AGRON 183: Soil Physical Properties

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Introduction

Soil is critical for life on Earth. It is the medium from which plants are able to take up water and other chemical substances (such as nutrients like nitrogen, as well as gases like oxygen) so that they can grow and develop. It is also the medium to which plants anchor themselves in order to remain in an environment that is suitable for them to live.

In general, soil is composed of four types of materials: mineral particles like quartz and clay; organic material, that is either currently, or was at one time, alive; water; and air. See Figure 1 for an illustration. It can be characterized biologically, chemically, and physically. In this laboratory, you will measure two important physical characteristics, soil bulk density and soil water content.

The *soil bulk density* is the ratio of the mass of dry soil to the total volume that this soil occupied in its natural state.

$$\rho_b = \text{soil bulk density} = \frac{\text{mass of dry soil}}{\text{total volume of soil}} \tag{1}$$

The mass of dry soil is found by putting soil in an oven at a temperature close to 105 °C (above the boiling point of water) for at least 24 hours, long enough for essentially all of the water in that volume of soil to evaporate and consequently leave the soil. What is left over after drying is just the mineral particles and dry organic material.

Note that the volume used in (1) is the total volume of the soil, which includes not only the mineral particles and organic material, but also what is called *pore space*, the empty pockets between the solid parts of the soil. Pore space is occupied by air and/or water. The bulk density accounts for the fact that the soil is made up of components (minerals, organic material, and pore space) which each have different densities.

Soil water content is the amount of water contained within the soil. See Figure 1 for an illustration of how the amount of water that occupies the pore space changes from saturated soil to nearly perfectly dry soil. Soil water content can be quantified in two ways: by mass and by volume. The *gravimetric soil water content* is the mass of water in the soil per mass of dry soil.

$$w = \text{gravimetric soil water content} = \frac{\text{mass of soil water}}{\text{mass of dry soil}} \tag{2}$$

The *volumetric soil water content* is the volume of water in the soil per total volume of soil.

$$\theta = \text{volumetric soil water content} = \frac{\text{volume of soil water}}{\text{total volume of soil}} \tag{3}$$

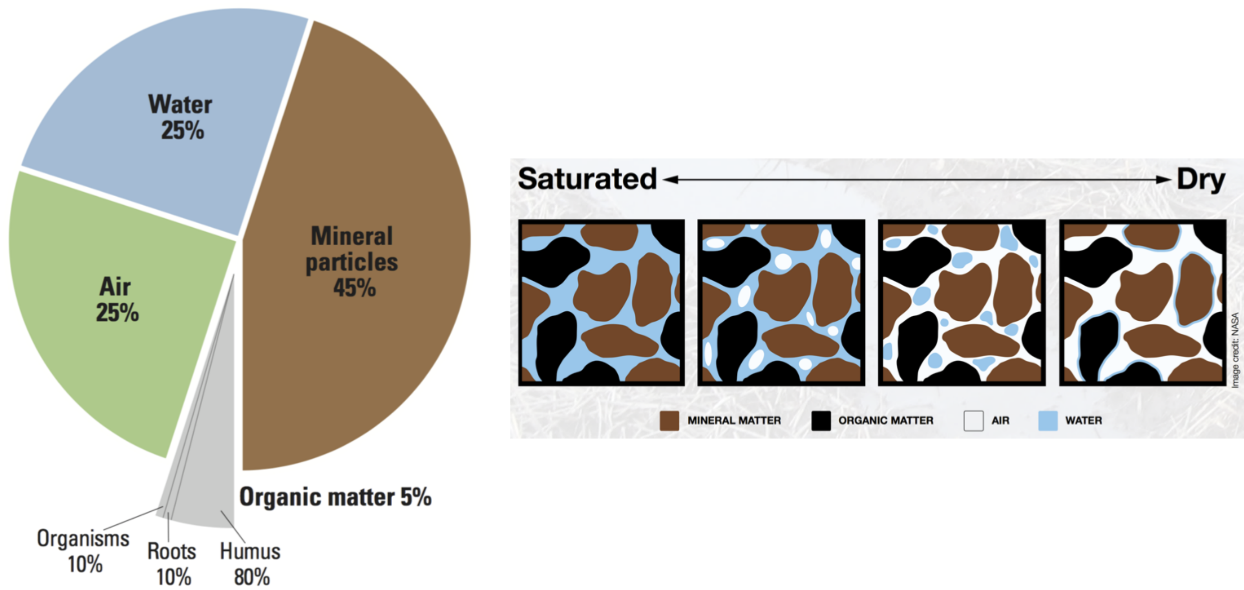

Figure 1: At left, the major components of soil. The volumetric water content of this illustration would be $\theta = 25\% = 0.25$ cm^3 cm^{-3} if the percentages are by volume because one–quarter of the total is water. Image credit: *Iowa Soil Health Management Manual*. At right, a cartoon illustration of soil at four different water contents. Image credit: NASA.

There are good reasons to use both the gravimetric soil water content, w, and the volumetric soil water content, θ. It just depends on the application. To convert from one to the other, you must use the soil bulk density, ρ_b, and the density of liquid water, ρ_w.

$$\theta = \frac{\rho_b}{\rho_w} w \tag{4}$$

If we use (2) and (3) we can see why (4) is the way it is by canceling common quantities and arriving at the result.

$$\frac{\rho_b}{\rho_w} w = \frac{\frac{\text{mass of dry soil}}{\text{total volume of soil}}}{\frac{\text{mass of soil water}}{\text{volume of soil water}}} \times \frac{\text{mass of soil water}}{\text{mass of dry soil}} = \frac{\text{volume of soil water}}{\text{total volume of soil}} = \theta \tag{5}$$

Since $\rho_w = 1$ g cm^{-3}, you will often see (4) expressed just as $\theta = \rho_b\, w$ (as on page 12 of the *Iowa Soil Health Management Manual*). Numerically, this is correct, but as you can see from (5), it is best to use (4) because then it is clear how w, θ, and ρ_b are related.

Sometimes w and θ are expressed as a fraction, like $w = 0.24$ or $\theta = 0.35$. Sometimes they are expressed as a percent by simply multiplying the fraction by 100% (e.g., to get $w = 24\%$ and $\theta = 35\%$). Sometimes the units are included, like $w = 0.24$ g g^{-1}, or $\theta = 0.35$ cm^3 cm^{-3}. All of these ways are acceptable. I prefer the last way because the units make it clear what these quantities are.

As illustrated in Figure 1, the maximum volume fraction of soil water is about 50%. Consequently, soil volumetric water content can range from around $\theta = 0.05$ cm^3 cm^{-3} (very dry soil) to nearly $\theta = 0.50$ cm^3 cm^{-3} (saturation).

Figure 2: At left, the scoop method of soil bulk density measurement. At right, the USDA method of soil bulk density measurement.

Objective

The objective of this laboratory is the following.

> Measure soil bulk density, gravimetric water content, and volumetric water content at three different locations within a field with three different methods.

There are several questions and hypotheses that you could ask and test. For example, do the three methods of soil bulk density measurement give the same answer? Or perhaps, is soil bulk density the same at different points within the same field? Is soil water content the same at each point in the same field?

General Instructions

You will measure soil bulk density using three different methods. As described above, to get soil bulk density you must find the mass of dry soil contained within a certain volume of soil. In each method you will use a different tool or apparatus to remove a specific volume of soil. You must determine this volume, and you must also find the wet mass of the soil that was removed. We will use the wet mass to calculate soil water content. After the laboratory Alex and Qi will dry your soil samples, find their dry mass, and make the data available available on CyBox so that you can calculate ρ_b, w, and θ.

The three methods are described below.

soil probe Attach a wooden handle to the probe. Mark on the probe using a Sharpie the depth of the layer you wish to sample so that you sample the same depth each time.

Record this depth. Use the spray lubricant to reduce the amount of soil that sticks to the probe. Gently push the probe into the soil vertically. Push the soil into a "pie pan" by sticking your pinky finger into the soil probe. Find its mass.

soil scoop See Figure 2. Use the soil scoop to remove a volume of soil by cutting a vertical face, excavating some soil to expose the vertical face, and pushing the scoop horizontally into the vertical face. Use a large putty knife to cut off your volume of soil, and a smaller putty knife to remove it from the scoop. Measure the sides of the scoop in order to determine the volume. Place your soil in a pie pan and find its mass.

USDA Again see Figure 2 and read the instructions on Canvas. The main idea is the following. Fix the plexiglass ring in the soil. Then find the volume of the space above the soil surface and the bottom of the hook hanging from the "hook gauge" using the thin plastic bag. Fill the bag with measured volumes of water (keep track) until the water level is high enough to just touch the bottom of the hook. The total amount of water used is the volume of the space. Remove the bag. Then excavate soil from inside the plexiglass ring until you have removed the layer of soil you wish to characterize. Place all of the excavated soil in a pie pan so that you can find its mass. Then use another thin plastic bag and the hook gauge to determine the new volume. Subtract the two volumes and you have the volume of the soil that was excavated.

Think carefully about how you should use each method so that they can best be compared to each other. For example, soil bulk density could depend on the depth of the layer of soil that you sample. So try to sample to the same depth with each method. As you make these measurements, also think about the positive and negative aspects of each method, and the errors that are associated with each method.

Equipment

Your group's Manager will check out the following equipment.

1. USDA method
   (a) plexiglass frame with foam attached
   (b) 3 threaded 1/2" metal dowel rods
   (c) 3 1/2" lock washers
   (d) 3 1/2" nuts
   (e) hook gauge
   (f) turkey baster
   (g) 1000–mL plastic graduated cylinder
   (h) 6 thin plastic bags
   (i) rubber mallet
   (j) bubble level
   (k) trowel
   (l) large metal spoon
   (m) 1–gallon empty milk container to transport and pour water
2. soil probe method
   (a) soil probe
   (b) wooden handle
   (c) can of lubricant
3. soil scoop method
   (a) soil scoop
   (b) large putty knife
   (c) small putty knife
   (d) metric ruler
4. 9 "pie pan" containers to hold soil: core, scoop, and USDA measurements (3 of each)
5. Sharpie marker to label pie pan containers
6. Wax paper to put between your pie pans when stacked in the bucket.
7. Five–gallon bucket to hold your pie pans.

There will be two mass balances (with wind shelters, also known as cardboard boxes) available. Fill your gallon milk container with water using the sink in the classroom. Use your team number to label your pie pans; if you are team 4, then label your three probe samples "4P1," "4P2," and "4P3," your three scoop samples "4S1," "4S2," and "4S3," and your three USDA samples "4U1," "4U2," and "4U3." Stack your pie pans (with wax paper in between) in the bucket.

Minimum Set of Measurements

Measure soil bulk density and soil water content at three different locations in a field. Use each of the three methods at each location. You will make a total of nine measurements.

Location

Our measurements will be made in a field adjacent to Hansen.

Tentative Timeline

9:00-9:05am Students gather in teams in our Hansen classroom.

9:05-9:30am Managers check out tablet computers. Short introduction. Teams ask questions through their Communicator and plan their strategy.

9:30-9:40am Managers check out the rest of the equipment outside in the parking lot.

9:40-11:20am Measurement period. At some point, consider visiting the soil probe truck and talk with Dr. Lee Burras, Department of Agronomy faculty member, and then return to measurements.

11:20am-11:40am Managers return tablet computers and other equipment.

11:40am-11:50am Recorders upload data to CyBox.