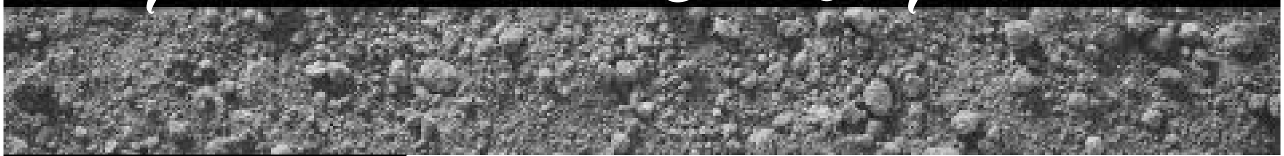
Chapter 2 Soil Improvements



Chapter Contents

Xeriscape Principle

Producing a thriving landscape requires knowledge of the site's soil characteristics, the needs of specific plants, and the ability to know when and how to amend the soil for water retention and plant nourishment.

Key Concepts

Organic matter/ inorganic matter, soil pH, water-holding capacity, physical properties of soil

Teacher's Notes

New Mexico's soils are quite varied, ranging from almost pure sand to heavy clay. The water-retention abilities of most New Mexico soils are improved with the addition of organic matter and other soil amendments. However, soil amendments may not be necessary when landscaping with native plants because some well-adapted xeric plants prefer not to have too rich a soil. For these plants, doing as little as loosening the soil is all the soil preparation that is needed.

The **Problem To Solve** in this unit is to help Mr. Andy Devalle evaluate the soil at his new home in Los Lunas and at his existing home in Santa Fe. He has submitted three different soil samples for analysis. The students will run a series of tests on the different soil samples to determine the soil types and what amendments might be necessary.

Two levels of **Project Cover Sheets** are provided — one for students who complete Level 1 projects and another for students who complete Level 2 (more advanced) projects. For Level 1, students will write a letter to Mr. Devalle with their recommendations for amending his soil. For Level 2, students will include a soil analysis from their tests, along with their recommendations for Mr. Devalle's landscapes.

Teacher's Notes, continued

The **Student Handout** provides background material about the physical, chemical, and biological structures of soil.

The **Activities** in this unit can be used in their entirety or adapted for the classroom's specific population. To conduct the activities in this unit, obtain a supply of sandy soil for Sample One, highly organic or amended soil for Sample Two (composted soil from the nursery works well), and a soil with a high clay content for Sample Three. If these specific soil types are not available, substitutions can be made. It is most important that there are three distinct soil types used in order to see the differences in water-holding capacities.

The soil chapter is the foundation for the rest of the curriculum. It is important that the students understand the principles in this chapter in order to understand the principles presented later in this curriculum regarding irrigation, mulch, lawns, plants, design, and maintenance.

Assessment of Problem to Solve

In **Problem to Solve: Andy Devalle's Soil**, the students make recommendations to Mr. Devalle about how to improve the soil at his two properties. Students must first recognize that Sample One is sand, Sample Two is compost or improved soil, and Sample Three is clay. They will need to be able to identify the different characteristics of each soil type and how those characteristics can affect the plants that live there. These characteristics include soil particle size, water-holding capacity, pH, organic matter, and living biological components such as arthropods[1]. Once these characteristics have been identified, the students can decide which amendments might work best for Mr. Devalle's soil. The two main recommendations should include adding amendments to improve water-holding capacity and, if needed, adding amendments to adjust the pH to between 6.5 to 7.0. Additional recommendations can include increasing the populations of arthropods and macro organisms[2] to increase soil quality and checking for salinity or caliche problems.

Each student's **Problem to Solve** work should be evaluated to determine whether the recommendations are factually correct, sufficiently detailed, and successfully communicated.

Soil Types

Teacher's Notes, continued

Notes on the Activities

Soil Through the Looking Glass – Students will explore the properties of soil including particle size, weight, porosity, and pH. When soil is added to water, the soil will settle according to particle size, with the largest particles (gravel, then sand) on the bottom and the smallest particles (clay) on top. Organic matter will float on the top of the water. When water is added to dry soil, the soil will swell up as the water fills the soil pores. Because most desert soils are alkaline, students will probably find that the pH of their soil samples is 7.0 or above. If the soil is collected from under a pine tree, however, it will be more acidic.

Holes in the Soil – Students will test the water-holding capacity and infiltration rates of different types of soil. When water is added to soil, the water goes into the pore spaces, which otherwise are filled with air. The water displaces the air in these pores. Hence, the amount and size of the pores, or porosity, of a soil will equal the water-holding capability. However, most plants do not grow well in soil that holds water in all the air spaces or is water logged. Students will also determine soil water-infiltration rates. If water goes through the soil too rapidly, the soil may dry out too quickly for water uptake by plants. The infiltration rate can be improved by adding compost. Compost breaks up tight soils like clay to add pore space and allow water to infiltrate. It also closes up large pore spaces in sandy soils to slow the infiltration rate.

Who Lives in Soil? – Students will compare and contrast soils with high and low organic content by collecting data on arthropods and macro organisms. The students may find both larvae and adults of a given species. Therefore, this is a good lab to introduce taxonomy and discuss the life history of insects. When students graph data, they should think of the differences between discrete data[3] and continuous data[4]. The data in this activity is discrete, since an arthropod is either present or absent. Students should also notice that an arthropod that is present in one soil might not be present in another soil. The arthropods feed on organic matter in the soil such as bacteria, fungi, algae, plant roots, detritus[5], and each other.

Examples of Arthropods Found in Soil

- Millipede/ Centipede
- Ant
- Beetle
- Earthworm
- Roundworm
- Snail/ Slug
- Wood lice
- Springtail
- Spider Mite

Best of the Best – In this experiment, which will take from two to six weeks, students determine how soil amendments affect plant growth. Depending upon the materials used, either the compost only or the half soil/half compost combination should work best. Students will need to determine how they will measure plant growth. (Measuring from the top of soil to the end of longest leaf is recommended.) Since students do not all have the same luck with growing plants, this lab should be scored based upon the quality and consistency of effort.

Complementary Activities

The following activities complement the **Problem to Solve** for this chapter:

✓ **4-4: Keeping the Water**

✓ **6-4: Dripping Blooms**

Background Information: Soil Improvement

Soil is the direct or indirect source of nutrition for most living things. It is constantly changing, being broken down through erosion and built up as organic matter decomposes and inorganic matter breaks down. Soil has physical, chemical, and biological structures that contain mineral particles, plant and animal matter, air, and water.

Physical Structure of Soil

Soil consists of decayed plant and animal bodies (organic matter) and ground-up rocks (mineral/inorganic matter). Although soil looks solid, it is actually clumps of organic and mineral matter with spaces, or pores, in between that hold water and air. The size of the soil particles determines the texture or structure of the soil.

Soil Particle Size

Soil Texture	Size of Particles in Millimeters
Fine Gravel	1.0-2.0 mm
Coarse Sand	0.50-1.0 mm
Medium Sand	0.25-0.5 mm
Fine Sand	0.10-0.25 mm
Very Fine Sand	0.05-0.10 mm
Silt	0.002-0.05 mm
Clay	Less than 0.002 mm

The "ideal" soil is said to be an equal mixture of sand, clay, and silt (along with plenty of organic matter). This mixture balances the advantages and disadvantages of the component parts.

- **Sandy soils** have a loose structure. They clump little and have large pore spaces. Water and nutrients move through these soils very quickly.
- **Clay soils** have a tight structure. They clump together tightly, providing very little pore space. Water and nutrients move through these soils very slowly or not at all.
- In well-structured, optimum soil, the individual soil particles tend to clump together into aggregate groups of sand, silt, and clay. This clumping provides more optimum pore spaces. The water and nutrients will not move too fast or too slowly through the soil, thus providing adequate time for the plant roots to absorb both moisture and nutrients.

Amendments for Physical Structure

If the soil in the area to be landscaped is too sandy or contains too much clay, it may need to be amended. Adding organic matter, such as compost or fertilizer, is the most common means of improving or amending the soil. Like the mixture of sand, clay, and silt, organic matter will work to clump sandy soils and break up clay soils. In sand, the organic matter tends to cement particles together to form larger air spaces between particles. These air spaces act as a sponge to hold water. In clay, the addition of organic matter breaks the clay particles into clumps and leaves spaces for roots, air, and water.

In truth, there is really no such thing as one type of "ideal" soil because different plants have different soil requirements. Native or

Background Information: Soil Improvement (continued)

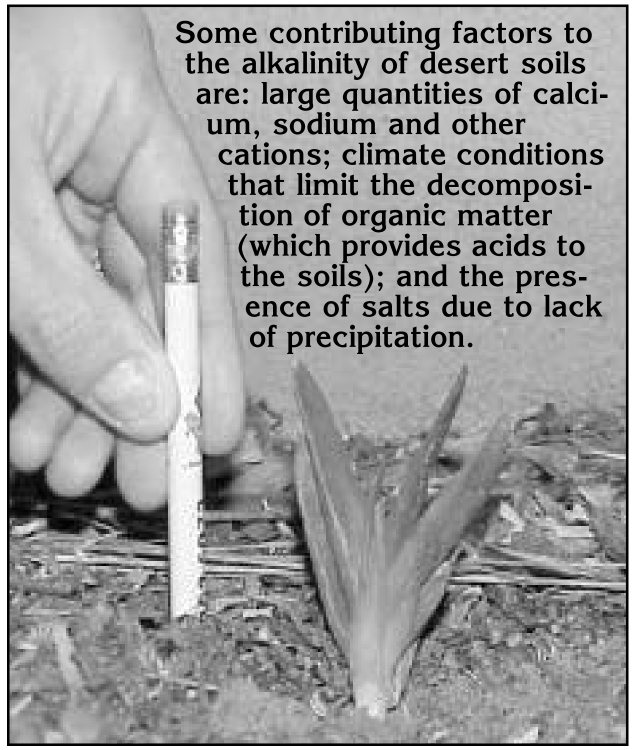
adapted plants may not need soil amendments at all, whereas imported plants may require large quantities of amendments to convert existing soil into something that more closely resembles their native soil. In most cases, it is easier to grow plants that are adapted to the existing soils than to make large-scale structural changes.

It is important to know when amendments can be added to the soil. In New Mexico, most of the soils are sandy with small amounts of silt and clay. Sandy soils are easy to work or amend. Amendments can be added and worked into the soil at any time without structural damage. Clay-based soils are harder to work or amend because they are sticky and heavy. If they are worked when they are wet, the soil structure can be damaged. Amendments should be added to clay-based soils when they are moist, but not wet. Dry clay is extremely hard and almost impossible to work.

Chemical Structure

The chemical structure of soil depends mainly upon the minerals in the soil. The minerals come from the decomposition of the rocks in the surrounding area. As the rocks are broken down, their basic components can add to the pH[6], caliche[7], and salinity[8] of the soil.

The minerals in the soil provide nutrients for plants. Plant growth is controlled by the amount of essential nutrients that are available. Plants obtain the nutrients through a process called cation[9] exchange. Water that leaches into the soil dissolves the minerals into a solution. This solution contains positively charged particles of the minerals called cations. Clay and humus[10] tend to be negatively charged. This negative charge attracts and holds the positively charged cations. The cations of the minerals are then available for exchange as nutrients with non-nutrient cations on the plant roots.



The pH of a soil also affects the ability of the plants to obtain the nutrients that are needed for their survival. The best conditions for the cation exchange to obtain the nutrients are when the soil pH is between 6.0 and 7.5 (slightly acidic to slightly alkaline). Desert soils tend to be alkaline (greater than 7.0), making it more difficult for the plants to receive the nutrients they need. In addition, nitrogen has to be converted out of organic materials in the decomposition process by soil bacteria for plants to be able to use it. This bacterial action is diminished when pH is too high or too low.

Background Information: Soil Improvement (continued)

Caliche and saline soils are common in the Southwest. Caliche is formed over thousands of years by the accumulation of calcium-cemented layers of soil at some depth from the surface. This occurs as the intermittent rains leach calcium from the surface to lower levels where it combines with the soil particles to form caliche. When the rains stop, the caliche has accumulated in layers of varying thickness at various depths. These layers are almost impenetrable for plant roots. In addition, caliche layers prevent water from draining down through the subsoil. As water accumulates on top of these layers and around plant roots, there is no oxygen left and the plant dies.

Saline soil is full of soluble salts, and too much salt can be toxic to many plant varieties. In the arid West, saline soil has developed from minerals that are naturally found in the soil. In addition, the salt content of soils is increased by the use of well water for irrigation, the addition of inorganic fertilizers and manure high in salts, and the lack of rain to flush salts deeper into the ground.

Amendments for Chemical Structure

Changing the soil's pH is tedious and rarely succeeds on a long-term basis. Because a soil's pH cannot be permanently altered, adjusting it requires large amounts of chemical additives that need to be tilled into the soil. For instance, the addition of sulfur or ammonium sulfate will change alkaline soils to a lower pH, but only temporarily, so the amendments must be applied repeatedly. Instead of such a time-consuming, labor-intensive process, it is easier to grow plants that are suited to the pH of the area. Native and adapted species are already tailored to New Mexico's alkaline conditions, and many other plants are not terribly particular about the exact pH of the soil in which they live.

Caliche and saline soils are also difficult to amend. If the caliche layer is shallow enough to be within the range of a tiller, organic matter can be added to assist with the breaking up of the caliche. However, with subsurface caliche, a raised bed with good drainage might be a better solution.

Saline soil can best be improved by improving the drainage. If you can improve the drainage, gypsum can be added to displace the sodium from the soil particles. The drainage will allow for movement of the sodium out of the soil completely. However, without the drainage, the sodium will remain in the soil solution and increase the damage to plants. If the drainage cannot be improved, a raised bed may be the best solution.

Biological Structure

The organic matter in soil is composed of living microorganisms and plant and animal matter in various stages of decay. The living microorganisms include bacteria, fungi, and other microbes that are decomposers, plus animals such as worms and insects that aerate and mix the soil as they move through it. Soil microorganisms form clumps of soil by helping minerals and organic particles aggregate. This helps create the soil structure.

Decaying organic material is a rich source of nutrients and is home to many soil microorganisms. The organic matter that decays on top of the soil forms a rich organic material called humus. Humus is light and

Background Information: Soil Improvement (continued)

airy, with good structure and plenty of pores. It acts as a sponge in the soil by holding water. Most soil contains only 6 to 12 percent humus, which is enough to support plant life. Desert soils have very small amounts of humus due to the limited availability of plant material and the lack of water to aid in the decomposition process.

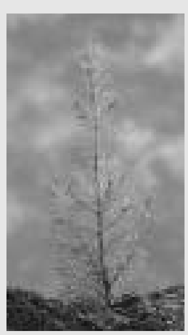
Water and air are necessary to help support the biological life in the soil. Soil organisms are best suited to living in soil that has equal amounts of air and water in the soil pores.

Amendments for Biological Structure

The addition of humus will benefit most desert soils. Compost is a form of humus and can be created by collecting food scraps and yard waste and allowing it to decompose. Remember that in arid environments it may be necessary to water the compost to aid in decomposition. The addition of a homemade compost or naturally occurring humus will increase the soil's ability to retain water and will benefit the existing decomposers and biological organisms already in the soil.

FINAL THOUGHT

All soils can be amended physically, chemically, and biologically. However, for a xeriscape, try to minimize large-scale amendments by choosing plants that utilize the existing soil. Small-scale amendments can be used for flowerbeds or that special non-native plant the homeowner cannot live without.



FOOTNOTES, pg. 44

1 Arthropod – any of the phylum Arthropoda of invertebrate animals (insects, arachnids, and crustaceans) that have jointed body and limbs

2 Macro organisms – an organism (living being) that can be seen with the naked eye

FOOTNOTES, pg. 45

3 Discrete data – a separate entity, individual; if the set of all possible values, when pictured on the number line, consists only of isolated points

4 Continuous data – marked by uninterrupted extension in space, time or sequence; temperature would be continuous data, if the set of all values, when pictured on the number line, consists of intervals

5 Detritus – a direct product of disintegration or wearing away, as in rock

FOOTNOTES, pg. 47

6 Acidity and alkalinity in soils are measured by testing the pH (potential Hydrogen) of the soil. The values of pH range from 1-14 with 7 being neutral (distilled water would test at a 7). A measurement of 1 would be very acidic and 14 would be completely alkaline.

7 Caliche – a crust of calcium carbonate that forms on the stony soil of arid regions

8 Salinity – salt

9 Cation – a positively charged ion

10 Humus – a complex mixture of partially decomposed, water-insoluble material found in the topsoil layer; it helps retain water and water-soluble nutrients so they can be taken up by plant roots

Problem to Solve: Andy Devalle's Soil

Valencia County Extension Agent
1000 Main St. NW Bldg. 16
P.O. Box 1059
Los Lunas, NM 87031

Dear County Extension Agent:

I just bought a new house up on the mesa in Los Lunas with beautiful views. I am planning to landscape the whole yard.

I have already put in a small flower garden. However, the soil in this spot is mostly sand and the water runs right through it. Before I landscape the rest of the yard, is there something I can do to improve the soil so that it holds water better?

I understand that the County Extension Service can analyze soil samples. I am enclosing three soil samples — two from my new yard and one from my property in Santa Fe. Sample one is typical of most of my Los Lunas yard. Sample two is taken from near a tree where the builder added compost. Sample three is from the house I am selling in Santa Fe.

Thank you for your advice.

Sincerely,

Andy Devalle in Los Lunas

Andy Devalle's Soil: Project Cover Sheet

Use the information you have learned from the activities, the handouts, and reference books to help Andy Devalle solve his landscape problem. You can give Mr. Devalle a plan that can be accomplished very quickly or a plan that will take him several years to accomplish.

When you have decided on a plan for Mr. Devalle, write him a letter telling him the steps you think he should take to improve his flower garden and any other areas around the house in Los Lunas (Samples 1 and 2) and in Santa Fe (Sample 3). Be sure to tell him why you are giving him the advice you are providing.

Your completed project will include:

_____ Soil Through the Looking Glass Student Worksheet

_____ Holes in the Soil Student Worksheet

_____ Who Lives in Soil? Student Worksheet

_____ Best of the Best Student Worksheet

_____ Letter of advice to Mr. Devalle

_____ Calculations for amount of soil amendments

Optional Extension

If you advise him to add any soil amendments, be sure to identify which amendments you recommend and include an estimate of how much of the material he will have to add per 100 square feet of landscaped area. You may have to research the cost and coverage of the various amendments.

Andy Devalle's Soil: Project Cover Sheet

Use the information you have learned from the activities, the handouts, and reference books to help Andy Devalle solve his landscape dilemma.

You will be sending Mr. Devalle a detailed soil analysis of the samples that he has sent you, along with an explanation of the tests you ran. Include soil particle size, pH, biological content, and any other relevant findings. This information can be in the form of a letter, chart, or diagram. If your lab group has only one of the samples, you will need to exchange data with other groups so that you have results for Soils 1, 2, and 3.

In addition, decide on a soil amendment plan for Mr. Devalle. Write him a letter telling him the steps you think he should take to improve his flower garden and any other areas around the houses in Los Lunas and in Santa Fe. You can give Mr. Devalle a plan that will take him several years to accomplish, or one that can be accomplished very quickly.

If you are advising him to add soil amendments, include an estimate of how much of the material he will have to add per 100 square feet of landscaped area. You may have to research the cost and coverage of the various amendments.

Your completed project will include:

_____ A brief description of the tests you ran

- Soil Through the Looking Glass Student Worksheet
- Holes in the Soil Student Worksheet
- Who Lives in Soil? Student Worksheet
- Best of the Best Student Worksheet

_____ A letter, chart, or diagram showing the results of your soil analysis
_____ A detailed statement of the soil amendments you are recommending
_____ Calculations for amount and cost of soil amendments for every 100 square feet of landscape

Andy Devalle's Soil: Tips For Getting Started

If you are having trouble getting started, answer the following questions and then use your answers to help you write a letter to Mr. Devalle.

1. What type of soil is in Mr. Devalle's flower garden (Sample 1)?

2. What are some of the characteristics of Sample 1 (size, porosity, pH, arthropods, etc.)?

3. What type of soil is at Mr. Devalle's Santa Fe home (Sample 3)?

4. What are some of its characteristics (size, porosity, pH, arthropods, etc.)?

5. Using the information from Soils Through the Looking Glass, Holes in the Soil, Who Lives in Soil?, and Best of Best, what would you recommend that Mr. Devalle do to improve his soil in Los Lunas (Samples 1 and 2)?

6. Using the information from Soils Through the Looking Glass, Holes in the Soil, Who Lives in Soil?, and Best of Best, what would you recommend that Mr. Devalle do to improve his soil in Santa Fe (Sample 3)?

7. Review the charts **Changing Soil pH** and **Common Soil Amendments**. Would you recommend any of these amendments for Mr. Devalle's soil? If so, which ones and how much?

Use the answers to the questions above to write a letter to Mr. Devalle. Be specific in your response.

It All Looks Like Dirt To Me!

Soil is one of the most valuable resources on our planet. In fact, soil is right up there with water and air on the list of things that are absolutely essential for survival. Did you know that soil is the direct or indirect source of nutrition for most living things? In order to protect this valuable resource, you will need to know how soil is made and constructed.

Soil is constantly changing. It is washed away through erosion and then built back up as organic matter (consisting of plants and animals) decomposes and inorganic matter (rocks) breaks down. It has physical, chemical, and biological structures because it contains mineral particles, plant and animal matter, air, and water.

Physical Structure

The physical structure of soil is formed from decayed plant and animal bodies (organic matter), ground-up rocks and minerals (inorganic matter), and the spaces in-between. Although soil looks solid, it is actually composed of clumps of organic and inorganic matter with spaces in between, which are called pores. The pores in the soil hold water and air. The size of the soil particles determines what kind of soil it is (sometimes referred to as the "texture" of the soil). The chart below shows the size ranges of soil particles and what the soil texture is called based upon those size ranges.

Try to think of one living thing that does not have a connection to the soil.

The ideal soil for landscapes or gardening is said to be an equal mixture of sand, clay, and silt - along with plenty of organic matter - because of its ability to hold onto water. Three common types of soils are listed below:

- **Sandy soils** have a loose structure. Sandy soil doesn't clump together and has large pore spaces. Water moves through these large pore spaces very quickly, leaving little chance for plant roots to access it.
- **Clay soils** clump together tightly, providing very little pore space. Water moves through these soils very slowly or sometimes not at all.
- **Ideal soils** contain a mixture of sand, clay, silt, and organic matter. (Silt is comprised of tiny particles that are smaller than fine sand but larger than clay particles.) Such a mixture balances the disadvantages of the individual soils. In well-structured soils, the individual soil particles bond into aggregate clumps of sand, silt, and clay. This clump of the three parts provides a more beneficial pore space. Water will not move too quickly or too slowly through well-structured soils, which allows plant roots time to absorb it.

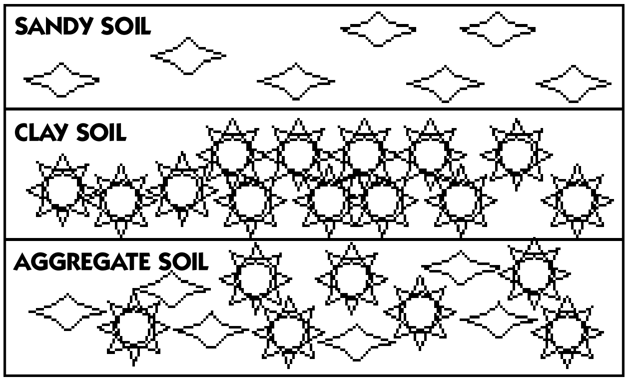
Soil Particle Size

Soil Texture	Size of Particles in Millimeters
Fine Gravel	1.0-2.0 mm
Coarse Sand	0.50-1.0 mm
Medium Sand	0.25-0.5 mm
Fine Sand	0.10-0.25 mm
Very Fine Sand	0.05-0.10 mm
Silt	0.002-0.05 mm
Clay	Less than 0.002 mm

Why is it important that water and nutrients not move too quickly or too slowly through the soil?

It All Looks Like Dirt To Me! (continued)

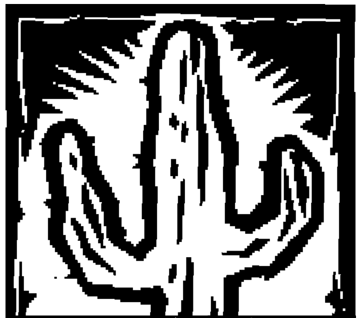
The diagrams below represent how soil particles relate to pore space. Notice how the sandy soil has large pores, the clay soil has small pores, and the aggregate soil is somewhere in between.



Amendments for Physical Structure

An amendment is something that is added to soil in order to improve the soil's water- holding capacity and nutrient content. The most common means of improving or amending the soil is adding organic matter, such as compost or fertilizer. This amendment works to provide a balance in the soil, like the mixture of sand, clay, and silt discussed earlier. In sand, the organic matter cements particles together to form larger air spaces. These air spaces act as a sponge to hold water. In clay, the addition of organic matter breaks the clay particles into clumps and leaves spaces for roots, air and water. In the New Mexican desert, most of the soils are sandy with small amounts of silt and clay. The mountain areas contain more silt and clay with less sand.

If you decide to use native or adapted plants in your landscape, you will probably not need as much soil improvement. Native or adapted plants are already well suited to survive the sandy or clay soils. Too much soil improvement can actually harm these plants. However, if you would like to landscape in sandy or clay soils with a variety of plants, you might want to consider amending or improving the soil.



Can you think of a reason that desert soils would not have many plant nutrients?

Chemical Structure

The chemical structure of the soil depends mainly on the rock formations in the surrounding area. The rocks are broken down through wind and water into their basic components, minerals. The minerals become part of the soil's composition. These minerals are also a source of nutrients for the plants. Plant growth is dependent upon the amount of essential nutrients that are available in the soil and the plant's ability to access them.

Minerals can also affect the potential Hydrogen, or pH[1], of the soil. Soil that has a pH between 6.0 and 7.5 has the best conditions for allowing plants to obtain those nutrients through a process called cation exchange.

Desert soils tend to be alkaline, which means they have a pH greater than 7.0. Desert soils are alkaline in nature because:

- they have large quantities of both calcium and sodium that contribute to the overall alkalinity of the soil;
- they receive very little precipitation, which means that salts aren't washed (or "leached") through the soil, and salts tend to produce a more alkaline soil; and,
- they have small amounts of decomposed biological materials.

[1] Acidity and alkalinity in soils are measured by testing the pH (potential Hydrogen) of the soil. The values of pH range from 1-14 with 7 being neutral (distilled water would test at a 7). A measurement of 1 would be very acidic and 14 would be completely alkaline.

It All Looks Like Dirt To Me! (continued)

Amendments for Chemical Structure

Changing the soil's pH is difficult, and it rarely succeeds on a long-term basis. You can try to till large amounts of chemicals into the soil, but the adjustments will only be temporary. The chemicals must be applied repeatedly. It is easier to use plants that are suited to the pH of the area. There are many plants that are not terribly choosy about the exact pH of the soil they live in. Native and adapted plants that are already tailored to fit the chemical conditions of the existing soil are also good choices.

Biological Structure

The biological structure in the soil is composed of living organisms and plant and animal matter in various states of decay. The living organisms come in two sizes—microorganisms[2] and macro organisms[3]. The microorganisms include bacteria, fungi and other microbes that assist in the decomposition process by feeding on the once living plant and animal matter. The macro organisms, such as worms and insects, also help with decomposition through their digestion, but they have the additional job of mixing or aerating the soil as they move through it.

The decaying plant and animal matter provides structure to the soil, and this decaying material is a rich source of soil nutrients. The decaying material breaks down into a rich organic material on top of the soil, called "humus." Humus is light and airy, with good structure and plenty of pores. It acts as a sponge in the soil by holding water. In addition, the decomposing material provides nutrients such as carbon and nitrogen that are needed by living plants.

Water and air are necessary to help support the biological life in the soil. Just like plants, the soil organisms are best suited to living in soil that has equal amounts of air and water in the soil pores.

Amendments for Biological Structure

Desert soils have very small amounts of humus and can benefit greatly from soil amendments. Compost is one form of humus that can be created by collecting food scraps and yard waste and allowing them to decompose. The addition of homemade compost to the soil will increase the soil's ability to retain water, add important nutrients, and benefit the biological organisms that are already in the soil.

Compost can also be purchased at almost any plant nursery. Commercial compost can come from a variety of sources, including wood and peat moss. Talk to the staff at your local nursery to find out which compost is the best for your soil.

Another soil amendment is manure from farm animals. You can often obtain free horse or cow manure from ranchers who have extra supplies. Make sure that the manure sits for one year or more before applying it to your landscape, because fresh manure can be too acidic for most plants. Adding manure has the same benefits as adding compost. It improves the soil structure and provides much needed nutrients.

Final Thought

It is possible to amend all soils physically, chemically, and biologically. However, try to minimize the large-scale amendments by choosing plants that can easily survive in the existing soil. Small-scale amendments can be used for flowerbeds, small lawns, or that special non-native plant that the homeowner cannot live without.

[2] Microorganism – an organism (living being) that is too small to see with the naked eye.
[3] Macro Organism – an organism (living being) that can be seen with the naked eye.

Charts & Graphs

Changing Soil pH[1]

To lower pH to 6.5, add sulfur or ammonium sulfate according to the soil type.		
Current pH	1,000 square feet of Sand	1,000 square feet of Clay
7.0	10 lbs.	20 lbs.
7.5	30 lbs.	45 lbs.
8.5	45 lbs.	70 lbs.

To raise pH to 6.5, add limestone according to the soil type.		
Current pH	1,000 square feet of Sand	1,000 square feet of Clay
6.0	15 lbs.	55 lbs.
5.5	30 lbs.	110 lbs.
5.0	40 lbs.	155 lbs.
4.5	50 lbs.	195 lbs.

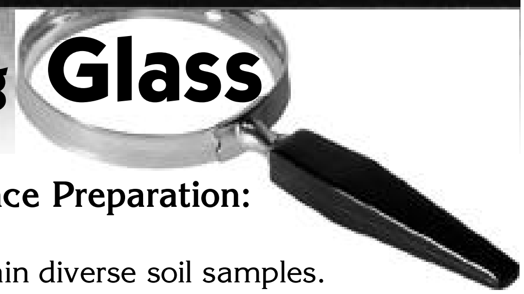
Common Soil Amendments

Amendment	Inorganic/Organic	Description
Sulfur	Inorganic	Can decrease soil pH, increasing acidity
Ammonium Sulfate	Inorganic	Can decrease soil pH, increasing acidity
Limestone	Organic	Can increase soil pH, decreasing acidity
Peat Moss	Organic	Nutrient value is low, used mainly for water-holding capacity and loosening of soil.
Composted Cow/ Horse Manure	Organic	Age for at least one year to avoid high ammonia that may burn plant roots. Easily available. Good for both clays and sands.
Sawdust and wood products	Organic	Helps clay soils by opening up the soil. Uses up nitrogen as it decomposes.
Compost	Organic	Cost effective, allows microbes to break down organic matter sufficiently so that the nutrients are released for the use of living plants. Good for both clays and sands.

• To change measurements to metric, see Appendix N

1 Ellefson, Connie, et. al., Xeriscape Gardening: Water Conservation for the American Landscape (New York: MacMillan Publishing Co., 1992), 39

Soil Through The Looking Glass



Main Question:
Are soils all the same? How are soils different?

Objectives:
- To observe and describe a sample of soil
- To characterize the physical properties of soil
- To measure soil pH

Subjects:
science, language arts, math, chemistry

Time:
1 to $1\frac{1}{2}$ hours

Vocabulary:
soil, pH, sand, silt, clay

Advance Preparation:
- Obtain diverse soil samples.

Procedure:
- Ask students to describe soil.
- Ask if all soil is the same. How might soil in a desert differ from agricultural soil? Forest soil? Soil in a parking lot?
- Discuss size of gravel, sand, silt, and clay particles.

Materials:
- dry soil samples
- magnifying glass or hand lens
- graph paper
- toothpick
- watch glass or petri dish
- eyedropper
- Two 50-ml. beakers, or small cups
- 1 pint screw-top jar
- pH paper or bromthymol blue
- water
- metric ruler
- alum or Calgon Bath Soap (optional)
- watch or timer

TEACHER TIP:
The recommended soil samples are:
1. Sand
2. Clay
3. A good combination soil including humus or compost

Do not use potting soil.

Each student can run tests on each of the three soil samples, or assign each group one of the soil samples and have the students compare soil properties at the end of the experiments.

Activity Procedures

Soil Through The Looking Glass

A. Particle Size

1. Fill the pint jar half-full with water. Add 75 milliiliters (ml.) of soil to the jar. Screw the lid on and shake the jar for one minute.
2. Set the jar where it won't be disturbed. Every five minutes look closely at the jar to observe the layers forming. On the student worksheet, describe what is happening. Are the sizes of the particles the same in all layers? Is there anything floating on top?
3. While the soil is settling, go on to the next activity.
4. After most of the soil has settled, use a ruler to measure the height of each layer.
5. Let the jar sit overnight and then examine it again.

B. Observation of Soil

1. Obtain a sample of soil.
2. Place some of the soil sample on a watch glass or petri dish.
3. Using a magnifying glass, carefully examine the particles in the soil sample.
4. On the Student Worksheet, describe the soil's appearance with words and diagrams.
5. Examine the soil by picking up a small amount and rubbing it. On the Student Worksheet, describe how it feels.
6. Place a small amount of water in a cup. While looking through the magnifying glass at the soil in the watch glass or petri dish, add one drop of water at a time onto the soil using the eyedropper. Record the observations on the Student Worksheet.
7. Scatter some of the dry soil on the graph paper so that the graph paper lines can be seen under the soil particles.
8. Using the magnifying glass, estimate the sizes of the soil particles and their size relationship to one another.
9. Record the observations on the student worksheet.
10. Draw a sketch of the different sizes of the soil.

C. Chemical Properties of Soil

1. Add a teaspoon of soil to a beaker or cup of water. Stir it for one minute. Let the soil settle.
2. After water has become fairly clear, insert a strip of pH paper or add a few drops of bromthymol blue (bromthymol blue remains blue in an alkaline solution, turns yellow in an acid solution and turns green in a neutral solution). What pH is the soil sample? Are all of the soil samples the same?

ACTIVITY TIP:
Add 2-3 drops of alum or Calgon bath soap to cause clay to clump and settle in one class period.

Student Worksheet

NAME

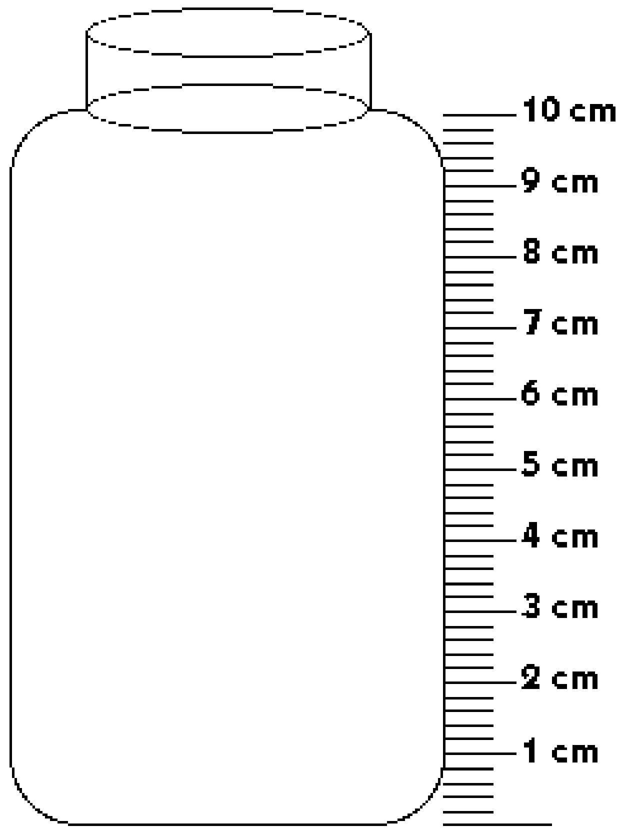
Soil Through The Looking Glass

Particle Size

1. Complete Chart

Top	Soil Layer	Size (cm.)
Bottom		

2. Draw layers to correct scale



3. Describe soil layers and particle size.

4. Describe layers in jar after settling overnight.

Observation of Soil

1. What does the soil look like?
   Describe or draw a picture:

2. How does it feel?

3. What happens when the water is added?

4. How does the wet soil smell?

NAME

Soil Through The Looking Glass

5. What was the size of the biggest soil particle?

6. The smallest?

7. What is average size of the soil particles?

8. Draw a comparison of the soil's different sizes.

9. List particle sizes below. Using information from your teacher, classify particles as sand, silt or clay.

	Particle Size	**Soil Type**
Biggest Particle		
Average Particle		
Smallest Particle		

Chemical Properties of Soil

1. List pH of soil samples

Soil Sample	**Color of pH Paper or Bromthymol Blue**	**pH**

Holes in the Soil

Main Question:
How well do different soils hold water?

Objectives:
- To compare the water-holding capacities of three types of soil
- To measure the amount of water stored in the pores of the soils
- To measure and compare the infiltration rates of soils

Subjects:
science, language arts, math, biology

Time: 2 hours

Vocabulary: infiltration, compost, porosity

Materials:

4 sandy soil
4 clay soil
4 potting soil
4 compost
4 balance
4 masking tape
4 Six 250-ml. beakers or 6 1-cup measuring cups
4 3 clear plastic bottles (small soda bottles)
4 petri dish or small plastic container
4 Three 5-centimeter squares of cheese cloth
4 cardboard
4 3 rubber bands
4 scissors or knife
4 food coloring
4 scoop
4 stopwatch or watch with a second hand

Advance Preparation:

- Complete previous activity, Soil Through the Looking Glass.
- Obtain diverse soil samples.
- Soils can be air-dried, put under a lamp, or placed in a very slow oven to dry. (Be sure petri dish doesn't melt.)

Setting the Stage:

- Have students refer to their description of soil from the Soil Through the Looking Glass activity. Did all of the soil particles fit together like a puzzle or were there spaces in between? What do they think is in those spaces?
- Is soil that is dug from the ground completely dry? How can it be tested for water content?
- Do all soils hold the same amount of water? How fast does water move through soil? Does it move through all soils at the same rate? Is there any way to change the amount of water a soil can hold or change the rate of infiltration?

TEACHER TIP:
Potting soil can be used for a comparison since many people think it is the "ideal" soil. It is very light and takes up moisture readily. It is not ideal for outdoor use since it has a very rapid filtration rate and loses water quickly.

Holes in the Soil

A. Water Content

1. Obtain small samples of three different soil types.
2. Label the side of the petri dish for each of the soil types.
3. Add a small scoop of soil to the petri dish and weigh it.
4. Record the weight on the student worksheet.
5. Without removing any soil, spread the soil sample out in the dish and set it in a safe place to air-dry for two days (or dry according to teacher's instructions).
6. Repeat this procedure for the all the soil samples.
7. When the soil has dried, re-weigh each sample.
8. Record the dried soil weight on the student worksheet.
9. Calculate the water content of each soil sample and answer the questions on the worksheet.

B. Porosity or Water-Holding Capacity

1. Place 250 ml. of each of the three soil samples in three separate waterproof beakers, one soil sample per beaker.
2. Label the three samples by their soil type.
3. Set the three labeled samples on a table or flat workspace.
4. Fill a new beaker with 250 ml. of water.
5. Slowly pour the water into the first soil sample. Stop pouring when the water level reaches the top of the soil.
6. Wait a moment to see if the water will settle down into the soil. If the water settles below the soil level, add water until the water level and the soil level remain the same. At this point, the soil has reached saturation and cannot hold any more water.
7. On the answer sheet record how much water was added to the soil sample.
8. Refill the water beaker to the 250-ml. mark.
9. Repeat steps 5 through 9 for the other soil samples.
10. Calculate the water-holding capacity or porosity for each soil sample and answer the questions on the worksheet.

(continued on next page)

ACTIVITY TIP:
If calibrated beakers are not available, tape a ruler to the outside of the beaker or mark it with masking tape.

Holes in the Soil

C. Water Infiltration Rate

1. Cut $^1/_2$ to 1 inch off the bottom of three clear plastic soda bottles using scissors or a knife.
2. Wrap the cheesecloth over the neck of each bottle and secure with a rubber band. **See Figure 1.**
3. Cut three cardboard pieces large enough to sit on top of a 250-ml. beaker. Cut a hole in the cardboard piece large enough for the neck of the bottle to fit through. This will be the stand that holds the bottle above the beaker. **See Figure 2.**
4. Label the bottles, one for each of the soil types.
5. Fill the first bottle with 100 ml. of the first soil type; fill the second bottle with 100 ml. of the second soil and the third bottle with 100 ml. of the third soil type, **Figure 3.**
6. Place the three bottles of soil into the cardboard holders on top of three 250-ml. beakers.
7. Place them side-by-side.
8. Fill an empty beaker with 200 ml. of water and add two drops of food coloring.
9. Slowly pour the dyed water into the first bottle of soil, **Figure 4.** As soon as the pourer has finished pouring all of the water, start the timer.
10. Every 20 seconds record the water level in the beaker under the soil.
11. When water stops dripping, stop timing.
12. Repeat steps 8 through 11 for the two remaining bottles of soil.
13. Answer the questions on the student worksheet.

Extension:

- If the infiltration rate of a soil is very slow or very quick, try mixing in compost and run the experiment again. Keep track of the amount of compost added.

- Create a “perfect” soil sample based upon what was learned in this lab by combining different amounts of soils and compost. Observe the soil through a magnifying glass, then test its pH, water-holding capacity, and infiltration rate. Save the soil sample to test it in the seed germination activity.

- Run these tests on soils from home gardens or soils from around the school. Select soils that have been designated as good and poor; give reasons for the designation. Test the soils.

Holes in the Soil

Figure 1

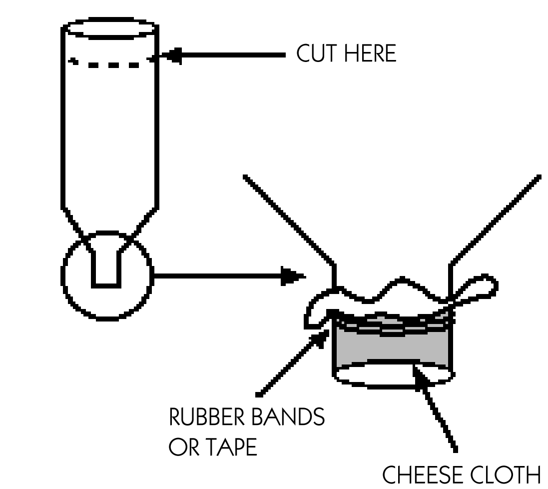


Figure 2

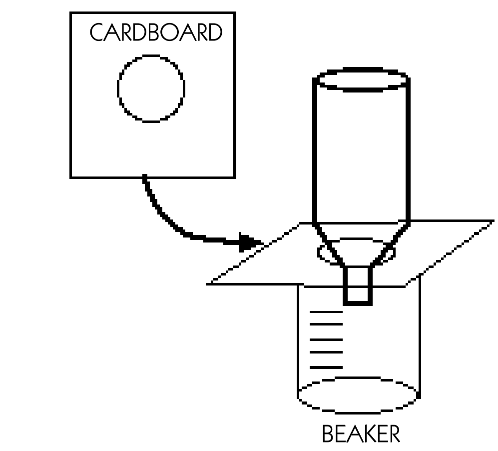


Figure 3

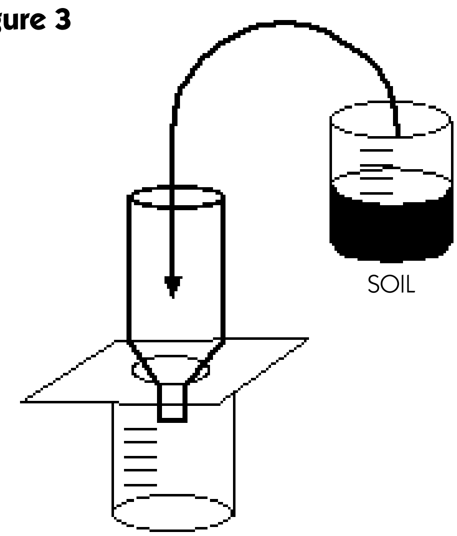
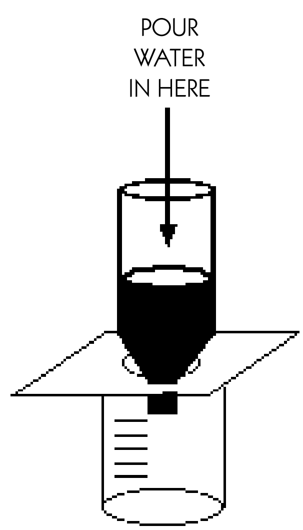


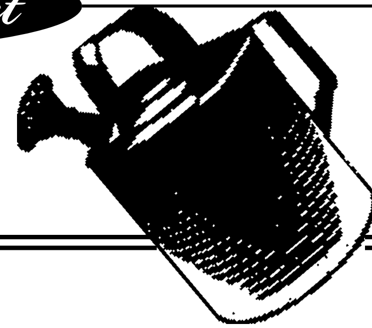
Figure 4



Student Worksheet

NAME

Holes in the Soil



Water Content

Soil Sample	Initial Weight of Soil	Final Weight of Soil	Difference in Soil Weight	Percentage of Water Content

Calculate the percentage (%) of water content in each soil using this equation:

$$\text{percentage water content} = \frac{(\text{Initial weight of soil} - \text{Final weight of soil}) \times 100}{\text{Initial weight of soil}}$$

1. Do all soils have the same percentage of water content?

2. Which soil had the most water?

3. Which soil had the least water?

Porosity or Water-Holding Capacity

Soil Sample	Initial Volume of Water	Amount of Water Added	Final Volume of Water (left in beaker)	Percentage of Water-Holding Capacity

Calculate the percentage (%) of water-holding capacity in each soil using this equation:

$$\text{percentage water-holding capacity} = \frac{(\text{Initial volume of water} - \text{Final volume of water}) \times 100}{\text{Initial volume of water}}$$

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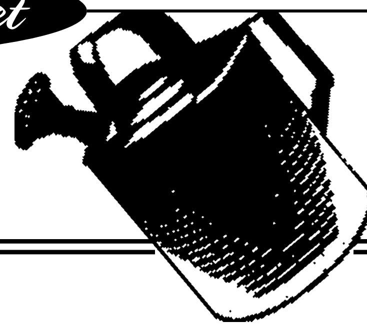
Student Worksheet

NAME

Holes in the Soil



1. When you added the water to the soil, where did it go?

2. Which soil sample held the most water?

3. Why is it important for soil to hold water?

4. Which soil do you think would be better for growing plants? Why?

Water Infiltration of Soils

Soil Type 1 ________________

Time	Water Level

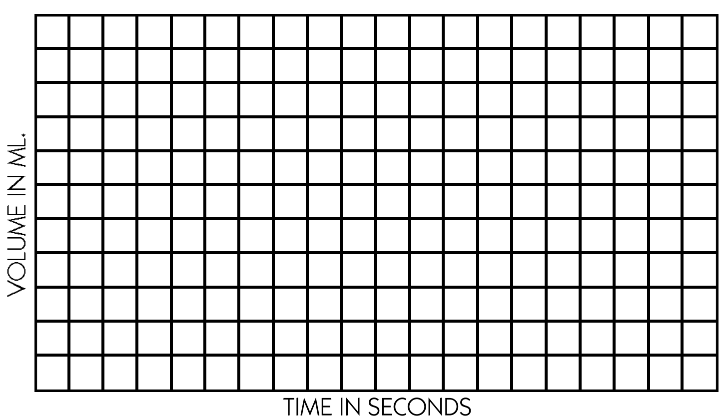
Soil Type 2 ________________

Time	Water Level

Soil Type 3 ________________

Time	Water Level

Graph the data for each soil type; use a separate color for each soil type.



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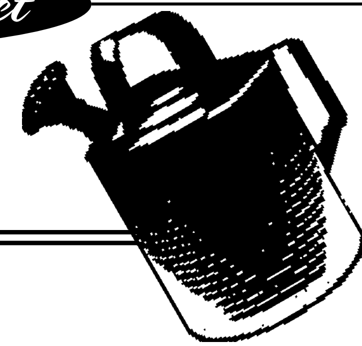
NAME PERIOD

Holes in the Soil



1. Which soil type did the water move through the fastest?

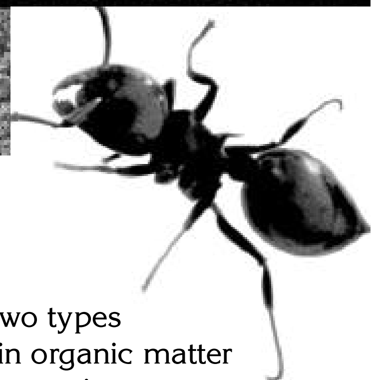
2. Which soil type did the water move through the slowest?

3. Which soil would provide the greatest potential for root growth? Why?

4. An infiltration rate is the rate that water moves into and through the soil. A slow infiltration rate means the water is slowly moving into and through the soil. What would be the problem with a very rapid or very slow infiltration rate?

5. What could be done to improve the infiltration rates of the soils?

Who Lives In Soil?



Main Question:
Who or what lives in the soil?

Objectives:

- To observe arthropods found in diverse soils
- To investigate the roles of arthropods in soil

Subjects:
science, math, biology

Time:
Day 1: 1 hour
Day 3: approximately 2 hours (varies)

Vocabulary:
arthropod, organic matter, extraction

Materials:

4 low-organic-matter soil
4 high-organic-matter soil
4 coarse steel wool or wire screen
4 plastic wrap
4 2 larger narrow-mouth jars
4 2 smaller jars that fit inside larger jars
4 2 rubber bands
4 masking tape
4 hand lens
4 rubbing alcohol
4 2 funnels
4 light source
4 arthropod identification books
4 forceps

Advance Preparation:

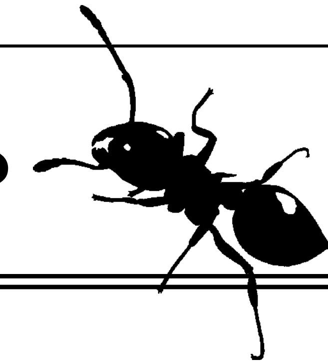
- Obtain at least two types of soil, one low in organic matter and one high in organic matter. Additional soils can also be tested.
- Since the data collected is discrete data, students should construct a bar graph.

Setting the Stage:

- Ask students what organisms they think may live in soils.
- Do all soils have the same number and types of organisms?
- How big are the organisms? Can they be seen with the naked eye? With a magnifying glass? With a microscope?

TEACHER TIP:
Soils high in organic matter can be found around water and decomposition. Look around a riverbank, pond, or forest floor, or use homemade compost.

Who Lives In Soil?



A. Extraction

1. Using masking tape, label the two larger jars with one each of the soil types.

2. Fill the two small jars half full with rubbing alcohol and set one in each of the two larger jars. **See Figure 1.**

3. Cut or trim the wire screen or steel wool to fit inside the two funnels.

4. Fill each funnel with a different soil to within $^{1}/_{2}$ inch of the top of the funnel.

5. Cover the tops of the funnels with plastic wrap and secure with a rubber band.

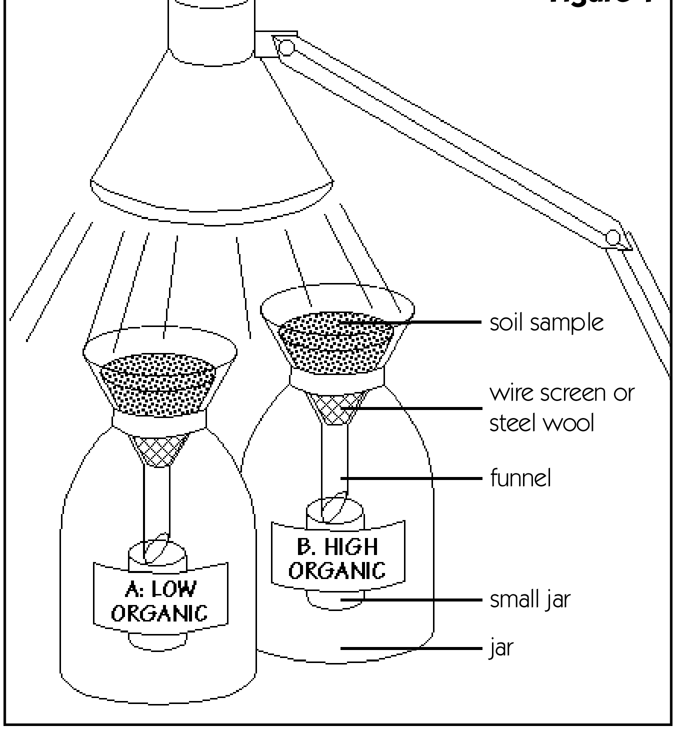
6. Put funnel on top of jar. The bottom of funnel should be resting just above the level of rubbing alcohol in the jar.

7. Set both jars under a light source that is 3-4 inches above the top of the funnel.

8. Leave light on for 24-48 hours.

Overnight the arthropods will move away from the heat and light source and will fall into the rubbing alcohol for preservation.

Figure 1



ACTIVITY TIP:
To complete this activity in one class, set up the extraction the night before and collect the data during class.

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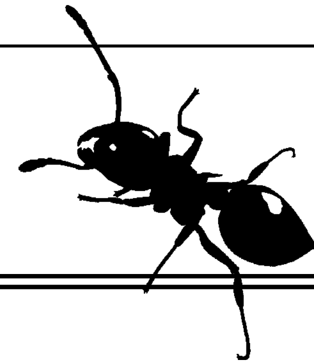
Who Lives In Soil?



B. Data Collection

1. With forceps, remove the arthropods from the rubbing alcohol and place them on paper towels to drain.

2. Use a magnifying glass and identification books to help observe and classify the arthropods.

3. Count the number of different kinds of arthropods collected from each sample and the number of individuals of each kind.

4. Identify arthropods using the identification books.

5. Organisms can be stored in capped alcohol jars or discarded.

C. Life History: A Day in the Life

Choose one of the following to complete.

1. Research the life history of one of the arthropods that was found. Explain its role in the soil ecosystem.

2. Become the arthropod that was researched and write a day in your life. This can be an essay, a short story, or a cartoon (like in the Sunday papers).

3. Draw a food web for the ecosystem and put a picture of the arthropod in the correct location for its role in the food web.

Extension:

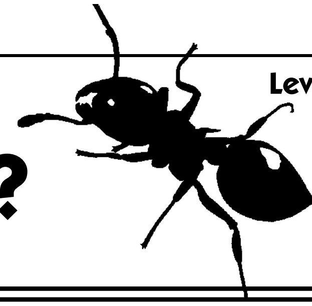
- Mount arthropods using insect pins and labels to create a collection of typical arthropods for each soil type.
- Compare agricultural, forest, and pond soils.
- Research food webs and complete a hypothetical food web for each soil.
- Collect the organisms in a jar without alcohol, and then build a terrarium to house the organisms that are extracted.
- Collect soils in different seasons and compare the number and types of arthropods found.

NAME

Student Worksheet

Level 1

Who Lives In Soil?



Soil Sample________________

#	**Description of Organism**	**Number of Individuals**	**Name of Organism**
Ex.	Gray, lots of legs, forms a circle	1	centipede
1			
2			
3			
4			
5			
	Total	Total	

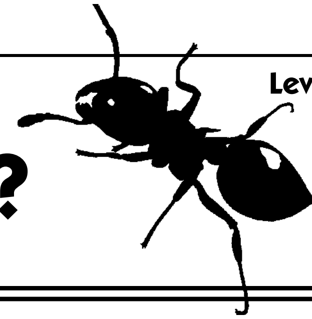
Soil Sample________________

#	**Description of Organism**	**Number of Individuals**	**Name of Organism**
1			
2			
3			
4			
5			
6			
	Total	Total	

(continued on next page)

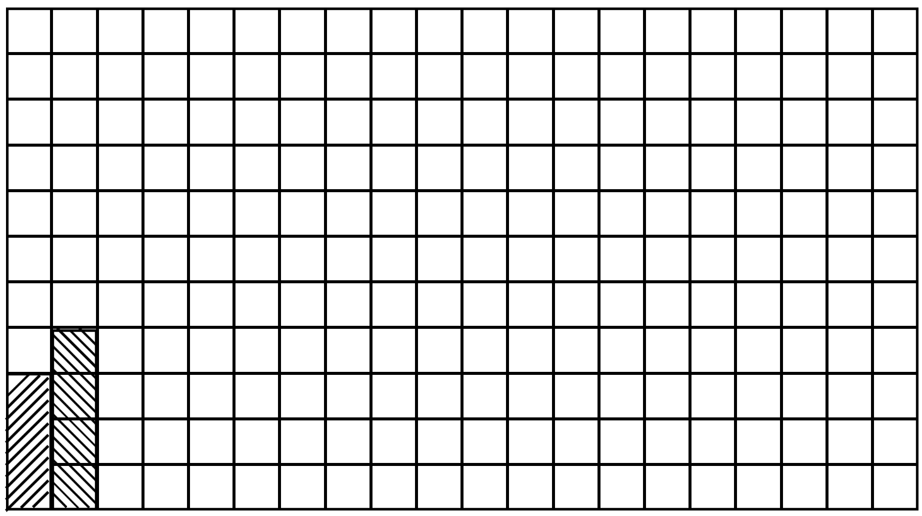
Student Worksheet

NAME Level 1



Who Lives In Soil?

Create a bar graph. Show the number of each organism found in each of the soils. Complete the key and all the labels necessary to read the graph.



Organism 1

Key

Low-organic-matter soil

High-organic-matter soil

Example:
Organism 1: Centipede

1. Which soil type had the most different types of organisms? Why?

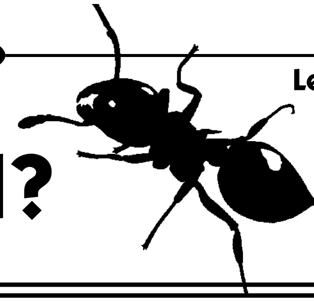
2. Did any soil have just one type of organism? Which one?

3. What is the role of these organisms in the soil?

4. How could you increase the number of organisms in the soil?
   (Hint: What do the organisms eat?)

NAME — Student Worksheet — Level 2

Who Lives In Soil?



Soil Sample_______________

#	Description of Organism	Number of Individuals	Name of Organism
1			
2			
3			
4			
5			
6			
	Total	Total	

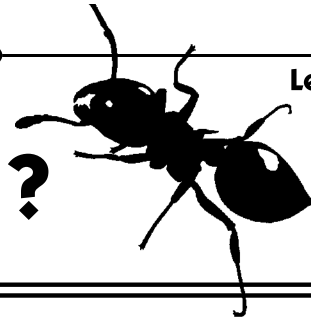
Soil Sample_______________

#	Description of Organism	Number of Individuals	Name of Organism
1			
2			
3			
4			
5			
6			
	Total	Total	

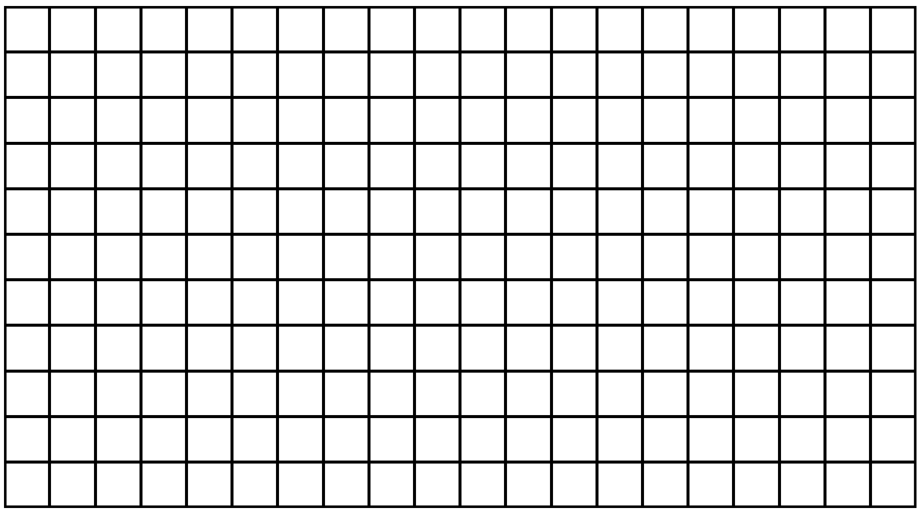
(continued on next page)

NAME **Level 2**

Who Lives In Soil?



Create a bar graph. Show the number of each organism found in each of the soils. Complete the key and all the labels necessary to read the graph.



Organism

1. Which soil type had the most different types of organisms? Why?

2. Did any soil have just one type of organism? Which one?

3. What is the role of these organisms in the soil?

4. How could you increase the number of organisms in your soil?

Best of the Best

Main Question:
What kind of soils do plants like?

Objectives:

- To determine whether plants grow better in amended or non-amended soil
- To determine types of amendments and how much works best
- To determine if all plants like the same kind of soil

Subjects:
science, language arts, math, chemistry

Time:
Day 1: 1 hour for setup; 15 minutes each day after seeds germinate

Vocabulary:
shoot, root

TEACHER TIP:
Compost can be purchased at plant nurseries, but look to farmers' markets and others for free compost.

Materials:

4 low-organic-matter soil (sand or clay)
4 compost
4 seeds: beans, corn, mustard, squash, or quick-growing grass seeds
4 4 large paper cups
4 pan to hold cups
4 metric ruler

Advance Preparation:

- Soak seeds overnight in water before starting experiment.

Setting the Stage:

- Ask students if they think all soils grow plants the same way.
- Do all plants grow in the same kind of soil?
- How can one determine if a plant is growing well?
- In the previous experiments, what could have been done to the sand or clay to increase the water-holding capacity?
- Discuss how to set up a controlled experiment. What variable will they be testing in this experiment? (soil quality) What variables should remain constant? (water and sunlight).

TEACHER TIP:
Amendment — material added to soils to improve soil structure and fertility.

Best of the Best

A. Setup

Cup #	Soil Combination
1	Soil only
2	$^{2}/_{3}$ soil, $^{1}/_{3}$ compost
3	$^{1}/_{2}$ soil, $^{1}/_{2}$ compost
4	Compost only

1. Label each cup with a number as outlined on the chart and punch three small (nail size) holes in the bottom.
2. Fill each cup to within 1inch of top with soil combination listed on the chart.
3. Plant 1 seed of each kind in each cup. Add water until it begins dripping out of holes in the bottom of the cup.
4. Place cups in a pan, then place the pan in a warm, well-lit place where cups will not get direct sunlight.
5. Do not allow cups to dry out. Always add the same amount of water to each cup.
6. Hypothesize which soil will show the most plant growth.

B. Data Collection

1. After first sign of growth, measure the height of each plant every day or every other day as determined by the group for 2 - 4 weeks.
2. At the end of experiment, pull up all plants and measure the size of the roots.
3. Record the data on the student worksheets.

Extension:

- Test out different soil combinations.
- Test out different plants, e.g., wildflowers or flower garden varieties.
- Test with plants that like sandy soils. Will they do better or worse in amended soils?

NAME

Best of the Best

Soil type 1: __________________. Record the shoot height in millimeters (mm).

Day	Plant 1	Plant 2	Plant 3	Plant 4

Soil type 2: __________________. Record the shoot height in millimeters (mm).

Day	Plant 1	Plant 2	Plant 3	Plant 4

Soil type 3: __________________. Record the shoot height in millimeters (mm).

Day	Plant 1	Plant 2	Plant 3	Plant 4

(continued on next page)

NAME

Student Worksheet

Best of the Best

Soil type 4: ________________. Record the shoot height in millimeters (mm).

Day	Plant 1	Plant 2	Plant 3	Plant 4

B. Record final plant sizes in the table below:

Plant	Variable	Soil #1	Soil #2	Soil #3	Soil #4
1	Shoot height				
1	Root length				
2	Shoot height				
2	Root length				
3	Shoot height				
3	Root length				
4	Shoot height				
4	Root length				

(continued on next page)

NAME

Best of the Best

1. In which soil type did the plants grow the best?

2. Did all plants prefer the same soil type?

3. What else could be done to improve the soil?

4. Graph your results. Either show plant growth over time for all four soils or show the final root height and shoot length for all four soils.

RESOURCES:

The Growing Classroom: Garden-Based Science
by Roeberta Jaffe and Gary Appel published by Pearson Learning provides an elementary perspective on soils. The chapter called *The Living Earth/Soil* includes 16 activities on soil. They range from fun songs to how to work the soil using tools. Highly recommended curriculum for younger groups that is available from a variety of sources, ISBN 0-201-21539.

Dig In! Hands-On Soil Investigations
authored and published by the National Science Teachers Association takes soil science down to the very youngest students. The curriculum is for kindergarten through fourth grade and provides wonderful drawings and stories to entertain and educate. It is available from a variety of sources, ISBN 0-87355-189-3.

Worms Eat My Garbage
written by Mary Appelhof and published by Flowerfield Press. Now in its second addition, it is a wonderful resource book for worm composting in the classroom. This book is extremely complete, everything from what and how much to feed the worms, to how to use the resulting compost. It is available from a variety of sources, ISBN 0-942256-10-7. Also *Worms Eat My Garbage: Classroom Activities,* ISBN 0-942256-05-0.

Let it Rot, The Gardener's Guide to Composting
by Stu Campbell from Storey Books. It contains advice for starting and maintaining a composting system, building bins, and using compost. It is available from a variety of sources, ISBN 1-580-17023-4.

Life in a Bucket of Soil
written by Alvin and Virginia Silverstein and published by Dover Publications. It includes good general information about the arthropods and invertebrates that live in soil. It is available from a variety of sources, ISBN 0-486-41057-9.

http://www.meritbadge.com/bsa/mb/106.htm
A how-to site for the Boy Scouts' soil and water conservation merit badge. It provides a list of links on where to find the answers to some of the problems posed.

http://www.fmnh.org/ua/netsoil.htm
Four classroom experiments on soil: compaction, percolation, mudshake, and texture test, in English and Spanish provided by The Field Museum in Chicago, Illinois.

http://www.calpoly.edu/~ss/career.html
A list of possible careers for a soil scientist provided by California Polytechnic State University.

http://www.statlab.iastate.edu/survey/SQI/soil_biology.htm
Soil Biology, from the United States Department of Agriculture's Natural Resource Conservation Service. This website includes a complete primer on soils for farmers, ranchers, agriculture professionals, resource specialists, conservationists, students and educators. It also includes classroom activities, resources lists and a section on microbiotic crusts.

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Ellefson, Connie, et. al., 1992. *Xeriscape Gardening, Water Conservation for the American Landscape.* New York: MacMillan Publishing Company.

Phillips, Judith. 1995. *Natural by Design.* Santa Fe: Museum of New Mexico Press.

Phillips, Judith. 1998. *New Mexico Gardener's Guide.* Franklin: Cool Springs Press.

Schultz, Randall D. 1998. *The Complete How to Guide to Xeriscaping.* Albuquerque: City of Albuquerque.