# Soil Particle Density Protocol

### *Purpose*

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

### *Overview*

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

### *Student Outcomes*

Students will learn laboratory techniques and mathematical formulas to calculate soil particle density and porosity. Students will learn about the relationships among bulk density, soil particle density and porosity.

#### *Science Concepts*

*Physical Sciences*

Objects have observable properties.

*Earth and Space Sciences*

Earth materials are solid rocks, soil, water and gases.

Soils have properties such as color, texture, structure, consistence, density, pH, moisture, and heat that support the growth of many types of plants.

Soils consist of minerals, organic material, air, and water.

#### *Scientific Inquiry Abilities*

Identify answerable questions.

Design and conduct an investigation.

Use appropriate mathematics to analyze data.

Develop descriptions and explanations using evidence.

Communicate procedures and explanations.

### *Time*

2 (45-min.) class periods

### *Level*

Middle and Secondary

### *Frequency*

Once for each soil profile. After collecting the soil samples, they can be stored and particle density for the different horizons can be measured over the course of a semester or 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 a sealed container.

Collect required equipment.

Calibrate the balance to 0.1 g.

### *Prerequisites*

*Soil Characterization Protocol*

## *What is Particle Density?*

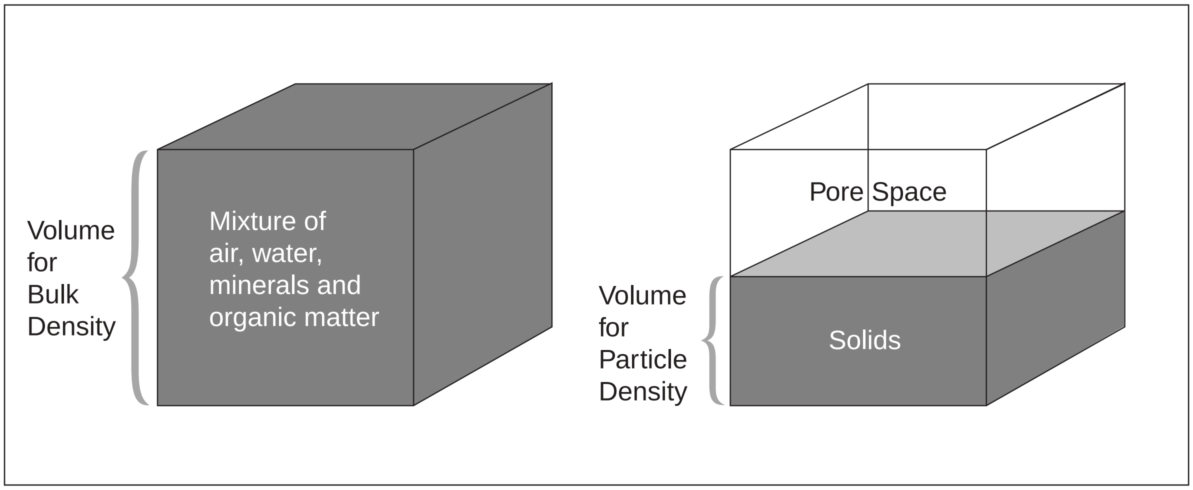
The particle density of a soil measures the mass in a given volume of particles. Particle density focuses on just the soil particles themselves and not the volume they occupy in the soil. Bulk density includes both the volume of the solid (mineral and organic) portion of the soil and the spaces where air and water are found. See Figure SO-DE-1.

Density is measured as mass per unit volume (mass divided by volume). Soil particle density depends on the chemical composition and structure of the minerals in the soil. Most mineral particles in soils have a particle density ranging from 2.60 to 2.75 g/cm$^3$. However, the density can be as high as 3.0 g/cm$^3$ for very dense mineral particles, and as low as 0.9 g/cm$^3$ for organic particles.

Particle density is important to determine because it allows us to understand many other properties of the soil. For example, knowing the particle density allows us to know something about the relative amount of organic matter vs. mineral particles in the soil sample. Because particle density can be compared to the density of known minerals such as quartz, feldspar, and micas, or denser minerals such as magnetite, garnet, or zircon, this measurement also helps to indicate the chemical composition and structure of the soil minerals.

If we have information on both the particle density and the bulk density of the soil, we can calculate the pore space (or porosity) that is occupied by air and water. This is useful because it helps us to understand other important soil properties such as how much water can be stored in the soil, how fast water and heat will be moved through the soil, how easily roots can move through the soil, and the potential for flooding or drought in an area.

*Figure SO-DE-1*



# Teacher Support

To calculate soil particle density, we measure the mass and the volume of *only the solid particles* in the sample. In soils, air and water are found within the pore spaces between the particles. If we could squeeze all the pore spaces out of a sample, all that would remain is the solid portion of the soil. The density of this solid portion is what we would like to measure. It is, however, difficult to compress soil to this extent, and to know whether all of the air has actually been removed, so we measure particle density in another way.

If we submerge a soil sample in a known mass and volume of water, remove the air from the soil, and subtract the mass of the water from the mass of the soil and water, we can determine the mass of the solid particles in the soil in a given volume. This value is the particle density.

### *Helpful Hints*

- When performing your soil profile description, look carefully at the color and other properties of the particles in the soil to see if there are differences that might be a result of the particle density
- Before conducting the Particle Density Protocol, do the Bulk Density Protocol. Discuss with the students what they measured as they conducted the Bulk Density Protocol. Explain that all density measurements measure the amount of mass in a given volume.
- Ask students why the Particle Density Protocol directs them to boil the soil water mixture. (Answer: to release the air in the pore spaces of the sample)
- Explain how to safely use the Bunsen burner or other heating element.
- Have students practice lifting the Volumetric or Erlenmeyer flasks with the tongs or oven mitts
- Have students practice boiling the soil and water mixture to ensure that they do not let the actual lab samples boil over.

### *Questions for Further Investigation*

What natural changes could alter 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 particle density of a soil sample

### *What You Need*
❑ Oven-dried, sieved soil

❑ Distilled water

❑ Small funnel

❑ Balance accurate to within 0.1 g

❑ Squirt bottle

❑ Oven mitts or tongs

❑ Three 100 ml volumetric or Erlenmeyer flasks with caps or stoppers

❑ Pencil or pen

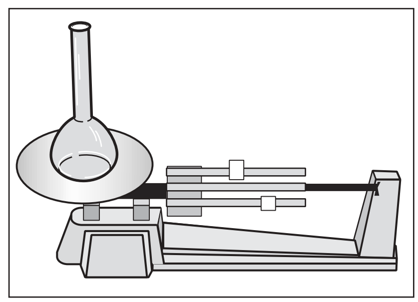
❑ Thermometer

❑ Squirt bottle for washing soil out of beaker

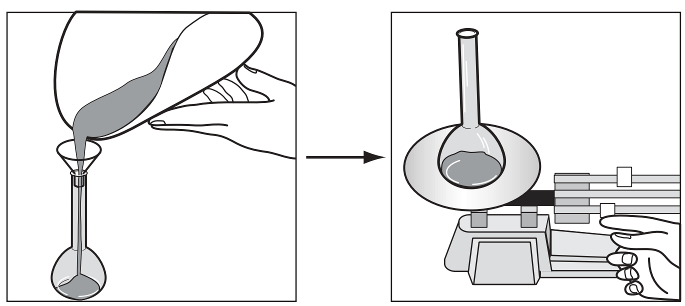
❑ Hot plate or Bunsen burner or other heat source

❑ *Soil Particle Density Data Sheet*

### *In the Lab*
1. Place distilled water in squirt bottle.

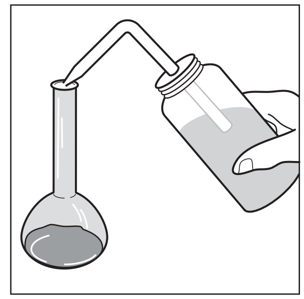


2. Measure the mass of the empty flask without cap. Record mass on the *Soil Particle Density Data Sheet*.
3. Measure out 25 g of dried, sieved soil. Place soil in the flask using the funnel. Since it is important to have 25 g of soil inside the flask, be careful to transfer all the soil into the flask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

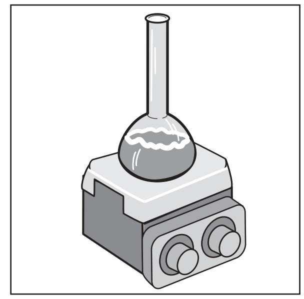


4. Record the length of time since the soil was dried in an oven, and how the soil has been stored (e.g. in plastic bag, air tight container, other.)
5. Measure the mass of the flask containing the soil (without the stopper/cap). Record the mass on the *Soil Particle Density Data Sheet*.

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.

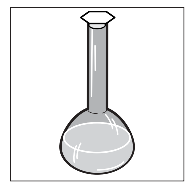


7. Bring the soil/water mixture to a gentle boil by placing the flask on a hot plate or holding it over a Bunsen burner. Gently swirl the flask for 10 seconds once every minute to keep the soil/water mixture from foaming over. Boil for 10 minutes to remove air bubbles.

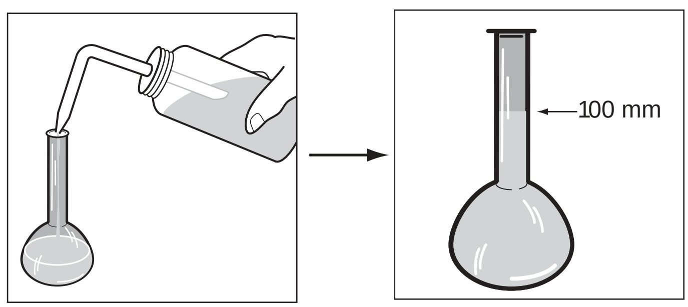


8. Remove the flask from the heat and allow the mixture to cool.

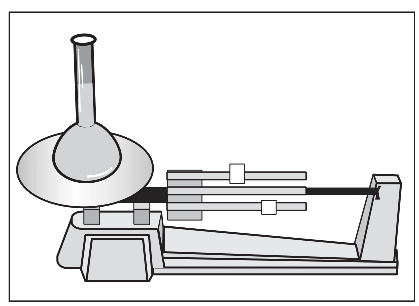
9. Once the flask has cooled, cap the flask and let it sit for 24 hours.



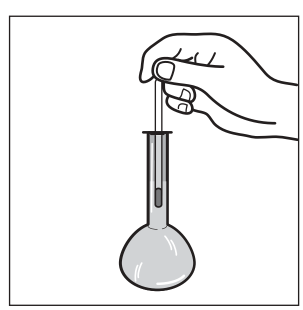
10. After 24 hours, remove the stopper/cap and fill the flask with distilled water so that the bottom of the meniscus is at the 100 mL line.




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 people look for in these data?*

Particle density measurements provide information about the kind of material present in a soil. If the particle density is high, we know that the parent material of the soil consisted of minerals that had a high density. This information can help determine the geologic history of the soil and reconstruct its "story". A low particle density (<1.0 g/$cm^3$) indicates high organic matter content, which is important for understanding how the soil formed as well as something about the climate, vegetation, and topography at that site. It also provides information about the potential release of carbon from the soil into the atmosphere as the organic matter decomposes over time.

Scientists also are interested in knowing how much space is in the soil (porosity). This information tells us about how much air and water can be stored in the soil profile. It also tells us the rate at which air, water and heat will move through the soil profile. By knowing this we can better understand the behavior of the soil, predict flooding, verify what life the soil can support, identify how the soil may change, and determine how the soil may be best used (or not used) for human activities.

## *Calculating Soil Porosity*

By knowing both the bulk density and particle density, we can calculate the amount of pore space, or porosity, of the soil using the following equation:

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

Let's look at this equation more closely to better understand it. Remember:

**Bulk Density** = mass of dry soil / total volume of soil and air

**Particle Density** = mass of dry soil / volume of soil particles only (air removed)

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

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 give you the percent porosity.

As an example, suppose students took 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 determined:

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/$cm^3$

Using these values in the equation for porosity:

$$\left(1 = \frac{1.32}{2.54}\right) \text{ x } 100 = 50\%$$

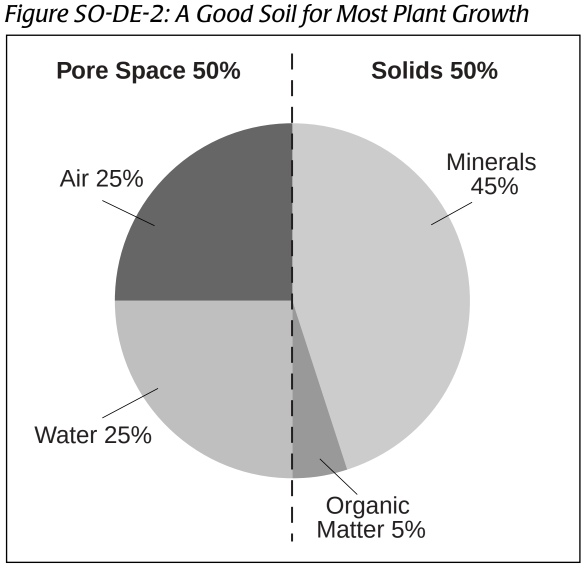
Thus, 50% of the total soil is pore space. The pore space at this site may be filled by either air or water or a combination of both.

A good soil for growing most plants generally contains about 50% pore space and 50% solids. The pore space should consist of half air and half water, and the solids should be a mixture of mostly 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 to occupy the soil pore space in order to grow properly. For other uses of the soil (such as for building roads, foundations), the soil should have much more air than water occupying its pore spaces.

While the porosity tells us how much total air space the soil has, it does not tell us exactly how much air or water is in the soil at a given time. In order to know this, we need to determine the amount of water in the soil using a method such as the *Soil Moisture Protocol*. With that information, we can determine how much of the total pore space is air, how much is water, how well plants will grow, whether the soil is dry or saturated, and what is the best plan for managing that particular soil.

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



### *How saturated is a soil?*

*Soil Moisture Protocols* measure 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

$$\begin{aligned}\text{Percentage of Pores Filled with Water} &= \frac{\text{Volume of Water}}{\text{Volume of Pore Space}} \\ &= \frac{0.20\text{ g/g}}{0.50} \times \frac{1.32\text{ (g/cm}^3\text{)}}{1.00\text{ (g/cm}^3\text{)}} \times 100 = 53\%\end{aligned}$$

# Examples of Student Research Investigations

Students from Grassland School in Illinois, USA, are trying to determine the amount of water their soil can hold. They will soon be entering the rainy season and are concerned about whether or not flooding will occur. They have characterized the soil at their school and have taken samples from four horizons to a depth of 100 cm. They know that if they calculate both the particle density and bulk density of each horizon, they can determine the porosity of the soil. Knowing the porosity of the soil will allow the students to know how much space each horizon has to hold water. The students dried and sieved soil samples for each of the horizons and then determined the particle density and bulk density using the GLOBE protocols.

Soil Characterization data for each of the four horizons the students studied is given in Table SO-DE-2. Table SO-DE-3 shows how the students determine the Particle Density of the soil in Horizon 1.

*Table SO-DE-2*

| 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 right away 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 the other soil characterization data to see if they could find any other clues in the data that might help them understand why the particle density of the first horizon was lower than that of the others.

The students noticed that the color of the first horizon was much darker than the others, which they knew usually indicates that the soil has high organic matter content. They knew that the granular structure they observed is often common when roots are abundant and they had found many roots at this depth in the soil. Both the friable consistence and lower bulk density allowed the roots to spread out easily throughout this horizon. The students hypothesized that the lower particle density values they found in Horizon 1 might be due to all 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 based on the following equation:

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

Their results for porosity of each of the four horizons is given in Table SO-DE-4.

*Table SO-DE-4*

| 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% |

The students then plotted the porosity of each horizon on a graph. See Figure SO-DE-3. For each horizon, they calculated the depth of the center point using the following equation:

(Bottom Depth – Top Depth)/2 + Top Depth

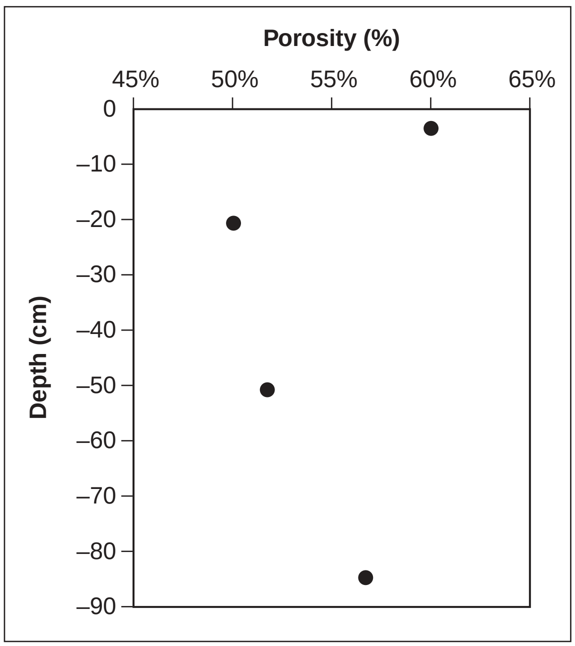
Horizon 1: (10-0)/2 + 0 = 5 cm

Horizon 2: (35-10)/2 + 10 = 22.5 cm

Horizon 3: (70-35)/2 + 35 = 52.5 cm

Horizon 4: (100-70)/2 + 70 = 85 cm

*Figure SO-DE-3*




From looking at this data, the students could see that the soil horizon at the surface with high organic matter content was more porous than the lower horizons, which are made up mostly of minerals. However, the lowest horizon, which had no roots, also had a higher porosity value. With the help of their teacher, the students hypothesized that because Horizon 4 has the texture of clay, it is likely that there are many small pores between each of the small particles. This results in a high porosity value for the deepest horizon.

With this information, the students also hypothesized that because there is more pore space in Horizons 1 and 4, these horizons have the capacity to hold more total water when it rains than do Horizons 2 and 3. Working with their teacher, they learned that by determining the soil water content, using the *Soil Moisture Protocol,* and using the bulk density and thickness of each horizon to convert from mass to volume, they could calculate the amount of rain that would be needed to saturate the soil profile.