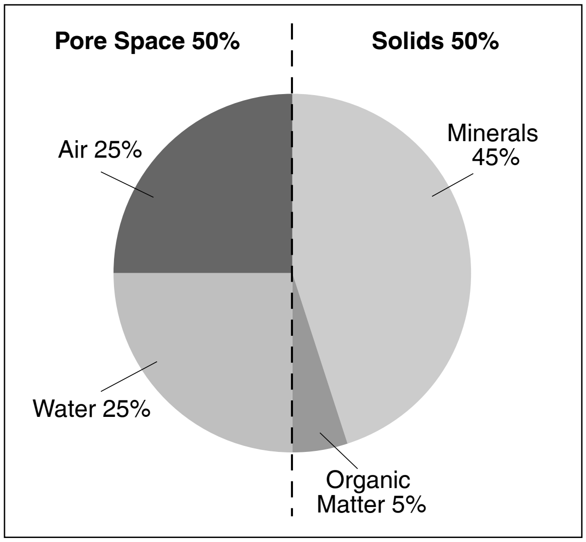
Porosity:

Using these values in the equation for porosity:

$$\text{Porosity} = 1 - \left(\frac{\text{Bulk Density}}{\text{Particle Density}}\right) \times 100\%$$

$$1 - \left(\frac{1.32}{2.64}\right) \times 100\% = 50\%$$

Figure SO-DE-2: A Good Soil for Most Plant Growth



Thus, 50% of the total soil is pore space. The pore space at this site may be filled by either air or water or a combination of both.

A good soil for growing most plants contains about 50% pore space and 50% solids. The pore space should be filled half with air and half with water, and the solids should be a mixture of minerals with some organic matter. See Figure SO-DE-2.

In some cases, certain plants, such as rice or wetland species, require much more water than air in the soil pore spaces in order to grow properly. For other uses of the soil, such as for building roads or foundations, the soil should have much more air than water occupying its pore spaces.

While the porosity reveals the amount of total pore space the soil has, it does not tell exactly how much air or water is in the soil at a given time. The amount of water in the soil is determined through the methods of the *Soil Moisture Protocol*. The total pore space can be determined and the amount of that space occupied by air and water becomes known. This information determines how well plants will grow, whether the soil is dry or saturated, and what is the best plan for managing that particular soil.

How saturated is a soil?

The *Soil Moisture Protocol* measures Soil Water Content (SWC) as the ratio of the mass of water to the mass of dry soil in a sample. Knowing the soil particle density, the bulk density, and the density of water, the ratio of the volume of water to the volume of soil may be calculated along with the percentage of the pore space filled with water.

$$\frac{\text{Volume of Water (mL)}}{\text{Volume of Soil (mL)}} = \text{Soil Water Content (g/g)} \times \frac{\text{Bulk Density (g/cm}^3\text{)}}{\text{Density of Water (g/cm}^3\text{)}}$$

$$\text{Volume of Pore Space (mL)} = \text{Porosity} \times \text{Volume of Soil (mL)}$$

$$\frac{\text{Volume of Water (mL)}}{\text{Volume of Pore Space (mL)}} = \frac{\text{Soil Water Content (g/g)}}{\text{Porosity}} \times \frac{\text{Bulk Density (g/cm}^3\text{)}}{\text{Density of Water (g/cm}^3\text{)}}$$

So, if SWC = 0.20 g/g, Bulk Density = 1.32 g/cm^3, Density of Water = 1.00 g/cm^3, and Porosity = 0.50 (50%), then

$$\text{Percentage of Pores Filled with Water} = \frac{\text{Volume of Water}}{\text{Volume of Pore Space}}$$

$$= \frac{0.20 \text{ g/g}}{0.50} \times \frac{1.32 \text{ (g/cm}^3\text{)}}{1.00 \text{ (g/cm}^3\text{)}} \times 100 = 52.8\%$$

Examples of Student Research Investigations

Students from the Grassland School in Illinois, USA, wanted to determine the amount of water their soil held. They were concerned about flooding during the approaching rainy season. They characterized the soil at their school and took samples from four horizons to a depth of 100 cm. They knew that if they calculated both the particle density and bulk density of each horizon, they could determine the porosity of the soil. Knowing the porosity of the soil would allow the students to know how much space each horizon had to hold water. For each of the horizons, the students determined the particle density and bulk density following the GLOBE protocols. Soil Characterization data for each of the four horizons the students studied is given in Table SO-DE-1. Table SO-DE-2 shows how the students determined the Particle Density of the soil in Horizon 1.

Table SO-DE-1

Horizon #	**Top depth (cm)**	**Bottom Depth (cm)**	**Thickness (cm) (bottom-top depth)**	**Texture (by feel)**	**Main Color**
1	0	10	10	Silt loam	10YR 2/2
2	10	35	25	Silty clay loam	10YR 6/4
3	35	70	35	Silty clay	7.5YR 5/6
4	70	100	30	Clay	7.5YR 6/8

Horizon #	**Structure**	**Consistence**	**Roots**	**Rocks**	**Bulk Density (mean)**
1	granular	Friable	Many	None	0.8
2	blocky	Friable	Few	None	1.3
3	blocky	Firm	Few	Few	1.2
4	blocky	Firm	None	Few	1.1

Table SO-DE-2

	Horizon 1	**Sample Number**		
		1	2	3
A	Mass of soil + empty flask (g)	82.0	83.0	81.0
B	Mass of empty flask (g)	57.0	58.0	56.0
C	Mass of soil (g) (A – B)	25.0	25.0	25.0
D	Mass of water + soil +flask (g)	169.5	169.9	169.0
E	Mass of water (D – A)	87.5	86.9	88.0
F	Water Temperature (° C)	20	20	20
G	Density of water (g/mL) (approximately 1.0)	1.0	1.0	1.0
H	Volume of water (mL) (E/G)	87.5	86.9	88.0
I	Volume of soil (mL) (100 mL – H)	12.5	13.1	12.0
J	Soil particle density (g/mL) (C/I)	2.0	1.9	2.1
	Mean of Particle Density of Horizon (from 3 Replicates)	**2.0 g/mL**		

The students used the same method to calculate particle density values for the other three horizons. The results (based on the mean of three replicates for each horizon) were:

Horizon 1: 2.0 g/mL
Horizon 2: 2.6 g/mL
Horizon 3: 2.5 g/mL
Horizon 4: 2.5 g/mL

The students noticed that there were differences in the particle density values for the four horizons. The biggest difference was in the first horizon, which had the lowest particle density value. They investigated their soil characterization data for clues as to why the particle density of the first horizon was lower than the others. They noticed that the color of the first horizon was much darker than the others, indicating that this horizon had a higher organic matter content. The structure of the soil in the first horizon was granular while in the other horizons it was blocky. Granular structures are common in soils where roots are abundant. The students had observed many roots in the first horizon as well. The first horizon also had a friable consistence and a lower bulk density than the other horizons. These properties allow roots to spread easily throughout this horizon.

The students hypothesized that the lower particle density value they found in Horizon 1 was the result of the roots at this depth in the soil. With this information, the students decided to calculate the porosity of each of the soil horizons. Using the mean values for particle density and bulk density, they calculated the porosity using the following equation:

$$\text{Porosity} = 1 - \left(\frac{\text{Bulk Density}}{\text{Particle Density}}\right) \text{ x } 100\%$$

Their results for porosity of each of the four horizons are given in Table SO-DE-3.

Table SO-DE-3

Horizon	Bulk Density (BD)	Particle Density (PD)	BD/PD	1- BD/PD	Porosity
1	0.8	2.0	0.40	0.60	60%
2	1.3	2.6	0.50	0.50	50%
3	1.2	2.5	0.48	0.52	52%
4	1.1	2.5	0.44	0.56	56%

After examining these data, the students could see that the first soil horizon, with its high organic matter content, was more porous than the lower horizons that consisted mainly of minerals. The lowest horizon, which had no roots, also had a relatively high porosity value. The students' hypothesis was that this horizon had small pores between each of its particles. They deduced this from their texture measurement of this horizon that indicated it was clay.

The students also reasoned that because there is more pore space in Horizons 1 and 4, these horizons have the capacity to hold more rainwater than Horizons 2 and 3. To test this hypothesis, they decided to determine the soil water content according to the *Soil Moisture Protocol*. They would then determine the bulk density and thickness of each horizon to convert from mass to volume, and calculate the amount of rain that would be needed to saturate the soil profile.