Properties of Soil: Agricultural and Water Availability Impacts

Investigation Manual

CAROLINA DISTANCE LEARNING

PROPERTIES OF SOIL: AGRICULTURAL AND WATER AVAILABILITY IMPACTS

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Overview

Earth's soil plays a major role in the world's agriculture and has a substantial effect on water availability in a given area. In this investigation, students will analyze the natural porosity and particle size of soil samples along with the chemical composition and profile of different soil types.

Outcomes

- Examine the properties of soil and their effects on agriculture and water availability.
- Describe and identify soil horizons based on their chemical and physical composition.
- Distinguish between the particle sizes of three different types of soil: sand, silt, and clay.
- Determine the porosity of different soil types.
- Analyze soil samples for a variety of nutrients to determine soil fertility.

Time Requirements

Preparation .... 5 minutes
Activity 1: Particle Size Distribution and Determination of Soil Texture
Day 1 .... 20 minutes, then let sit for 24 hours
Day 2 .... 30 minutes
Activity 2: Porosity of Different Soil Types...................... 60 minutes
Activity 3: pH Test Comparison of Soil Samples............ 30 minutes
Activity 4: Nitrogen, Phosphorus, and Potash Test Comparisons of Soil Samples
Day 1 .... 20 minutes, then let sit for 24 hours
Day 2 .... 60 minutes

Key

Personal protective equipment (PPE)

goggles gloves apron

follow link to video

photograph results and submit

stopwatch required

warning corrosion flammable toxic environment health hazard

Background

Soil Horizons and Chemical Composition

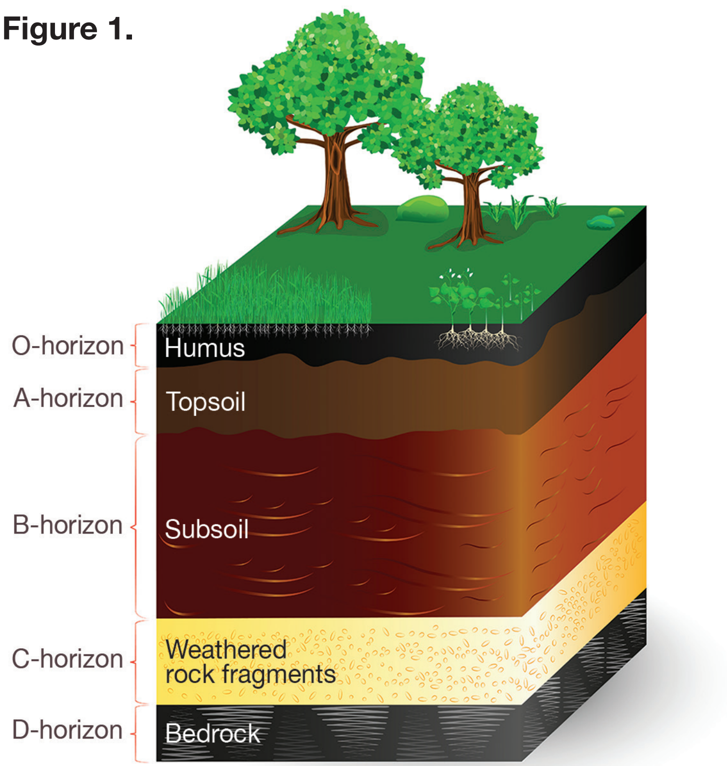
The type of dirt that makes up the dry surfaces of the earth has numerous effects on humans and the environment, and vice versa. Humans can modify the suitability of some areas for agriculture based on prior land use. The properties of soil also determine water availability in a given area. Areas that contain the most suitable soil for farming are often limited.

Certain properties of soil determine whether an area is suitable for human activity. When considering the properties of soil, its texture, shape, particle aggregation, and suitability for growth come to mind. These properties all play a major role in determining the capability of an area to retain water and air, which are necessary for several agricultural processes that are vital to human life.

It is important to understand the profile and chemical composition of soil to understand how they affect agriculture and water availability. For instance, some farmlands have been plowed for hundreds of years yet the soil has remained very fertile. However, in other areas with a similar history, much of the soil has been adversely affected (over one-third of the soil in the United States is now deemed as destroyed). With years of continuously turning over the soil to cultivate crops, the damage accumulates and many areas are left vulnerable to erosion, weathering, and deterioration of nutrient and organic material. Why then is there such great disparity in the way certain soils flourish? It is because of the various layers, or **horizons**, of the soil.

Soils differ greatly depending on the proportion of each of these horizons (see Figure 1). If you were to dig a hole or drive a corer (a special drill that uses a hollow steel tube to remove a cylindrical dirt sample) deep into the ground to extract a sample of soil, a visible color difference would be evident in the **soil profile**, or horizon composition. The colors of the various horizons differ based on the organic content and mineral composition of each soil. Each horizon can also vary in texture, which is determined by the makeup of sand, silt, or clay.

Figure 1.



As shown in Figure 1:

- The **O-horizon** is the most nutrient-rich part of the soil profile, mainly because of its abundance in organic matter. This layer is often referred to as the **humus layer** and is usually dark brown or black in color.

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Background continued

- The **A-horizon**, also known as **topsoil**, is the next layer down. This layer contains some organic matter in addition to a mixture of minerals. This horizon tends to be lighter black to brown in color.
- Further down is the **B-horizon**, or the **subsoil**. Much of the soil in this region has undergone some degree of weathering and is composed almost entirely of mineral material. Its high iron and clay content usually imparts a reddish color.
- The **C-horizon** is generally composed of weathered rock fragments and material from the layers above.
- The lowest region is known as the **R-layer** (sometimes referred to as the **D-horizon**), which mostly consists of unaltered bedrock material.

It is important to note that all these layers are not necessarily present in every soil profile and the proportions of each layer can vary drastically among various soil samples. Thus, with the farmland example earlier, much of the fertile soil may have had thicker O- and A-horizons, making it more suitable for agriculture even after many years, whereas the damaged soil may have had much thinner top layers. The ages of these soils may make a considerable difference as well. Older soils tend to have almost all horizons present, and younger soils tend to have far fewer horizons.

Identifying Soil Types: Texture and Structure
In addition to distinguishing the chemical and biological makeup of soil, it is also important to understand the impact of soil on water availability in a given area. **Particle size** is one of the most important aspects of soil type descriptions that helps to determine the holding capacity of the soil as well as its ability to filter water. The size of soil particles determines the soil's **texture**, which can be classified into smaller subcategories (primary units) depending on the mineral components of the soil. Texture is determined by the ratio of sand, silt, and clay in the soil sample (see Table 1).

Table 1.

Soil Type	Particle Size
Sand	Particles with a diameter greater than 0.05 mm
Silt	Particles with a diameter between 0.002 and 0.05 mm
Clay	Particles with a diameter less than 0.002 mm

Every soil sample will have different proportions of these primary units. Based on these proportions, each soil sample can be further categorized and identified. Figure 2 shows a soil analysis chart that illustrates the different classes of soil based on their combinations of sand, silt, and clay. **Loam** is a close-to-equal mixture of these three primary units and can be used to identify multiple soil types.

Determining particle size (based on these subcategories of soil texture) is the first step in soil characterization. The next step is determining the **structure** of the soil, which defines how the individual particles aggregate.

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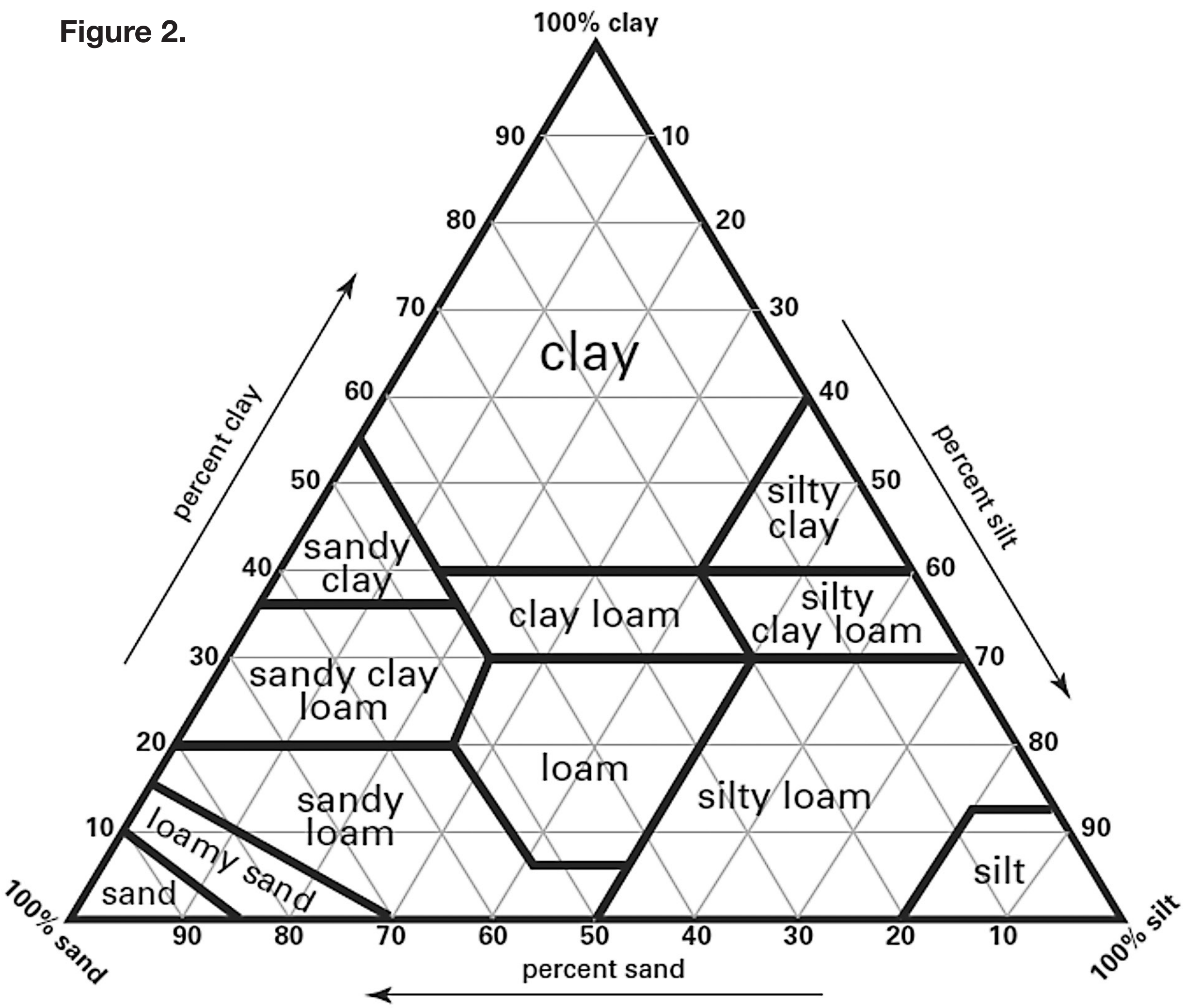
The soil structure affects how easily air, water, and the roots of plants are able to move within the soil. The arrangement of soil particle aggregates can be broken down into **peds**, or secondary units of the primary soil particles—sand, silt, and clay.

Knowing the type of soil present by first identifying the primary and secondary particle types can help determine whether the soil is suitable for agriculture. Soil **permeability** (ability of water to flow through a soil) is directly related to the particle size (texture) and the aggregation of those particles (structure) (see Figure 3). Rounded, granular peds are particularly suitable for plant growth because their structure easily permits penetration by air, water, and roots. Clay

Figure 2.



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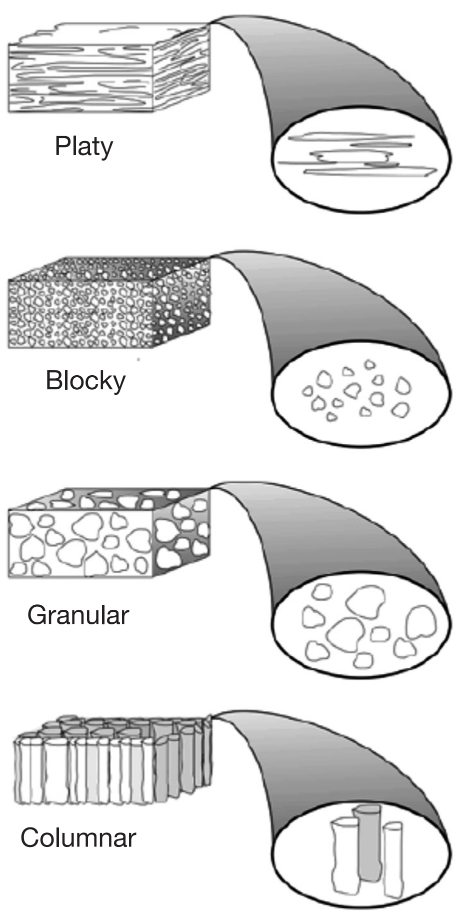
PROPERTIES OF SOIL: AGRICULTURAL AND WATER AVAILABILITY IMPACTS

Background continued

and loamy soils often have blocky peds that are angular and somewhat irregular in shape and permit the flow of air and water. In platy peds, however, some passageways are blocked because the soil particles are tightly packed. A platy soil usually has high clay content and often occurs in areas that are frequently flooded. These classifications are not applicable to sand because of its inability to form aggregates; thus, instead of clumping, it falls apart.

The roots of plants require air and water. Just as a plant can die from lack of water, it can also die in waterlogged soil owing to a lack of air. Soil must retain water and permit root penetration to support plant life. However, certain particle sizes and arrangements of particles allows for permeability conditions that could be detrimental to agriculture. Therefore, particle size and arrangement need to be identified to determine proper soil usage. **Porosity** is defined as the amount of void space between individual soil particles. With high porosity between particles, a greater volume of water can permeate but might also waterlog certain systems. Porosity is another major property of soil that has a significant effect on water infiltration and **soil fertility**, or the ability of soil to hold sufficient nutrients for plant growth. In the following section, nutrient availability and chemical composition—and their effects on different soil types—are discussed.

Figure 3.



Processes Affecting the Fertility of Soil

Determining the productivity of the soil in a given area is crucial. The **pH value**, or the number of hydrogen ions present in the soil, is a major indicator of soil fertility. The pH scale ranges from 0 to 14, with a value of 7 being neutral. Anything less than 7 is acidic, and anything more than 7 is considered basic. This scale is logarithmic, so if a solution has a pH of 6, it has ten times the number of hydrogen ions (or is ten times more acidic) than a solution with a pH of 7 possesses. There are wide ranges of pH for a variety of soils; for example, quartz-rich sandstone is rather acidic, whereas limestone tends to be basic.

Rainwater, which has a pH of approximately 5.5, has a significant impact on soil pH. The low pH of rainwater is caused by the mixing of water with carbon dioxide in the atmosphere. Carbonic acid is formed when the precipitation

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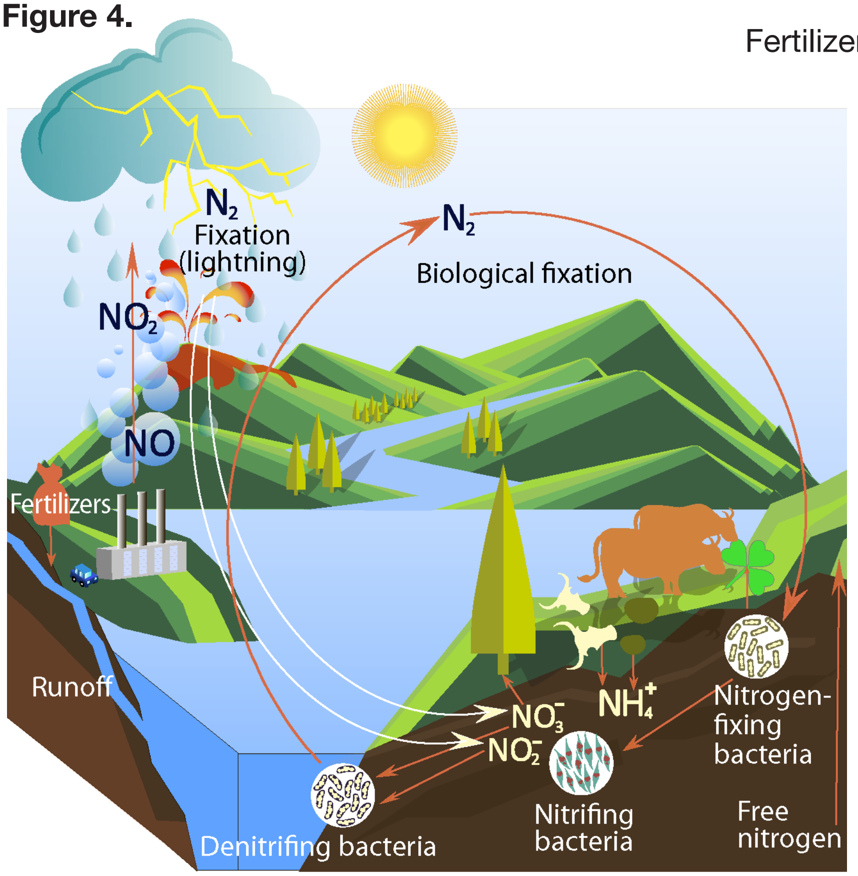
makes contact with the earth's surface. As this rainwater flows into and along soil surfaces, it transmits many nutrients into the depths of the soil. Iron, along with other minerals such as calcium and magnesium, tends to flow through the higher horizons, which are usually flourishing with life, and continues into the lower horizons that tend to be lacking in nutrients.

Besides pH, **decomposition** is another important factor in determining the health of soil. Organisms such as bacteria and fungi decompose (break down) organic matter that plants and animals produce at the surface and deposit into the soil, allowing for the survival of organisms deeper in the soil. The rate of decomposition can be increased by worms and other organisms living near the surface. These organisms break down detritus (debris and waste) into smaller bits that sink farther into the soil, feeding the bacteria and fungi.

Nutrients are essential for plant growth. One major issue regarding the health of certain soil types in some areas is the inability of the soil to retain sufficient nutrients. Adding fertilizers and pesticides helps replenish crops and soil, but an excess of these nutrients can also exert negative effects. **Macronutrients** are nutrients needed at high concentrations by all living things. Nitrogen, potassium, phosphate, and magnesium are examples of these nutrients necessary for plant growth. **Micronutrients**—such as the metals zinc, iron, and copper—are those needed in smaller quantities.

Figure 4.



Fertilizers are useful to replace macronutrients lost from the soil. Many fertilizers, such as manure, are either purely or mostly organic matter; however, numerous synthetic fertilizers have also been developed. Nitrogen, phosphorous, and potassium are commonly regarded as the limiting nutrients in crop production and are therefore typically added to soils in specific amounts via fertilizers.

Nitrogen is a special case; plants require nitrogen in the form of ammonium or nitrate, and atmospheric nitrogen can only be converted synthetically, or by soil-dwelling microbes, as part of the **nitrogen cycle** (see Figure 4).

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Background continued

Additional ways in which nitrogen can enter the soil include via the death and decomposition of plants and by the production of nitrogenous waste from plants being eaten by animals. Nitrogen is vital for plant growth; it is a very important structural component of chlorophyll, the compound used by plants in photosynthesis to produce oxygen and sugars. Nitrogen is also a major component of amino acids, which are the building blocks of proteins. Since it is not retained by soil, excess nitrogen can leach onto the surface or into groundwater, causing algal blooms and a loss of oxygen. Although nitrogen is an essential element, because it is not retained by the soil, farmers frequently need to reapply fertilizers containing nitrates, which in turn can lead to environmental challenges.

Phosphorus is usually present in the form of phosphates in the soil. Phosphate is an important component of adenosine triphosphate/adenosine diphosphate (ATP/ADP) in plants and is therefore necessary for energy transport and storage. Phosphates, along with pentose sugars, make up the backbone of DNA and RNA. Phosphorus availability frequently limits plant growth and flowering; therefore, the introduction of phosphates into soil can lead to rapid plant growth. This element also plays a major role in keeping the root systems of plants strong and thriving. However, like excess nitrates, too much phosphorus can lead to algal blooms, which can harm aquatic ecosystems (see details of the **phosphorus cycle** in Figure 5).

The last main nutrient in fertilizer is known as potash. It is a mixture of various salts that contain soluble potassium, which is vital for the development of many flowers and fruits. Potassium is required for the activation of numerous enzymes and for the regulation of pH as well. It also controls the opening and closing of the stomata (pores in the leaves), which affects photosynthesis, water and gas transport, and temperature regulation.

In this investigation, you will conduct experiments to determine the texture and structure of soil samples as well as the ability of water to permeate each sample. You will also perform chemical tests to determine the fertility of two soil samples.

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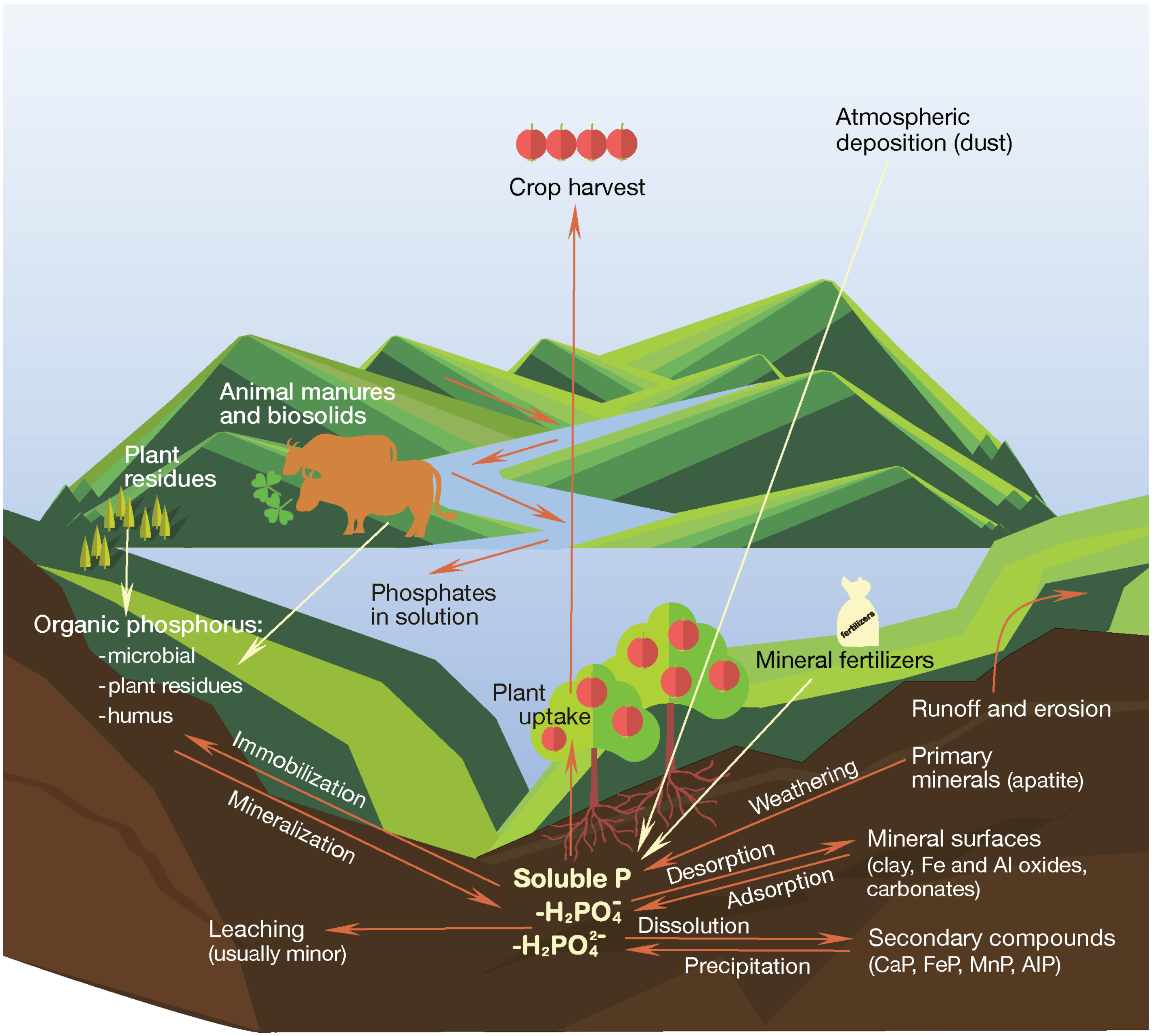
Figure 5.



Atmospheric deposition (dust)
Crop harvest
Animal manures and biosolids
Plant residues
Organic phosphorus:
-microbial
-plant residues
-humus
Phosphates in solution
fertilizers
Mineral fertilizers
Plant uptake
Runoff and erosion
Primary minerals (apatite)
Immobilization
Mineralization
Weathering
Desorption
Adsorption
Mineral surfaces (clay, Fe and Al oxides, carbonates)
Soluble P
$-H_2PO_4^-$
$-H_2PO_4^{2-}$
Dissolution
Precipitation
Leaching (usually minor)
Secondary compounds (CaP, FeP, MnP, AlP)

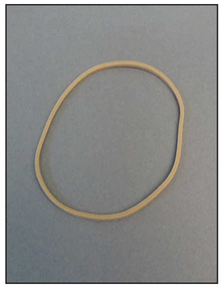
PROPERTIES OF SOIL: AGRICULTURAL AND WATER AVAILABILITY IMPACTS

Materials

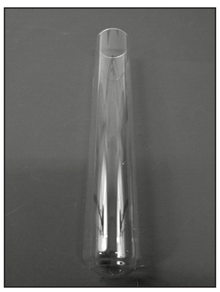
Included in the materials kit:

Bag of clay, ½ c

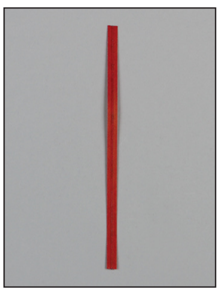
rapitest® Soil Tester kit



3 Rubber bands



3 Plastic tubes



6 Twist ties

Cheesecloth

Graduated cylinder, 10 mL

Needed from the Groundwater and Surface Water Interactions investigation materials kit:

- 2 small handfuls of sand from the large bag of sand

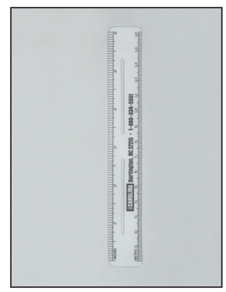
Needed from the equipment kit:

3 Test tubes

Test tube rack

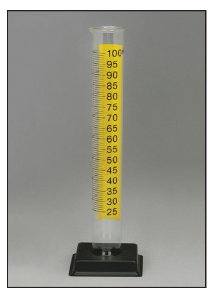
Permanent marker

2 Pipets



Ruler

Plastic cup



Graduated cylinder, 100 mL

Needed but not supplied:

- Sheet of white paper
- 2 Soil samples
- Distilled water
- Tap water
- Liquid hand soap
- Tool for digging soil (trowel, large spoon, etc.)
- Scissors
- Stopwatch (or cell phone with a timer)
- Camera (or cell phone capable of taking photographs)
- 2 jars or cans,16 oz or less

Reorder Information: Replacement supplies for the Properties of Soil: Agricultural and Water Availability Impacts investigation can be ordered from Carolina Biological Supply Company, item number 580822.

Call: 800.334.5551 to order.

Safety

Wear your safety goggles, gloves, and lab apron for the duration of this investigation.

Read all the instructions for these laboratory activities before beginning. Follow the instructions closely, and observe established laboratory safety practices, including the use of appropriate personal protective equipment (PPE).

Avoid contact with skin, eyes, and mouth when working with rapitest® Soil Tester capsules. Wear PPE at all times when using these capsules. Wash your hands immediately following the use of these capsules.

Do not eat, drink, or chew gum while performing these activities. Wash your hands with soap and water before and after performing each activity. Clean the work area with soap and water after completing the investigation. Keep pets and children away from lab materials and equipment.

Preparation

1. Read through the activities.
2. Obtain all materials.
3. Identify a location where you can easily collect a small amount of soil out of the ground (e.g., at the edge of your yard or at a nearby park).
4. Using your digging tool, collect a few handfuls of soil from about 3 inches below the surface and place it in a plastic cup from the equipment kit. (There should be enough to fill the cup approximately halfway.) This sample will be known as “Soil Sample A” and will be used in all the activities. Before using the sample, remove excess grasses, roots, and other plant materials and break up any large clumps.

ACTIVITY

ACTIVITY 1

A Particle Size Distribution and Determination of Soil Texture

Day 1

1. Take three test tubes from the equipment kit and label them “Sand,” “Clay,” and “Soil Sample A” (one for each sample).
2. Fill each vial halfway with its designated soil sample. For each test tube, add tap water to about 1 cm below the top. Then add one drop of liquid hand soap to each sample (this helps settle the particles).
3. With gloved hands for each test tube, place your thumb over the opening. Shake each test tube for 30 seconds. Allow the samples to settle overnight in the test tube rack. Place a piece of paper over the top of the three test tubes to prevent contamination of the samples.
4. Hypothesize what percentages of sand, silt, and clay you expect to find in “Soil Sample A.” Remember: your percentages must add up to 100%. Record your hypothesis in the “Hypotheses” section of the **Lab Worksheet**.

Day 2

1. Place a sheet of white paper behind the test tubes containing the settled soil samples, and observe the layers that have formed in each. Take a photograph of the three samples with the paper behind them. Include in your photograph a strip of paper with your name and the date clearly written on it. You will be uploading this photograph to your lab report.

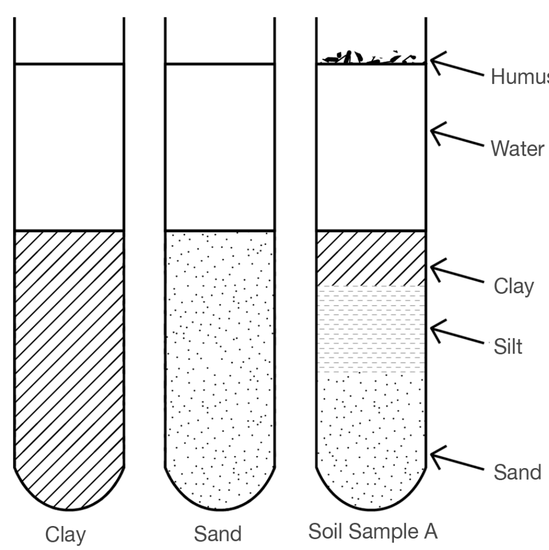
[How to Determine Soil Composition](https://bcove.video/2N8VShc)
https://bcove.video/2N8VShc

2. Using the “Sand” and “Clay” samples as controls, identify the layer types in “Soil Sample A.” You may use a marker to label each layer. See Figure 6 for guidance.
3. Use a ruler to measure the thickness (in centimeters) of the sand, silt, and clay layers in “Soil Sample A.” The silt layer is the layer formed between the clay and sand layers, owing to its particle size that is larger than that of clay but smaller than that of sand (see Figure 6). Record these values in Data Table 1 of the “Observations/Data Tables” section of the **Lab Worksheet**.

All layers may not be visible or may vary substantially in depth in “Soil Sample A.”

4. Measure the total depth of the soil. Be careful to exclude the humus layer containing floating dirt and grasses at the top of the sample (see Figure 6). Record the total depth in Data Table 1 of the “Observations/Data Tables” section of the **Lab Worksheet**.

Figure 6.



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5. Calculate the particle size distribution of "Soil Sample A" by dividing the depth of each layer by the total depth of the soil, and then multiplying that value by 100. Record the percentages of the primary particles clay, silt, and sand in "Soil Sample A" in Data Table 1 of the "Observations/Data Tables" section of the **Lab Worksheet**.
6. Use the soil analysis chart (see Figure 2) to determine the soil texture of "Soil Sample A," and record this in Data Table 1 of the "Observations/Data Tables" section of the **Lab Worksheet**.

   How to Determine Soil Texture
   https://bcove.video/305wPQ6

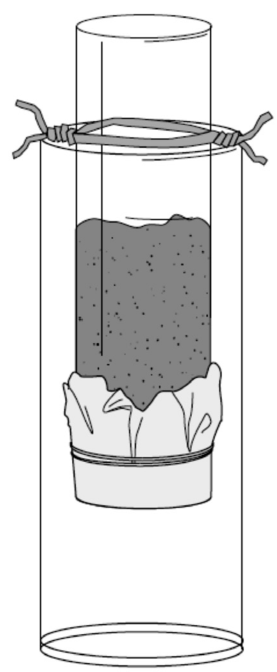
Note: In Figure 2, each corner of the triangle represents 100% of one of the three types of soil: silt, sand, and clay. Locate these points. Loam is found in the center of the triangle. Following the arrows on the sides of the triangle, start by pointing to the percentage of your soil sample that is composed of silt (from Table 1) on the right edge of the triangle. With your other hand, point to the percentage composed of sand along the bottom edge. Following the corresponding diagonal lines, move your fingers toward each other until the lines intersect. (*If you have found the correct intersecting lines, the percentage of clay of your sample should line up horizontally on the left edge from the point at which your fingers meet*). This point of intersection represents the class of soil texture; if the point falls on a boundary between two types, choose the one that occupies a larger area. Also, if the percentage of either silt or sand is less than 10% for your specific "Soil Sample A," start your fingers on clay and the existing primary particle and follow the same process.

ACTIVITY 2

A Porosity of Different Soil Types

1. Ensure the remaining "Sand," "Clay," and "Soil Sample A" are ready for use. In this activity, you will be determining the porosities (relative empty space) of three different samples. Before you begin, hypothesize which sample you think will have the highest porosity and which one will have the lowest porosity and explain why. Record your hypothesis in the "Hypotheses" section of the **Lab Worksheet**.
2. Cut two 3-cm squares from the cheesecloth.
3. Secure these two pieces of cheesecloth over one end of a plastic tube with a rubber band (see Figure 7).
4. Make a mark on the tube 4 cm up from the end covered by cheesecloth.
5. Pour one of the three samples onto a paper towel, and make sure any lumps or rocks are crushed or removed. Fill the tube up to the 4-cm mark with the particular sample (see Figure 7). Use twist ties to suspend the tube in the 100-mL graduated cylinder (see Figure 7).

Figure 7.



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ACTIVITY 2 continued

6. Start a timer as you pour 10 mL of tap water from the 10-mL graduated cylinder into the plastic tube in the setup.
7. Record the time (in seconds) taken for the first drop of water to emerge from the column, and record this data in Data Table 2 of the "Observations/Data Tables" section of the **Lab Worksheet.** For some samples, this could happen very quickly (*even as you are pouring*), so keep a close eye on the sample as you are pouring.
8. Repeat Steps 2–7 with the two remaining samples (using new materials for each sample).

ACTIVITY 3

A pH Test Comparison of Soil Samples

For Activities 3 and 4, use the soil from the initial collection in the "Preparation" section ("Soil Sample A"). For another soil sample (this will be called "Soil Sample B"), collect a sample of your choice—for example, this can be commercial potting soil, soil from a different outdoor location, or any remaining clay from this lab. ***Avoid using any remaining sand since it carries little nutritional value due to its large pore space.***

Ideally, the best option would be to find another soil sample from a different outdoor location with contrasting properties. For example, if "Soil Sample A" was from a very dry area without plants, try to find a very moist soil sample that is covered with grass for "Soil Sample B." You can also select a deeper soil sample for comparison with the surface-based "Soil Sample A."

1. Propose a hypothesis concerning which of the two samples will be the more acidic of the two and which one the more basic. Explain your reasoning. Record the hypothesis and reasoning in the "Hypotheses" section of the **Lab Worksheet**.
2. Open the rapitest® Soil Tester kit.
3. Wearing PPE, remove the capsules from one of the green-capped vials (the pH test capsules).
4. Fill the vial with "Soil Sample A" up to the first line.
5. Carefully open one of the green capsules and pour the powder into the vial. (Do this over the vial to prevent any spillage.)
6. Add distilled water up to the fourth line.
7. Cap the vial, and shake it thoroughly (about 20 seconds).
8. Allow the soil to settle for approximately one minute.
9. Compare the color of your sample to those on the pH color chart on the back of the rapitest® Soil Tester kit instructions (the "Plant Food Color Chart") to determine the pH of the soil sample. Record this data in Data Table 3 of the "Observations/Data Tables" section of the **Lab Worksheet**.
10. Take a photograph of your vial held up next to the "Plant Food Color Chart." Include in your photograph a strip of paper with your name and the date clearly

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written on it. You will be uploading this photograph to your lab report.

11. Dump out the soil mixture into the household trash.
12. Rinse the vial, and repeat Steps 2–11 with the other soil sample you chose ("Soil Sample B").

ACTIVITY 4

A Nitrogen, Phosphorus, and Potash Test Comparisons of Soil Samples

Consider your two soil samples, particularly in terms of where you obtained them and their appearance. Based on the characteristics and what they have contained so far, hypothesize which will have a higher level of nutrients (nitrogen, phosphorus, and potash) and which will have a lower level. Explain why, and record your hypothesis in the "Hypotheses" section of the **Lab Worksheet**.

Day 1

1. Fill a clean jar or can with 1 part "Soil Sample A" and 5 parts water. Thoroughly swirl the soil and water together for 1 minute; then allow the mixture to settle (approximately 24 hours).
2. Repeat Step 1 with "Soil Sample B" and a different jar or can.

Day 2

1. Wearing PPE, remove the caps from the purple, blue, and orange vials from the rapitest® Soil Tester kit and remove their capsules.
2. Using a pipet from the equipment kit, fill each vial up to the fourth line with the supernatant (liquid above the soil) from the "Soil Sample A" mixture made on Day 1.
3. Carefully separate the capsules, and pour the powder into the corresponding-colored vials. Make sure the colors of the capsules match the respective vials. (Perform this step over the vial to prevent spillage of the powder).
4. Cap the vial, and shake it thoroughly (for about 20 seconds).
5. Allow color to develop for 10 minutes.
6. Use the "Plant Food Color Chart" on the back of the rapitest® Soil Tester kit instructions to determine the nutrient content of the soil sample. Record this data in Data Table 4 of the "Observations/Data Tables" section of the **Lab Worksheet**.
7. Take a photograph of your vial held up next to the "Plant Food Color Chart." Include in your photograph a strip of paper with your name and the date clearly written on it. You will be uploading this photograph to your lab report.
8. Rinse the vials, and repeat Steps 1–7 with the other soil mixture ("Soil Sample B").

Submission

Using the **Lab Report Template** provided, submit your completed report to Waypoint for grading. It is not necessary to turn in the Lab Worksheet.

Disposal and Cleanup

1. Rinse and dry the lab equipment from the equipment kit, and return the materials to your equipment kit.
2. Discard the soil samples and any other materials from the materials kit in the household trash. The 10 mL graduated cylinder and plastic tubes may be recyclable.
3. Sanitize the work space, and wash your hands thoroughly.

Lab Worksheet

Hypotheses

Activity 1.

Activity 2.

Activity 3.

Activity 4.

continued on next page

ACTIVITY

Observations/Data Tables

Data Table 1.

Particle Size Distribution and Soil Type								
	Depth of Clay Layer (cm)	Depth of Silt Layer (cm)	Depth of Sand Layer (cm)	Total Depth (cm)	% Clay	% Silt	% Sand	Soil Texture
Soil Sample A								

Data Table 2.

Determination of Soil Porosity	
	Time Taken for First Drop to Emerge from Column (s)
Sand Sample	
Clay Sample	
Soil Sample A	

Data Table 3.

pH Comparison of Soil Samples		
	Soil Sample A	Soil Sample B (Location Description: ______________________________)
pH		

Data Table 4.

Nitrogen, Phosphorus, and Potash Comparison in Soil Samples			
	Nitrogen	Phosphorus	Potash
Soil Sample A			
Soil Sample B			

NOTES

ENVIRONMENTAL SCIENCE
Properties of Soil: Agricultural and Water Availability Impacts
Investigation Manual

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Carolina Biological Supply Company
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