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ABSTRACT

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field guide to SOILS

Henry Foth and Hyde S. Jacobs

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This pamphlet discusses the importance of soil to plant and animal life, the evolution of a soil profile, and the major kinds of soil in the United States. On a field trip students examine different kinds of soil profiles; they also measure soil acidity and water-holding capacity.

Dr. Henry Foth is Professor of Soils at Michigan State University where he teaches soil science with an emphasis on investigation. He is interested in studying soils in the field, and many of his publications have dealt with the relationship of soils to plants. He coauthored the book *Fundamentals of Soil Science* and was a writer for the ESCP text *Investigating the Earth*.

Dr. Hyde S. Jacobs is Professor of Soils and Director of the Water Resources Research Institute at Kansas State University. His interests include the effect of irrigation on the chemical properties of soil as well as evaporation of water from both soils and plants. He has coauthored two soil laboratory manuals and was a writer for the ESCP text *Investigating the Earth*. He served as Chairman of the Student Activities Subdivision and Chairman-Elect of the Resident Education Division for the American Society of Agronomy.

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FIELD GUIDE TO

Soils

Henry Foth

Hyde S. Jacobs

Series Editor: Robert E. Boyer

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Soils

INTRODUCTION

It would be hard to imagine a less promising place for life than the earth when it was first formed. No one is sure precisely when this occurred, but earth scientists place the date about five billion years ago. Many scientists believe that the earth was originally composed of molten rock which slowly cooled, forming a thin crust of solid rock. There was no animal or plant life. In fact, there was no soil in which plants could have grown.

Some plants can grow on bare rock today. You have probably seen the beautiful grayish-green plants called lichens that commonly live on rocks (Figure 1). In Hawaii, fantastic tall plants called silver swords grow on bare lava. But most plants need soil in which to grow, and all animals need plants to survive.

How is soil formed from bare rocks? What role does soil play in supporting plants and animals? How does soil supply essential nourishing ingredients, or *nutrients*, to living things? What is the source of these nutrients? How does the soil absorb water that falls as rain? Why are some soils fertile and others not?

Earth scientists ask all these questions. Soil scientists study the role of soil in the balance of life on earth, searching for ways to help people in areas like farming, city planning, or flood control.

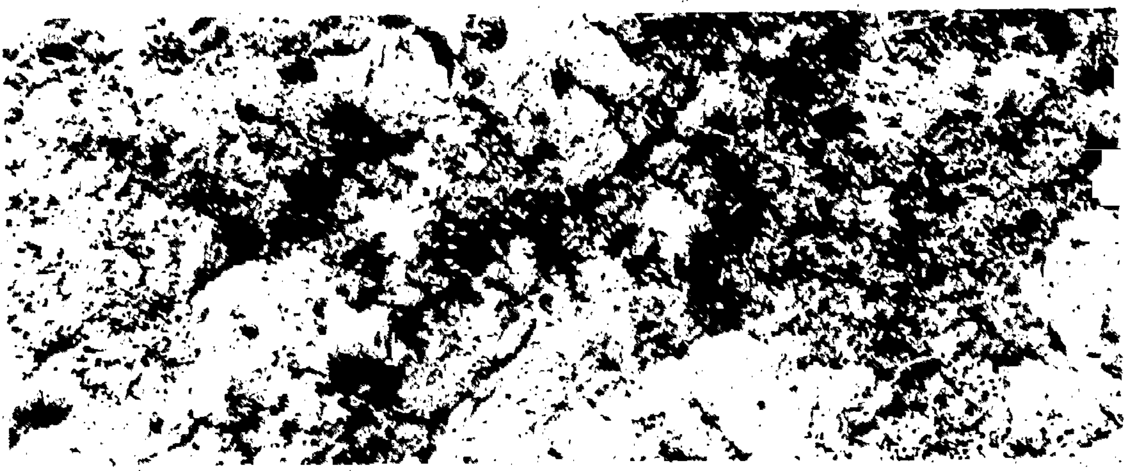


Figure 1. Lichens and mosses are generally the first plants to grow where rocks are exposed to weathering.

THE IMPORTANCE OF SOIL

Soil supplies water, nutrients, and support for plants. It also serves man in many other ways. Homes, roads, and cities are built on soil. Proper filtration through soil purifies water containing sewage and similar waste products. Water evaporated from the soil cools and helps regulate the temperature on earth.

A Source of Plant Nutrients

Almost every growing plant requires 16 chemical elements as nutrients. Twelve of the 16 elements essential for plant growth are supplied by rock and mineral particles in the soil (Figure 2). Of the remaining four, carbon and oxygen are taken from the air, hydrogen from water stored in the soil, and nitrogen from organic matter present in the soil. Thus soil links the nonliving world of rocks and minerals with the living world of plants and animals.

Even plants growing in the oceans use nutrients from the soil. In a process called *leaching*, rainwater seeping through the soil dissolves and carries away nutrients, some of them as far as the oceans. There microscopic plants utilize these nutrients; they, in turn, serve as food for animals, including fish.

Figure 2. Lack of any of the essential elements produces characteristic symptoms in plants. Symptoms of manganese deficiency include dark green leaf veins and yellow intervein areas.

In humid areas, the ability of the soil to supply nutrients to plants is reduced as nutrients from dead plants and animals are leached or carried away by water seeping through the soil. Leaching thus makes soils less fertile or able to support plant growth. The extent of leaching and the resulting degree of soil fertility affects the value of the land for crop production. Forests may grow in leached soils, however, because trees have deeply penetrating roots and may take many years to obtain all the nutrients they need. By contrast, a corn plant must obtain all of its nutrients within four or five months. Consequently, crops that grow rapidly require fertile soils. In colonial days, settlers found that many soils where forests had grown could not support rapidly growing crops. Squanto, an Indian, showed the Pilgrims how to bury a dead fish near each hill of corn to supply nutrients to the corn as the fish decomposed.

During the westward migration in the early history of the United States, land was rapidly cleared and crops were planted until the soil's fertility was exhausted. Then the settlers moved farther west to seek more fertile land. In 1906, Hilgard, an early American soil scientist, observed that corn yields dropped from 25 bushels per acre the first year to less than 10 the third year in soils that had developed under long-leaved pines on the uplands of the cotton-producing states. In an area where the shortleaf pine was also present, however, good crop production would last longer. And the presence of oak and hickory meant a still longer period of good production without added fertilizer. In other words, Hilgard showed that the native vegetation was an indicator of the soil's productivity for agricultural crops.

Moving to find more fertile land was a common practice throughout the world until man began to understand the needs of the soil and the crops he grew. In the mid-nineteenth century it was discovered that leaching produced acid soil, which limited plant growth. It was also found that lime (calcium oxide) or limestone (calcium carbonate) neutralized the acidity and improved crop production. Lime and other fertilizers are now commonly added to soils to replace nutrients that have been leached out. This practice stabilizes crop production, not only in former forested areas, but wherever calcium or other essential nutrients are lacking. Today, the manufacture and sale of fertilizers is an important industry in the United States. In fact, the addition of fertilizer is estimated to account for over 25 percent of agricultural production. Increased crop production through the use of fertilizers is considered one of the major ways to enable many underdeveloped countries to feed their people.

In the early history of the United States, when much less was known about soils and the crops we grew, most of our population lived on farms. Today the art of soil management is part of the technology that enables each American farm worker to produce enough food for himself and 34 other people. This striking efficiency resulted from studies of both soils and crops.

A Source of Water

The water held in soil is essential to all living things on our planet, including man. Plant roots absorb the 12 essential nutrients from the soil in the form of a solution. Water is held in the soil in thin films on the soil particles, usually less than 0.000008 millimeter thick. Plant roots are especially effective in obtaining this film of water from the soil. For example, a single rye plant grown for only four months in 0.03 cubic meter of soil developed 620 kilometers of roots, plus 10,600 kilometers of root hairs. Together, the roots and root hairs gave an estimated area of almost 650 square meters of plant tissue through which water could be absorbed. Roots penetrated every crevice of the

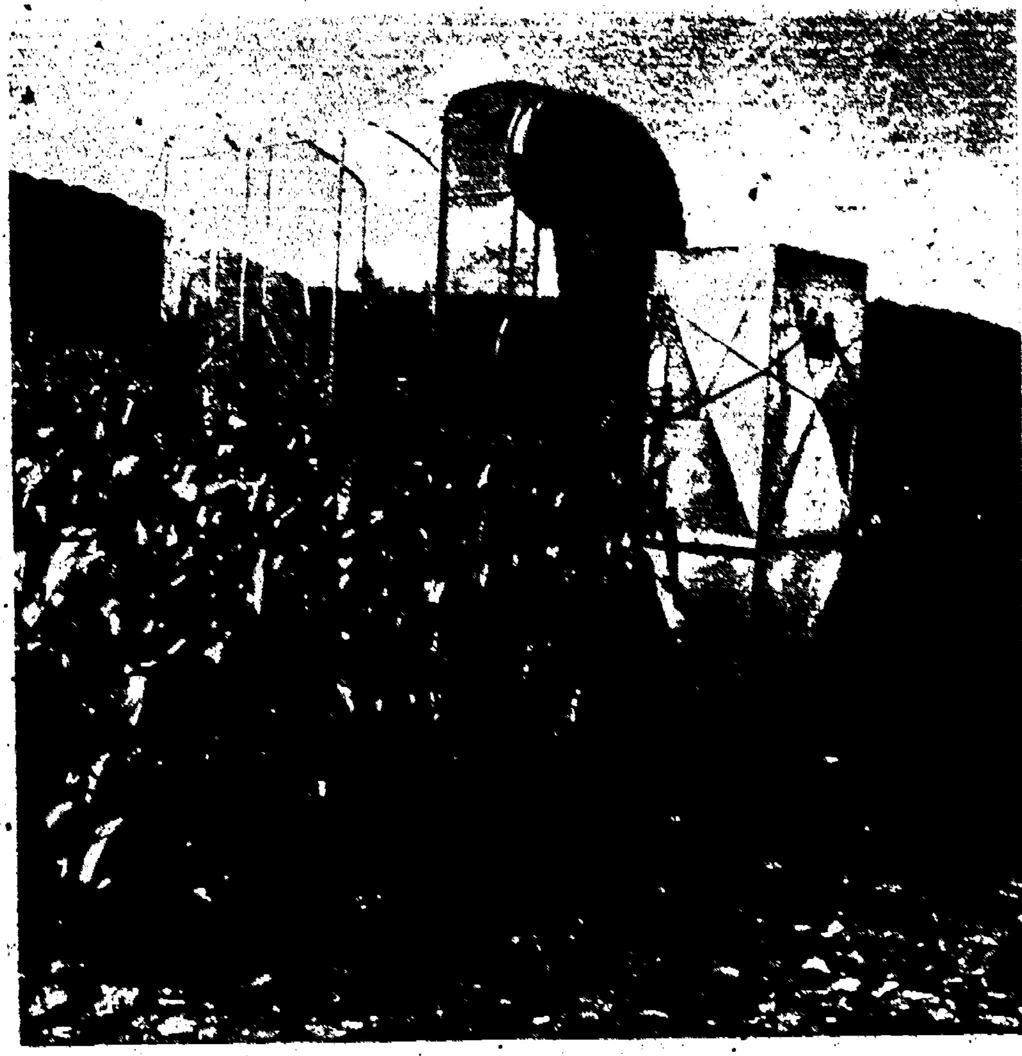


Figure 3. Apparatus used at Cornell University to determine the water requirements of plants under natural conditions.

soil because, on the average, there was less than 0.05 millimeter between root surfaces.

The soil is a great reservoir of water. Dig in the soil almost anywhere a day or two after a rain; you will find it moist within just a few centimeters of the surface. In Kansas, more water is stored in the soil at one time than is carried by the rivers of that state in an entire year. Most people know that plants obtain water from the soil through their roots; however, few realize just how much water plants actually need (Figure 3). To grow a single kilogram of wheat requires about 500 kilograms of water. Plants require quantities of water many times your weight each day to grow enough to supply your daily food.

Water evaporated from the soil and through plant leaves also serves to air-condition the earth. To evaporate a gram of water requires almost 3000 times more energy than to heat a gram of soil one degree Celsius. Because the energy to evaporate water from the soil comes from the heat in adjacent soil particles, evaporation is a cooling process. Without water to evaporate, the sun would quickly heat the earth to a temperature that man probably could not survive.

EVOLUTION OF A SOIL PROFILE

The physical and chemical breakdown of rock at the earth's surface, known as *weathering*, produces a layer on the earth's surface which we call *soil*. Weathering continues even after the soil material is formed. Other changes also occur, so that layers develop in the upper few meters of the weathered debris. Each of these layers differs from adjacent layers in some way. Collectively, the vertical soil layers are called a *soil profile*.

Soil profiles are produced over hundreds or thousands of years. The time required for a soil profile to form depends on whether hard rock must first be weathered down or the profile forms in loose sediments. The climate also plays a role in determining the rate at which soil profiles develop. As you may have guessed, soil profiles with few layers are *youthful* or *immature soils*. *Mature* or *old soils* will have a greater number of layers, called *horizons*, and the horizons will be more sharply differentiated (Figure 4). The development of soil horizons is like the development of wrinkles on a person's face. Old age is associated with many

Figure 4. Layers called horizons make up the soil profile. Each horizon differs from adjacent horizons in one or more properties.

deep-seated wrinkles, while youth is associated with smooth skin and few, if any, wrinkles.

Immature Soil Profiles

If moisture and temperature are favorable, plants quickly gain a foothold in the loose mineral debris on the earth's surface. Growing plants protect the soil from the action of raindrops and slow the movement of water over the soil. As a result, more water enters the soil and is stored there to speed up weathering and be used by plants. Since vegetation reduces both raindrop splash and runoff, the rate of *erosion*, the removal of rock debris and soil, under vegetation is much less than on a bare surface. Once plants are established, the small weathered particles that might otherwise be easily eroded tend to remain in place. In this way the plant cover helps weathering and soil-forming processes keep ahead of erosion. Consequently, the soil becomes thicker with time.

Plants also promote weathering and soil development in a number of other ways. Roots expanding in cracks in rocks help break the rocks apart. Have you ever stubbed your toe on a sidewalk that has been cracked and then lifted by a tree root growing underneath? Plant roots also give off carbon dioxide as they breathe. Carbon dioxide (CO_2) reacts with the water (H_2O) in the soil to form carbonic acid (H_2CO_3), which increases the rate at which many minerals weather:

$$CO_2 + H_2O \longrightarrow H_2CO_3$$

The weathering process, in turn, makes soluble and ready for use 12 of the 16 essential elements plants need.

Microorganisms also contribute to weathering. There are probably more microorganisms such as bacteria and fungi in a teaspoonful of soil than people on the earth. They exhale carbon dioxide, which contributes to carbonic acid formation. While soil minerals generally do not contain nitrogen, a nutrient essential for plant growth, certain bacteria convert nitrogen gas, taken from the air, to forms that plants can use. When the plants die and decay, some of this nitrogen is released for use by the next generation of growing plants. Much of it, however, remains in the *humus*, the organic residue formed by the decomposition process. Humus is a primary source of nitrogen for plants and is therefore a valuable soil constituent.

The dark-colored humus causes the uppermost layer to become darker than the underlying soil. The dark-colored layer containing humus is the *topsoil* and is called the *A horizon*. In the immature soil shown in Figure 5A, the topsoil lies directly on

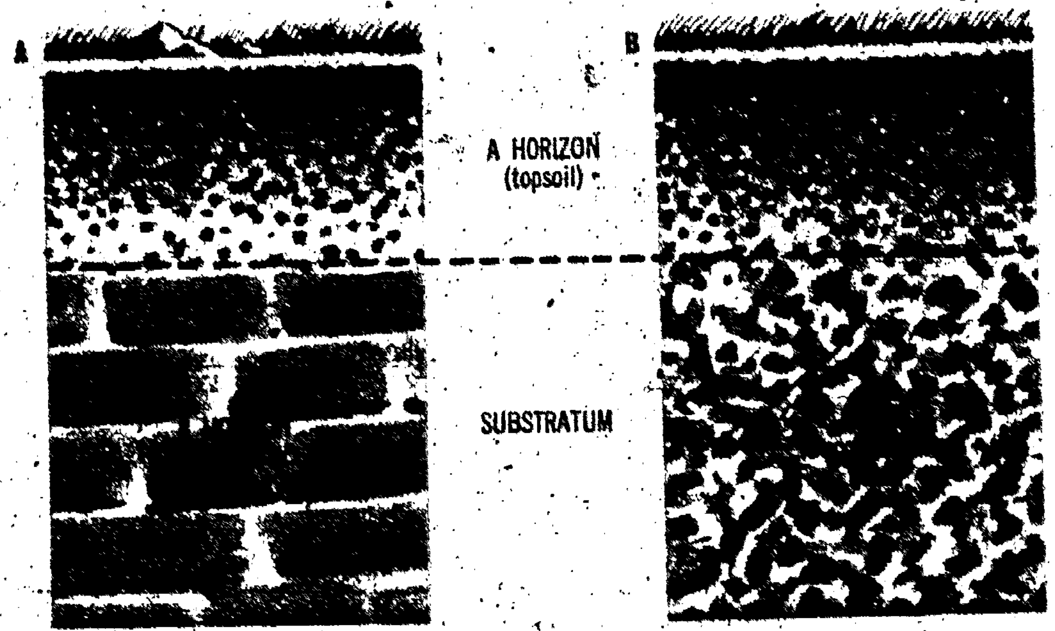


Figure 5. (A) Immature soil formed directly from bedrock. (B) Immature soil formed from unconsolidated sediment.

top of the *bedrock*, which is solid or *consolidated rock*.

Most soils and loose rock above bedrock are subject to some degree of erosion. The materials being carried from one place are eventually deposited elsewhere as sediments. Youthful or immature soils may develop on these deposited sediments (Figure 5B). Immature soils are thin and have only two major horizons, the topsoil or A horizon and the underlying parent material, called either a C or an R horizon. If the material is unconsolidated or loose—as in Figure 5B, the *substratum* or parent material is called a *C horizon*. If the underlying material is consolidated rock as in Figure 5A, it is called an *R horizon*. Mature soils have an additional horizon, the *subsoil* or *B horizon*, sandwiched between the A horizon and the substratum (Figure 4).

Mature Soil Profiles

Suppose you could return after 100,000 years to examine the site shown in Figure 5A. What changes would have taken place? A number of possibilities exist. If the rate of weathering and soil formation continued to exceed the rate of erosion, the soil would have become deeper. On the other hand, if the erosion rate had increased, the soil could have been removed. If the weathering and soil formation processes were balanced with the erosional forces, the soil would appear much the same as it does now.

Immature soils exist in some places because of the slow rate of bedrock breakup. Rapid erosion may also keep soils thin and immature. The abundance of sediments and the slow rate of erosion under most natural vegetation covers account for most soils in the United States being mature.

The soil shown in Figure 6 has more horizons than the soils shown in Figure 5. Notice that it has both a subsoil or B horizon and an A horizon composed of two subhorizons. It is a mature soil developed from glacial debris that was deposited when a continental glacier—a great sheet of ice that extended downward from Canada—melted in southern Michigan about 12,000 years ago.

As the glaciers spread southward they picked up and carried both soil material and rock fragments with them. When the ice melted, it left the ground covered with a mixture of rock debris ranging from boulders to clay, known as *till*. Plants quickly invaded the area. In time a forest was established. Most of the organic matter added to the soil came from tree leaves which fell on the ground. Consequently, a thin topsoil rich in humus developed. After perhaps 100 years a thin soil, similar to that in Figure 5B, existed in the upper part of the till.

Water carried small amounts of carbonic acid downward through the soil. After a few hundred years, enough carbonic acid had passed through the soil to dissolve the reddish-brown iron oxide coatings from the mineral particles in the surface layer. Iron in these oxide coatings had been produced by the release of iron from minerals by weathering. Later the iron reacted with oxygen in the air between the mineral particles to form iron oxide like that produced when metal rusts. Removal of iron oxide coatings from the mineral grains just

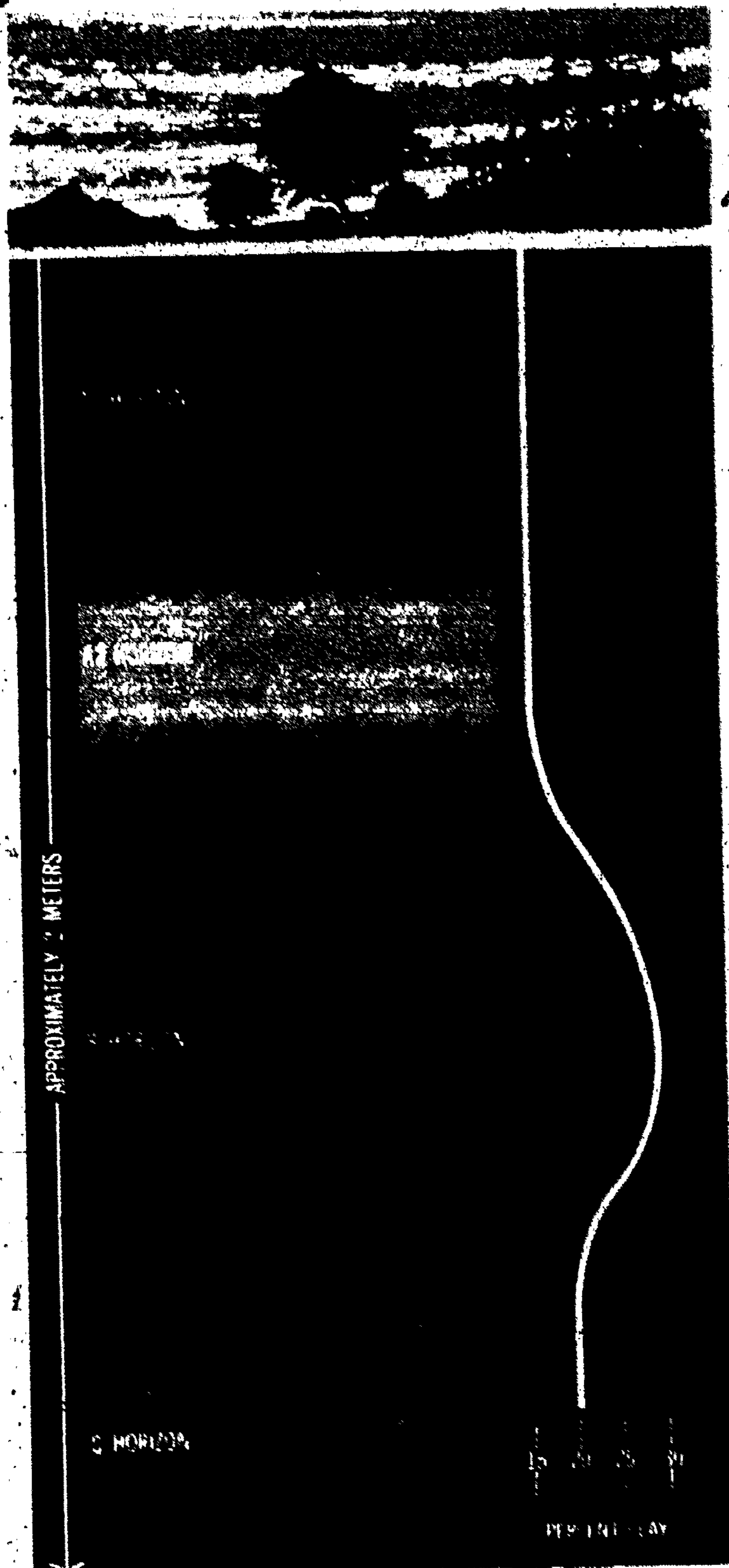


Figure 6. Mature forest soil formed from glacial till, and corresponding graph showing clay distribution.

under the humus-enriched layer produced a light gray zone. The topsoil remained dark because of its high humus content.

The thin dark-colored topsoil layer is called the *A1 horizon*. The gray or light-colored layer, where the removal of iron oxide is most apparent, is called the *A2 horizon*. Both subhorizons, which together make up the entire A horizon, lie above the subsoil or B horizon.

Some of the smallest mineral particles (clay and iron oxide) were carried downward out of the A horizon as water seeped through the soil. The fine pores of the underlying soil acted somewhat like a sieve and the small particles were sifted and collected in the subsoil. A typical clay distribution curve for a mature forest soil is shown in Figure 6. Clay content is lowest in the A horizon because clay has been removed. Clay content is highest in the B horizon because the clay transported from the A horizon has accumulated there. The same is true for iron oxide, so the B horizon is darker. Because of its higher clay content, the B horizon is much harder to plow or dig than the topsoil. As the clay content increases, clay particles block the spaces between the larger particles. Plant root penetration becomes more difficult, and water moves more slowly through the B horizon.

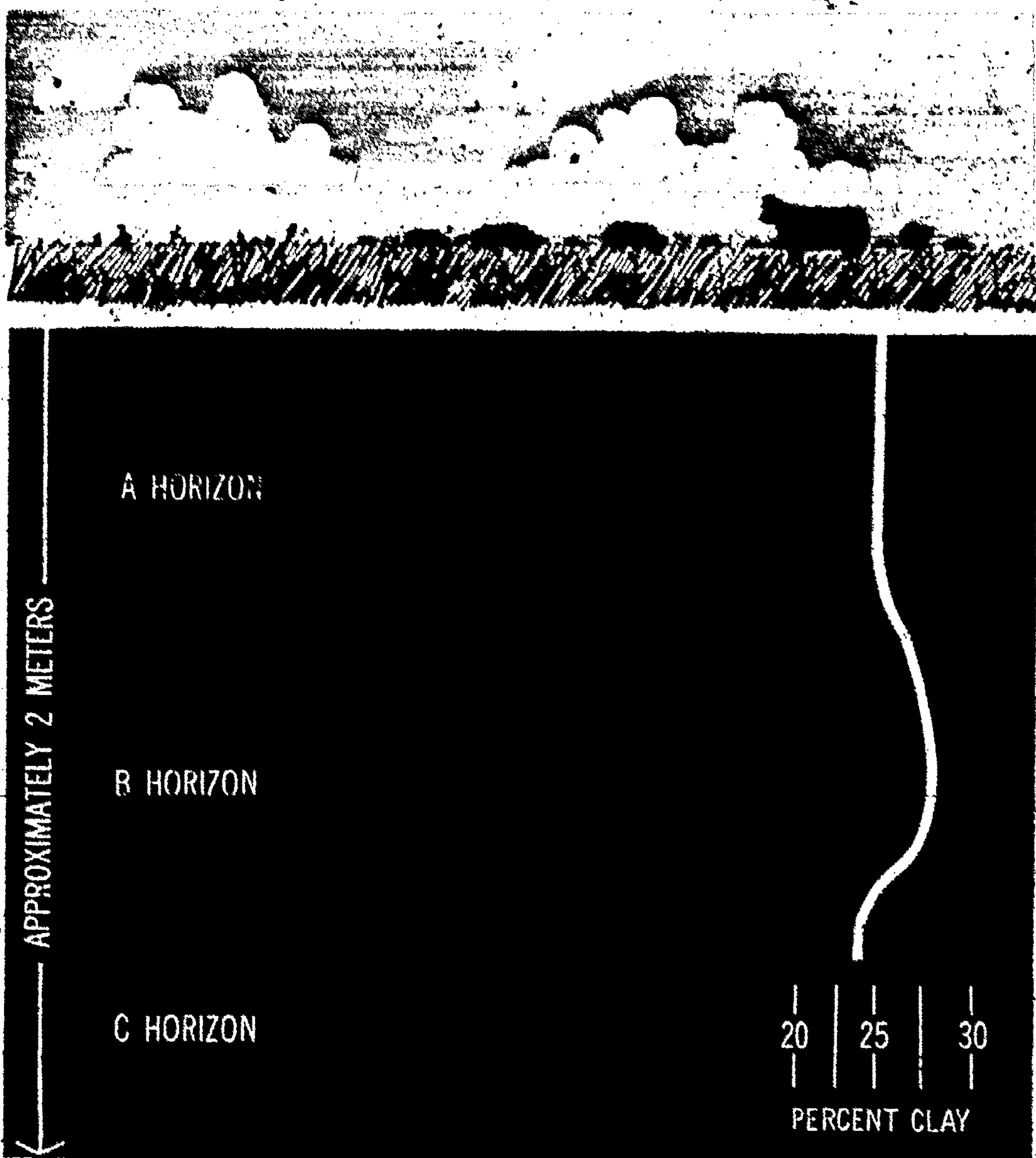
Below the B horizon lies the relatively unaltered glacial till. This is the C horizon or parent material. Soil scientists believe that calcium carbonate ($CaCO_3$) was once present throughout the entire soil depth, because it is still present in the C horizon. It is thought that frequent leaching with water containing small amounts of carbonic acid removed the calcium carbonate from the A and B horizons. Because calcium carbonate is one of the more soluble substances found in soil, its presence in the C horizon indicates that weathering has been less severe there than in the A and B horizons.

Forests generally occur in areas of high rainfall where the climate is humid, whereas grassy vegetation develops in areas of moderate or low rainfall where the climate is drier. The same basic processes of weathering, plant growth, and movement of materials by water which occur in forest soils also occur in grassland soils. However, grassland areas have less rain and less water seeping through the soil. Therefore weathering does not proceed as rapidly. Furthermore, grass grows much differently from trees. The humus content of grassland soils is much higher than that of forest soils because the growth of the fibrous root system of the grass rapidly adds organic matter to the soil. Consequently, grassland soils differ from forest soils in several important ways. The A horizon in the grassland soil (Figure 7) is much darker and much thicker than the topsoil or A1 horizon in the forest soils (Figure 6). This is because of the fibrous grass roots that contribute organic matter to a thick layer of soil. The boundary between the A and B horizons in the grassland soils is diffuse and hard to see.

Evidence of leaching at the depth where the A2 horizon shows in the forest soil is not present in the grassland soil, so the A2 horizon is absent. The dark color goes so deep because of the high amount of organic matter deep in the soil. The B horizon can be differentiated from the A horizon by its greater stickiness or clay content. Some clay moves downward from the A1 horizon to the B horizon so that the clay distribution pattern for mature grassland soil (Figure 7) is similar to that for forest soil (Figure 6). It is evident that the major horizons in the grassland soil are a thick A1 horizon, a B horizon, and a C horizon.

Leaching and nutrient removal is much less severe in low-rainfall areas than in forests. As a result, grassland soils usually contain more plant nutrients than do forest soils. In addition, the A and B horizons of grassland soils usually contain calcium carbonate because rainfall has not been great enough to dissolve it and leach it from the soil. In contrast, the A and B horizons of forest soils are typically leached of calcium carbonate. In Figure 7, a large quantity of calcium carbonate is present in the soil below a depth of one meter. The calcium carbonate leached from the upper part of the soil has been deposited there by water penetrating to that depth during the wettest season of the year. Calcium carbonate imparts a gray-white color to the soil and supplies abundant calcium to growing plants.

Figure 7. Typical mature soil developed under grass in a subhumid climate, and corresponding graph showing clay distribution.



MAJOR KINDS OF SOILS IN THE UNITED STATES

Immature soils occur where the hardness of rock, rapidity of erosion, or lack of time have prevented the development of mature soils. They are therefore common in mountainous regions. Soils located where flooding occurs regularly are commonly immature because new parent material is deposited with each flood and the soil horizons have little time to develop. On the other hand, mature soils reflect the weathering pattern where climate and vegetation have been able to work their full effect. For this reason, mature soils may develop in a given locality from materials ranging from glacial till to limestone, granite, or sediments.

The generalized soil map in Figure 8 shows the distribution of the major kinds of mature soils in the United States. Representative soil profiles—vertical cross sections of soils—are depicted for each major area. While these profiles are basically representative of the soils in the areas, local variations must be expected. From the map, you can tell whether you are located in an area that is predominately forest or grassland.

Forest Soils

The great forested area extends over the eastern part of the United States (Figure 8). Soils that develop throughout this region have many properties in common. For example, the soil in a northern forested area has a thin topsoil and the same horizon sequence (A1, A2, B, C) as the soil in a southern forested area. In each, the iron oxides have been removed from the A2 horizon to leave a light-colored layer directly underneath a thin topsoil. However, there is a difference in subsoil colors associated with these two different forested soils. Gray-brown subsoil colors predominate in the northern soils, whereas in the southern soils red

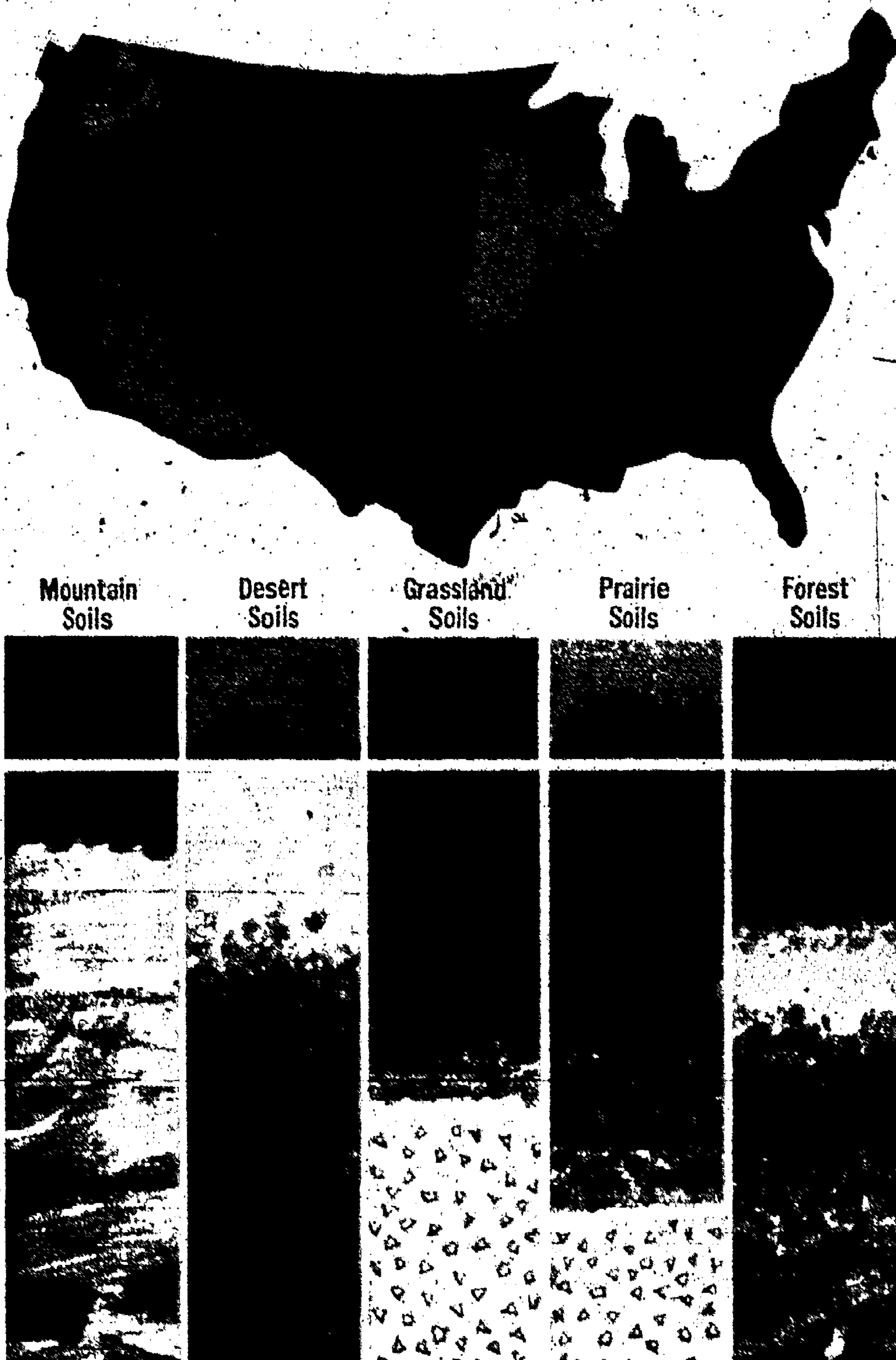


Figure 8. Generalized soil map of the continental United States, and profiles of the soil types shown.

and yellow colors predominate. Greater oxidation and dehydration of iron oxides produces the brighter colors in regions of higher temperatures.

When forested soils are plowed, the thin topsoil or A1 horizon is often mixed with the A2 horizon. The resulting mixture is relatively low in nutrients because of the intense weathering and leaching that occur during soil formation. Lime and other fertilizers must be added for profitable crop production.

Prairie Soils

The prairie soil region on the map (Figure 8) is unique. Rainfall is sufficient for forests, but the natural vegetation is grass. American Indians used fire to drive game; this is believed by some to be one reason that the area was not forested. Prairie soils that developed here resemble forest soils because there has been enough rainfall to leach the calcium carbonate from the topsoil and subsoil; on the other hand, they resemble grassland soils of the subhumid regions because their high humus content results in a deep, dark topsoil. The area of prairie soils comprises most of the Corn Belt and includes parts of Illinois, Iowa, Minnesota, and adjacent states. Prairie soils are among the most productive in the world because of their deep topsoil with a high humus content, and ample rainfall during the summer.

Grassland Soils of the Great Plains

A great area of grass and shrubs lies between the Rocky Mountains and the forested areas of the eastern states. This region generally coincides with the area called the Great Plains. Much of the land in the more arid western part is used for grazing cattle. The area is also known as the Wheat Belt. Wheat is better adapted to the subhumid and semiarid climate of this area than are corn and soybeans, which grow better in the more humid climate of the

Corn Belt. Note that the prairie soils are very similar to the grassland soils (Figure 8). Both have thick topsoil horizons, and neither has the A2 horizon that is characteristic of the forest soils. The absence of the A2 horizon indicates that weathering and leaching have been less severe in the soils developed under grass than in the forest soils. Because of this, grassland soils contain calcium carbonate, as shown by the gray-white colors in the C horizon.

The topsoil in the prairie region is somewhat thicker than in the grassland soils, but differences in topsoil thickness are most striking when grassland soils are compared to forest soils. Because relatively few nutrients have been leached from the grassland soils and the topsoil is high in organic matter, grassland soils are inherently more fertile than forested soils.

Desert Soils

Desert soils occur in the arid regions of the West. Due to low rainfall, vegetation is sparse, and little organic matter accumulates in the soil. Few nutrients or soluble materials are leached from the soil because of the low rainfall. Consequently, these soils are ordinarily fertile. Many ancient civilizations constructed irrigation systems to supply water to their desert soils. Some authorities believe it was easier for these people to supply water to a dry but otherwise fertile desert than it was to supply nutrients to the relatively infertile forested areas.

Summary

The specific properties and appearance of a soil are determined by the kind of parent material and the environment—including climate, vegetation, and slope—under which the soil developed. These factors act over a period of time to transform soil material into soil profiles. Similar soil profiles develop whenever similar combinations of these factors are found. For example, deep topsoils are characteristic of mature soils developed under grass. Forest soils characteristically have thin topsoils. Soils in humid regions usually contain little or no calcium carbonate, whereas soils in the subhumid regions and the drier regions usually contain calcium carbonate.

STUDY OF A SOIL PROFILE

We commonly observe the surface of a soil but rarely make the effort to examine the whole soil profile. A growing plant, however, "examines" the entire soil. The plant germinates in the topsoil and its roots grow downward through the subsoil (and sometimes through the parent material) to obtain water, oxygen, and nutrients. All of the soil horizons penetrated by the roots contribute to plant growth. Be sure to examine the whole soil profile and not just the surface.

Field Trip Preparation

Wear old clothes and take the following materials to the field:

- Pencil and notebook
- Ruler
- Pocket knife
- Dilute hydrochloric acid (10% solution in a 1-oz dropper bottle; available in most drugstores)
- Spade or shovel
- About eight small paper sacks for bulk samples
- Materials to construct miniature soil profiles:
  - Bottle of glue (white glue or model glue)
  - Soil sampler (construct sampler by punching a hole in half of a metal aspirin box)
  - 12 pieces of cardboard or manila folder cut to fit into the soil sampler
  - Two 13 cm × 20 cm pieces of cardboard

Be sure to ask permission from the owner to do your study if the site you choose is located on private property. Select sites that have horizons that are the result of natural soil-forming processes and not due to man's earth-moving activities. Areas where the topsoil has been scraped off or that have been filled during construction activities should be avoided. For your first site select an upland location that is not subject to flooding, so that the soil is not merely a recent accumulation of water-deposited sediment. You may want to ask an earth science instructor for help in selecting a site. Your goal is to find a location where natural processes have had sufficient time to develop soil horizons.

Choose a second location that contrasts with the soil at the first site. Generally the kind of soil changes each time topography, vegetation, or parent material changes. Consequently, soils at the top of a hill commonly differ from those at the bottom, soils on an upland site from those in the lowlands along a stream, and soils in forested areas from those in grasslands.

To examine the entire soil profile extending from the topsoil down to the parent material you will have to expose one to two meters of soil. So try to select soil that is already exposed in a roadcut, a gravel pit, a ravine, or an excavation for a building.

A Look at the Whole Soil

After the soil profile has been exposed for study, make sure that the surface represents fresh soil and is not marred with distracting shovel marks. Use your pocket knife to chip away the outer material to expose fresh soil. Start at the top and work down through the underlying horizons. The fresh surface exposed in this manner will give you a clearer view of the soil horizons and their properties. When this is finished, stand back about two meters to get a good look at the entire profile. Now decide whether the soil is mature or immature, and whether it is a forest, grassland, or desert soil. Use Figures 5A, 5B, 6, 7, and 8 for comparison. An immature soil will have only A and C (or R) horizons. A mature grassland soil will have A, B, and C (or R) horizons, while a mature forest soil will have A1, A2, B, and C (or R) horizons.

Now move close to the soil and locate the boundaries between horizons. Generally each horizon has a distinctive color by which it can be distinguished from adjacent horizons. In soils the true color of the mineral particles may be masked because many of the particles become coated with humus or iron oxide. The surface horizon is distinctive due to the dark-colored humus present. The A2 horizons can be recognized by their light color. In forest soils there is a sharp contrast between the dark-colored topsoil and the light gray A2 horizon which lies directly below it. An abundance of calcium carbonate in any horizon will tend to give that horizon a lighter color. Some layers of calcium carbonate accumulation may even be gray-white.

The presence of calcium carbonate in soil can be detected with dilute hydrochloric acid. Hydrochloric acid reacts with calcium carbonate to release carbon dioxide gas. To test for calcium carbonate, add a drop or two of hydrochloric acid to the soil. If calcium carbonate is present, bubbles of carbon dioxide will form and break rapidly.

$$\underset{\text{(hydrochloric acid)}}{2HCl} + \underset{\text{(calcium carbonate)}}{CaCO_3} \longrightarrow \underset{\text{(carbon dioxide)}}{CO_2 \uparrow} + \underset{\text{(water)}}{H_2O} + \underset{\text{(calcium chloride)}}{CaCl_2}$$

Start at the surface and check for calcium carbonate about every 15 centimeters as you go down the profile. The junction where a layer containing calcium carbonate meets a calcium carbonate-free layer usually represents a soil horizon boundary. In humid areas there may be no calcium carbonate in the entire soil depth exposed.

TYPICAL SOIL STRUCTURE TYPES

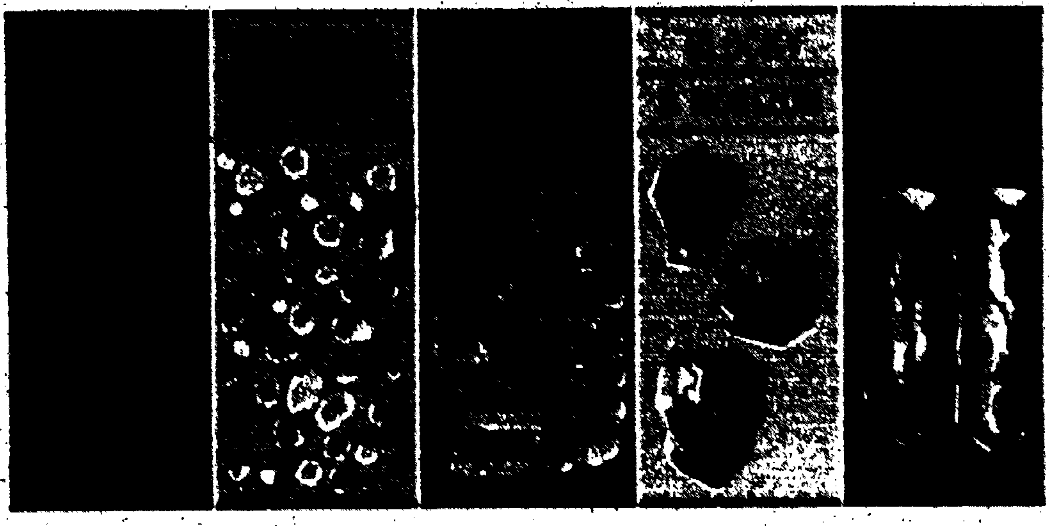


Figure 9. Shapes of soil aggregates.

The *soil structure*, the way soil particles are arranged, will also help you distinguish one horizon from another. The soil structure in most surface soils consists of rounded *aggregates*, single masses or clusters of soil particles loosely cemented together. In the B horizons the aggregates are more angular or blocky. Use Figure 9 to help decide the kind of structure present.

Aggregates are held together mainly by the binding action of the clay and humus they contain. In a muddy area soil sticks to your shoes chiefly because of the stickiness of clay. You can often walk on wet sandy soil without getting muddy and without compacting the soil. This is one reason that golf greens contain a high proportion of sand.

Soil horizons that contain very little clay and humus usually do not contain aggregates. In these horizons the structure is called *single-grained*; it is common in highly sandy soils. Aggregates are also absent from some fine-textured horizons where the soil material exists as large compact masses. Such structure is called *massive*.

The clay content of the subsoil or B horizon is typically greater than that of the A horizon (Figures

6 and 7). Moisten a small ball of soil and knead it with your fingers to the consistency of putty. The higher the clay content, the stickier and more plastic the soil mass will be. On the other hand, the higher the clay content, the harder it will be to crush *dry* soil aggregates. As you exposed fresh soil with your pocket knife, perhaps you found some layers from which the soil chipped away more easily than from others. The soil mass is firmer and harder to penetrate in areas high in clay content. Likewise the structure is usually best developed and easiest to see in the B horizon where the clay content is highest. A blocky type of structure is most commonly found in the B horizon.

Table 1. Characteristics of a Sample Soil Profile

Horizon and Depth	Color	Structure	Lime Test	Number of Roots	pH
A1 0-20 cm	dark brown	granular	negative	many	5.7
A2 20-50 cm	yellow brown	weak. platy	negative	few	5.5
B 50-130 cm	brown	blocky	negative	few	6.4
C 130 cm+	light brown	blocky to massive	positive	few	7.8

Using these instructions, decide which horizons are present. If you are still in doubt, use your knife to take a small sample (about a tablespoonful) of soil every 15 centimeters from the top to the bottom of the exposure. Lay these samples side by side on a piece of paper and in the same order that they existed in the soil. This will make the changes in color, structure, and clay content more apparent and provide clues as to the location of horizon boundaries.

Sometimes the boundaries between horizons are sharp and clear; sometimes they are indistinct and marked by a transition rather than a sharp dividing line. After you have located the horizon boundaries, clearly mark them on the exposure face with your knife so that you can locate the horizons quickly. Set the results of your tests as in Table 1. See Soil Acidity for a discussion of pH.

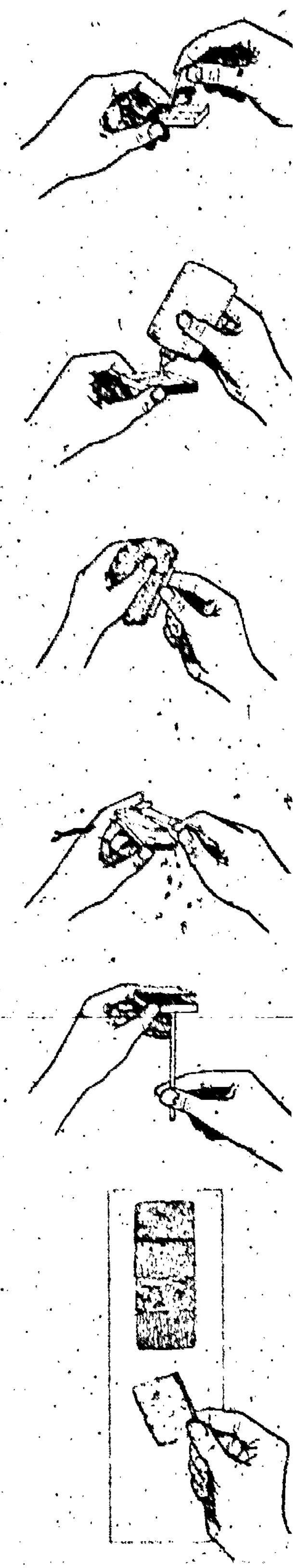
Making a Miniature Soil Profile

When you have identified the horizon boundaries, you are ready to make a miniature soil profile that will serve as a permanent record of your observations. This consists of small samples of each horizon mounted on a piece of cardboard (Figures 10 and 11). By making a miniature profile, you will be able to take home a representative sample of the entire soil profile. In addition, you will be able to see more clearly the differences between soil horizons and be able to compare the horizons and properties of the two soils you examined. When you have collected various kinds of soils in your community, you can easily compare their properties.

The procedure for making the miniature profile is shown in Figure 10:

1) Place a cardboard chip in the bottom of your soil sampler.
2) Spread some glue on the cardboard chip.
3) Press the sampler into a chunk of soil taken from the uppermost horizon.
4) Break off excess earth with your pocket knife, leaving a natural surface about the thickness of the sampler depth. Do not cut the sample off even with the edges of the sampler, as the process of cutting destroys the natural appearance.
5) Push the tip of a pencil through the hole in the sampler to remove the sample.
6) Draw the soil profile to scale on the mounting board to show the relative thickness of each horizon as in Figure 11.
7) Glue your sample to the center of the area of mounting board allocated for the uppermost

Figure 10. Constructing a miniature soil profile.



horizon.

8) Repeat the procedure for the other soil horizons and the second soil profile. When finished, place the samples in a box for safe transport home.

If you have difficulty determining where the horizon boundaries are, take some arbitrary length (for example, 20 or 30 centimeters) and take sample chips this distance apart from the top to the bottom of the exposure.

Figure 11. Completed miniature soil profile.

SOIL ACIDITY

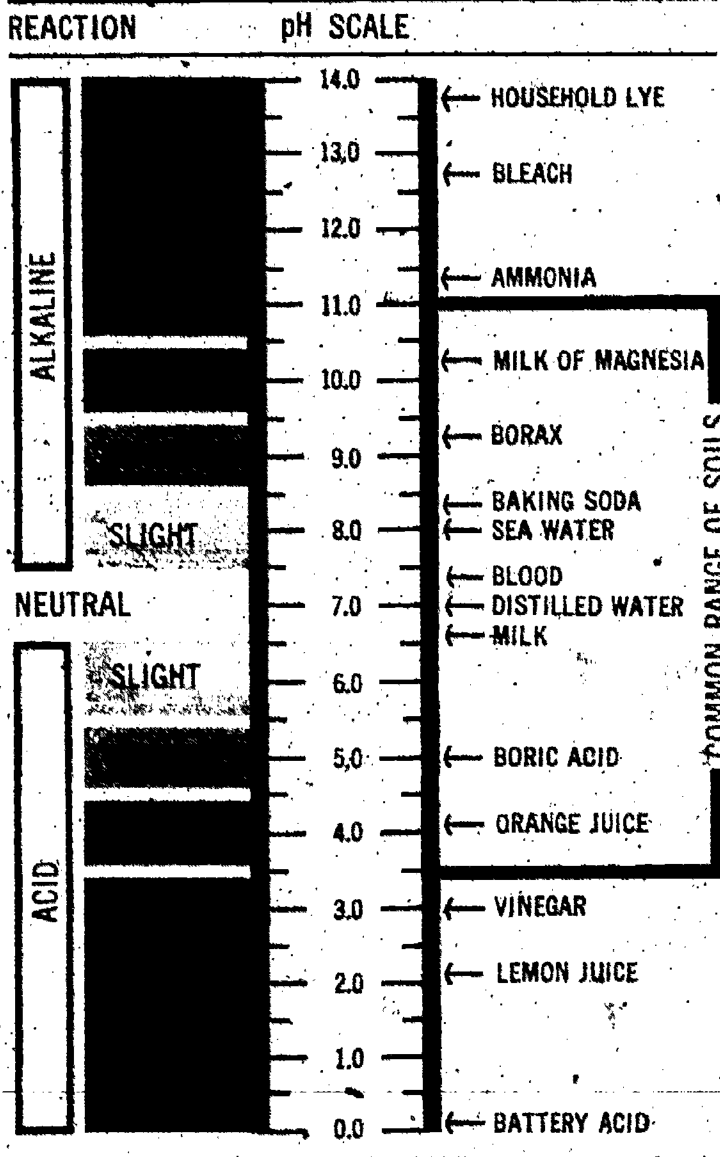
During your study of the soil profile, you tested for calcium carbonate by adding a few drops of dilute hydrochloric acid to the soil sample. A bubbling indicated that the hydrochloric acid had reacted with calcium carbonate present in the soil. These bubbles, and the presence of calcium carbonate, meant the soil was *alkaline* rather than *acid.*

If the test did not produce any bubbles, then the soil you tested may be either acid, neutral, or alkaline. Unfortunately, this test does not tell you anything more. Since some plants grow best in soil that is slightly acid, others in soil that is even more acid, and still others in soil that is alkaline, it is important for the farmer or gardener to know precisely the degree of acidity or alkalinity of his soil. Then he can change it to provide the best possible soil for his crop.

Fortunately, scientists know that the acid content of soil is caused by an excess of hydrogen ions in the soil. The concentration of hydrogen ions, or *pH*, can be measured on a scale called the *pH scale* (Table 2). The pH scale shown here ranges from 0.0 to 14.0. Extremely acid materials, such as battery acid, measure about 0.0. At the opposite extreme, very alkaline substances like household lye measure about 14.0. Neutral substances like distilled water measure about 7.0.

Soil usually measures somewhere between 4.0, if it is strongly acid, and 10.0, if it is strongly alkaline. Most plants grow best in soil ranging from 5.0 to slightly over 7.0 on the pH scale. The supply of calcium, potassium, magnesium, and many other nutrients is lowered when leaching makes the soil acid. When soil becomes too acid, lime (which is an alkaline substance) can make the soil more alkaline. On the other hand, the low solubility of iron in alkaline soil can cause an iron deficiency in many plants, so the amount of lime needed must be carefully calculated.

TABLE 2. pH of Some Common Substances



Test the pH of soil samples obtained during your field trip. Most garden supply centers and hardware stores sell inexpensive soil-testing kits, with complete directions for their use. Or perhaps you can adapt pH tests available in your school. You may also wish to test soil from your lawn, a field, or a flower box. The pH of tap or well water may also be tested. Most municipal water contains enough calcium carbonate to make the water alkaline. Lawns and gardens that are watered for long periods of time with such water will become alkaline even if the soil was once acid.

If you find an acid soil, you may wish to experimentally determine its *lime requirements*, the amount of lime needed to raise the pH of the soil to 6.5. Obtain some calcium carbonate or lime from the chemistry laboratory and determine its pH. This gives a measure of the maximum pH change possible through adding lime. From the pH values of the soil and the lime you can figure out what proportion of lime is needed.

Take three 1000-gram soil samples with the same pH. A 29-oz can holds about 1000 grams of soil. Apply one, three, and six grams respectively of calcium carbonate or lime. Grow the same kind of plant in each sample. Follow the pH changes by testing the soil at monthly intervals. The pH change will be most rapid if the soil is moistened regularly. However, to observe the full effect of liming on the pH of the soil may require several months. Because the effect of lime in neutralizing soil acidity acts slowly but lasts a long time, a single application of calcium carbonate or lime may satisfy soil requirements for five to ten years. Lime replaces that which was originally present in many soils but has been leached out.

STUDY OF SOIL WATER

Soil is an important reservoir of water for plants and man. The rate at which water enters the soil reservoir is critical in a number of processes. For example, farms and some suburban areas often dispose of sewage in private disposal systems consisting of a septic tank and a filter field. All sewage is discharged into the septic tank and the water that flows out of the tank is purified by filtering it slowly through the soil. If the liquid flows from the tank faster than it can soak into the soil, raw sewage will soon rise to the soil surface, contaminating the area and perhaps the community.

A porous soil helps guard against damaging floods. The amount of water that runs off the land to swell the streams during most rains is small if the soil is dry and can soak up water readily. Floods are most severe when the soil is wet and can absorb little additional water. However, in a heavy rainstorm water falls much faster than it can enter the soil. The excess water runs over the land, causing erosion. Erosion may ruin farmers' fields, fill storage reservoirs with mud and debris, and pollute rivers and streams. The amounts of runoff and erosion are directly related to the rate at which water enters the soil.

There are two important questions about the soil reservoir: 1) How fast can it be filled with water? and 2) How much water will it hold? To answer these questions, you will need the following equipment:

- Large can, preferably five to ten liters (two gallons), with both ends removed
- $2\frac{1}{2}$ cm × 5 cm × 30 cm board
- $2\frac{1}{2}$ cm × $2\frac{1}{2}$ cm × 30 cm stick with a pointed end
- Hammer
- Ruler
- Watch
- Shovel
- Pencil and paper
- About 12 liters of water
- Two empty tuna fish cans
- Two pieces of cloth 12.5 cm × 12.5 cm
- Two rubber bands to fasten cloth to cans

The Percolation Test

The rate at which water enters the soil reservoir may be determined using the *percolation test.* Perform the percolation test on undisturbed soil near the site where you examined the soil profile. Place the large can on the soil where the percolation test is to be made. Place the board on the can to protect the edges and then drive the can into the topsoil to a depth of five centimeters. Add water slowly to avoid disturbing the soil. Fill the can about three quarters full of water. With the board in place, lower the pointed stick until the point just touches the water as shown in Figure 12. Using the top of the board as a straight edge, draw a line on the pointed stick and designate this measurement No. 1. Immediately record the time at which the measurement was made on a chart similar to Table 3.

Table 3. Intake Rate of a Soil Sample

Measurement No.	Time	Elapsed Time (Minutes)	Time Interval (Minutes)	Change in Water Level (Centimeters)	Intake Rate (cm/hr)
1	3:00 P.M.	0	—	—	—
2	3:10	10	10	1.3	7.8
3	3:20	20	10	0.6	3.6
4	3:30	30	10	0.3	1.8
5	4:00	60	30	0.6	1.2
6	4:30	90	30	0.5	1.0
7	5:00	120	30	0.3	0.6
8	8:30 A.M.	1050	—	—	—
9	9:00	1080	30	0.2	0.4
10	9:30	1110	30	0.2	0.4

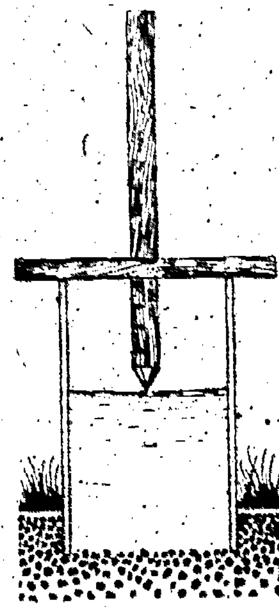


Figure 12. Setup for a soil percolation test.

Repeated measurements of the depth of the water will show how fast the water is entering the soil. Measure the depth of the water at ten-minute intervals for the first 30 minutes and at half-hour intervals after that. The depth of water entering the soil in the first ten-minute interval equals the distance between the lines representing measurement No. 1 and measurement No. 2 at ten minutes of elapsed time.

Calculate the intake rate in centimeters per hour for each time interval and enter this value in your table. For example, the intake rate for the first ten-minute interval in Table 3 is 1.3 centimeters per ten minutes. Because there are six ten-minute intervals in each hour, the intake rate in centimeters per hour is $6 \times 1.3 = 7.8$.

Did the water intake rate change with time? Figure 13, a graph of the data in Table 3, shows how the intake rate for one soil changed with time. The intake rate was rapid at first but slowed markedly as the soil became wet. The clay in some soils swells when wet and shrinks when dry. As the soil becomes wet and the clay swells, the pores in the soil become smaller and smaller and the intake rate decreases. In addition, water attracted to the surfaces of the soil particles causes a resistance to flow. The greater the resistance to the flow, the less the intake rate.

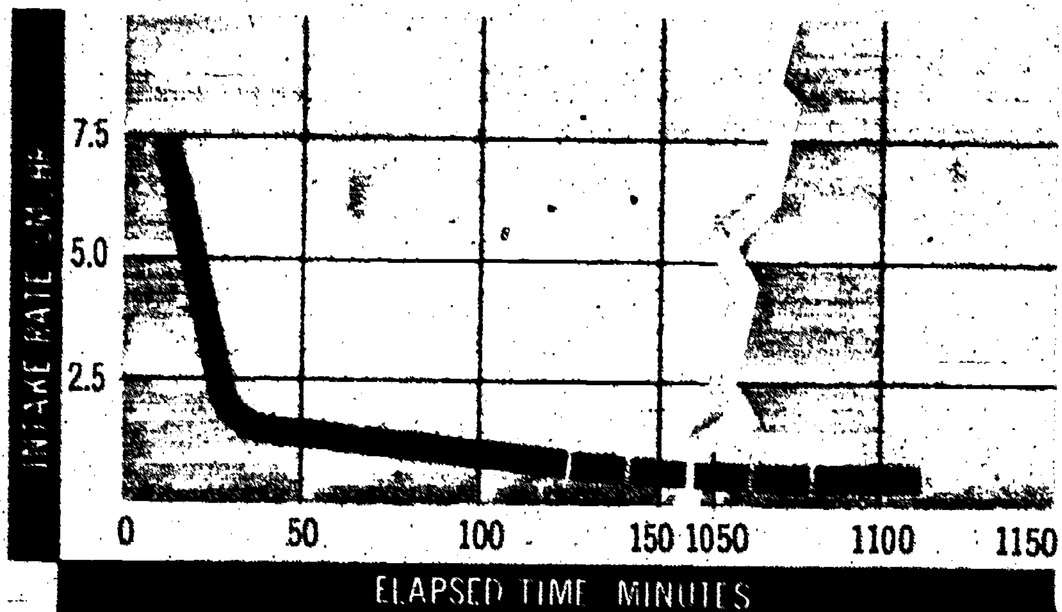


Figure 13. Graph of the change in rate of water intake in the topsoil layer of a soil in Kansas.

After taking seven readings, fill the can with water and leave it overnight so that the underlying soil will become thoroughly wet. Then carefully refill the can to the three-quarters mark and take two additional intake-rate measurements at half-hour intervals. These two readings represent the intake rate when the soil is wet and would approximate the rate of water intake during the wettest season of the year. This procedure allows for making the test in either a wet or a dry season, so that the results will be generally useful.

At a nearby site dig a hole about 2.5 centimeters into the subsoil, carefully remove loose dirt, and repeat the percolation test. This site can be prepared between readings during the first test.

Compile your intake-rate data into tables similar to Table 3 and glue them to the back of the miniature profile mounting card. This will provide a permanent record of the data.

After completing the percolation test for both subsoil and topsoil, consider the following questions. If rain fell at that spot at the rate of 2.5 centimeters per hour, how much water would run off? Would it make any difference whether the soil was dry or wet at the beginning of the rain? Was the intake rate in the subsoil as high as that in the topsoil? In a prolonged rain, would the intake rate in the subsoil eventually limit the rate at which the entire soil absorbed water?

The Public Health Service recommends that no soil for which the intake rate is less than 2.5 centimeters per hour when the soil is wet should be used as a filter bed for discharging liquid sewage in a septic tank filter bed. Is the soil you tested suitable for a filter bed? Base your answer to this question on your subsoil results.

Soil Pore Space and Water-Holding Capacity

While you are waiting to take readings for the percolation tests, you can collect samples for a determination of the amount of pore space in the soil and therefore the important water-holding capacity.

Determine the weight of water a tuna fish can will hold. Then push one of the empty tuna fish cans upside down into the topsoil. Remove it carefully with a shovel and smooth off the soil so that the can is level full. With the other can do the same with the subsoil sample on which you ran the percolation test. Carry both samples to your home or classroom for further work.

Place a piece of cloth over the top of each can and fasten it tightly enough to hold the soil *in* the can when it is inverted.

Turn the cans over and remove the bottoms with a can opener. Place the cans in a pan of water and let them soak thoroughly. Now carefully put the saturated soil on a dish, weigh it to the nearest 0.1 gram, and record this weight. Next place the dish of soil in a warm oven to dry. When the soil is dry, reweigh the dish and record this weight. The difference is the weight of water contained in pore spaces of saturated soil. Compare this weight to the weight of water in the empty cans. The ratio is an estimate of how much pore space the soil you examined contained.

Questions

1) If the water from a 2.5-centimeter rain entered the soil, could all of it be retained in the upper meter of soil for later use by plants? What about a 5-centimeter rain?
2) Find the characteristics of the most intense rainstorm likely to occur in your area over a ten-year period. The U.S. Weather Bureau in your area can help you. Could your soil permit the water to enter rapidly enough to prevent runoff? If not, calculate the percentage of water that would run off. Could the soil you studied retain this amount of water in the upper meter if the soil were dry at the beginning of the storm?

SUGGESTIONS FOR FURTHER STUDY

Numerous additional studies of the soil can be made. You may find the following suggestions interesting and be able to improvise or develop the procedures for carrying them out.

1) Observe and count the animal life in the soil.

Select a sample where the soil is moist and rich in organic matter. Few animals will be observed in cold soils, so make this study in the summer or fall. The presence of both animals and plants, like fungi or molds, can best be observed after mixing some bread crumbs into the soil and keeping it moist for a week or two in a warm room. Many dormant plants and animals will grow under these conditions and will provide you with additional observations.

2) Observe the coatings on soil particles with a hand lens or low-power (10-20) microscope.
3) Observe the intimate relationship between grass roots and soil particles by using a hand lens or low-power microscope.
4) Dig up some leguminous plants such as beans, clover, or alfalfa. Look for the small nodules on their roots where bacteria live that obtain nitrogen directly from the air and thereby help supply it for the plants.
5) Obtain a soil survey report of your county from the Soil Conservation Service or the County Agricultural Extension Agent. Find out the names and properties of some soils where you live. Can you identify the soil at the place where you made the percolation test or collected the miniature soil profiles?

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Glossary

A horizon—the surface layer of a soil, or the topsoil. Here the most biological activity or removal of materials by water, or both, occur.

acid soil—a soil having an excess of hydrogen ions, H^+, over hydroxyl ions, OH^-, in the soil solution. Its pH is less than 7.

aggregate—many soil particles forming a mass with a characteristic shape, as granular, blocky, or platy.

alkaline soil—a soil having an excess of hydroxyl ions over hydrogen ions in the soil solution. Its pH is greater than 7.

B horizon—a soil horizon, usually beneath an A horizon, or surface soil, in which (1) clay, iron, or aluminum, with accessory organic matter, have accumulated by receiving suspended material from the A horizon above it or by clay development in place; (2) the soil has a blocky or prismatic structure; or (3) the soil has some combination of these features. In soils with distinct profiles, the B horizon is roughly equivalent to the general term "subsoil."

C horizon—the unconsolidated rock or parent material found immediately underneath the A or B horizon.

clay—soil particles with a diameter less than .002 mm.

humus—the well-decomposed, more or less stable part of the organic matter of the soil, found in the A horizon or topsoil.

immature soil—a young soil that lacks a well-developed profile.

leaching—removal of soluble material by the passage of water through the soil.

mature soil—a soil with well-developed characteristics, produced by the natural processes of soil formation, and in equilibrium with the environment.

parent material—bedrock or unconsolidated rock from which soil develops.

percolation—downward movement of water through soil.

pH scale—a way of describing the acidity of a substance. Very acidic materials have a pH of 0, neutral substances 7, and very alkaline ones 14. pH is a function of the concentration of hydrogen ions.

R horizon—consolidated rock or parent material found immediately underneath the B or A horizon.

soil profile—a vertical section of soil through all its horizons and extending into the parent material.

soil structure—the way in which the individual soil particles are arranged. Soil structure in most surface soils consists of rounded aggregates; in sub-surface soils the aggregates are more angular or blocky.

till—a deposit of a mixture of earth, sand, gravel, and boulders transported by glaciers. Till is not layered.

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