The Soils Around Us

What is soil?

- Webster: The upper layer of earth that may be dug or plowed

- Brady & Weil: A dynamic natural body composed of mineral and organic solids, gases, liquids and living organisms which can serve as a medium for plant growth

What is soil?

- Singer & Munns: Complex, natural, inorganic (mineral) and organic, vertically differentiated body at the earth's surface that is capable of supporting plant life

- Gardiner & Miller: Surface land material, mineral and/or organic, capable of supporting plants

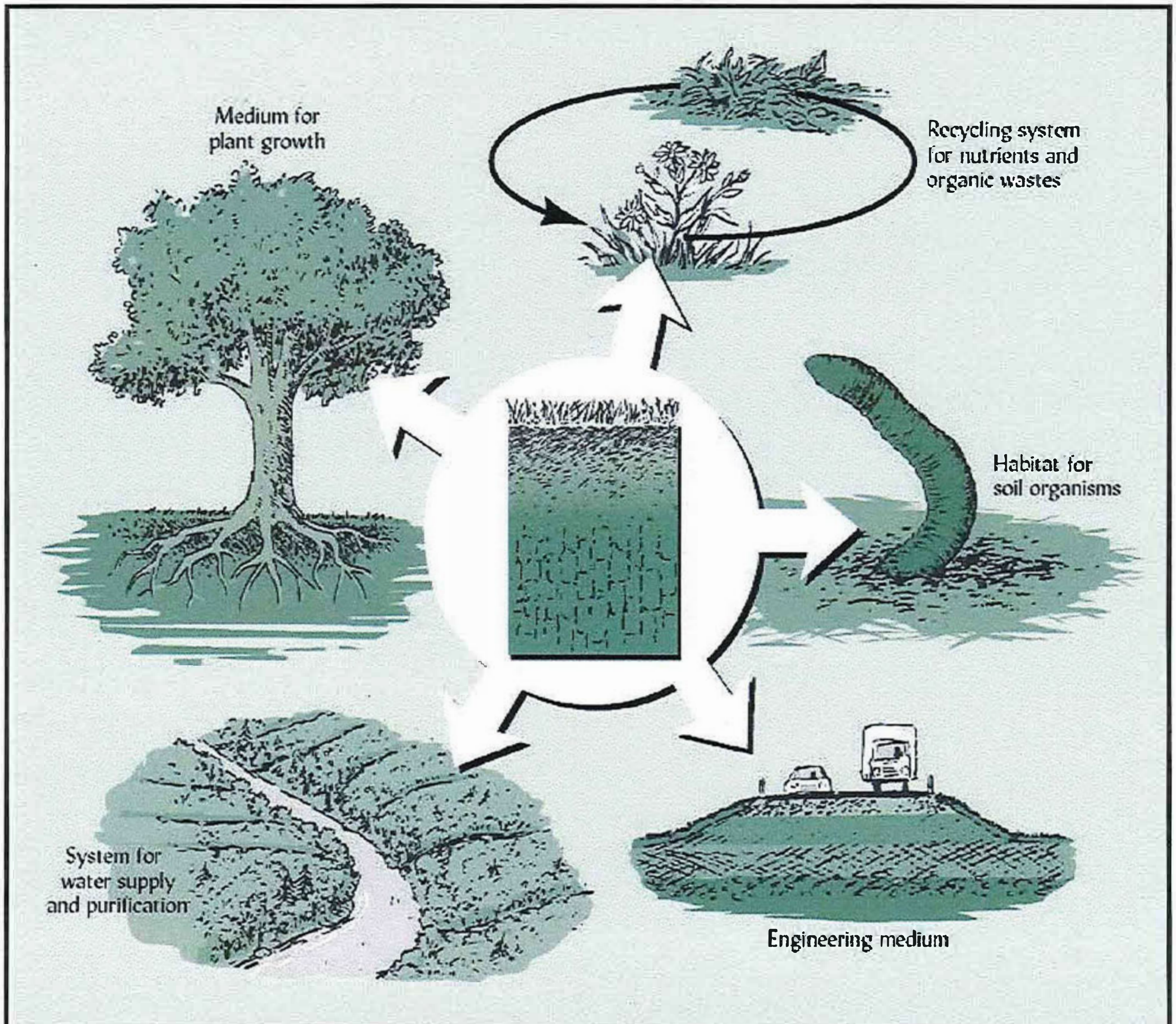
Engineering definition of soil

- Material to be removed
- Medium for construction
- Concerned with physical properties

Homeowner definition of soil

- Dirt – Soil out of place
- Suitability for garden plants

The Five Main Roles of Soil



The Roles of Soil

- Medium for plant growth
  - Physical support
  - Aeration for roots
  - Moisture supply and storage
  - Moderation of root zone and near ground air temperature
  - Protection from toxins
  - Provides 13 of the 18 essential nutrient elements

The Roles of Soil

- Largely controls the flow of water thru the hydrologic cycle
- Recycles waste products of society and nature
- Provides habitat for diverse organisms
- Functions as construction material and foundation support in "built" environments

United States
Department of
Agriculture

Natural
Resources
Conservation
Service

Urban Soil Primer

For homeowners and renters, local planning boards, property managers, students, and educators








Contents

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Cover: Urban scenes and soil profiles from across the United States.

Preface

The *Urban Soil Primer* is intended to give planning officials and people who live in urban areas an introduction to soils. It provides information important in planning and managing land resources in a manner that helps to prevent or mitigate problems associated with sedimentation, contamination, runoff, and structural failure. In nontechnical language, this publication describes the basic processes and functions common to all soils. Much of the complexity of soil science is simplified, and many sensitive issues are discussed only in passing.

This primer lists many affordable resources available to people seeking information about soils in urban areas. These resources include government agencies, such as the Environmental Protection Agency (www.epa.gov), which provides information about contamination, and the Natural Resources Conservation Service (www.nrcs.usda.gov), which provides assistance with conservation planning and implementation through local field offices. The Natural Resources Conservation Service (NRCS) provides leadership in a partnership effort to help people conserve, maintain, and improve our natural resources and environment. Other resources include universities, private consultants, and nonprofit groups experienced with soils in urban areas.

This primer provides the basic vocabulary and key concepts needed for further explorations in urban soil survey and for the development of interpretive guidelines for specific local uses by soil type. Many of the terms used in this publication are defined in the Glossary. The primer was produced by staff at the NRCS National Soil Survey Center with assistance from a cadre of NRCS field soil scientists. It is available as a printed booklet and as a compact disc (CD), or it may be downloaded from the NRCS Web site (http://soils.usda.gov/use).

Contact your State or local office of the Natural Resources Conservation Service for more information. Visit http://offices.usda.gov/scripts/ndCGI.exe/oip_public/USA_map to find the NRCS field office near you.

Welcome to the fascinating field of urban soils.

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Chapter 1: Introduction

Soil is an amazing, mostly natural material that covers nearly all of the land surface of the earth. Soil, along with water and air, provides the basis for human existence. It is the interface between the earth's atmosphere and bedrock or ground water. It has either formed in place or has been transported to its present location by wind, water, ice, gravity, or humans. Soils may have been deposited thousands or millions of years ago by volcanoes, glaciers, floods, or other processes or were delivered to the site by truck or other mechanical device an hour ago, a week ago, or several months ago. These facts illustrate why soils are very complex. Soil functions, as part of a natural ecosystem, are also very complex and diverse. Basic knowledge about soil allows us to use it wisely.

The primary goal of this publication is to help people who live in cities understand soil and to help them know where and how to get information about soil. Knowing about soil and its potentials and limitations helps urban planners and those living in urban areas to make good decisions about using their soil as a basic and valuable resource. Soil is the basic raw material and common link to all projects whether one wants to build a park, a street, a golf course, or a large building, landscape a yard, or just plant a backyard garden. Soil lies beneath each activity!

Figure 1.1: Urban garden.

Figure 1.2: Playground.

Figure 1.3: City skyline.

Urban project managers and homeowners can predict a soil's behavior under similar situations when they know how soil responds to the same use in other locations. Similar kinds of soil tend to behave in the same ways. There are more than 22,000 different soils identified and mapped in the United States. Some States recognize more than 1,000 different kinds of soil. Knowing soil responses to specific uses allows engineers and others to design projects that will not require high maintenance costs, will last a long time, will not harm individuals, society, or ecosystems, and will not fail and/or require expensive repair and/or removal costs.

Figure 1.4: Urban development.

Growth Trends in Urban Areas

Figure 1.5 demonstrates that urban areas are expanding at a rapid rate within the United States. Urbanization is also a worldwide issue. Soils that are best suited to other uses, such as providing food and fiber for our Nation, are commonly the easiest to use as sites for homes and cities. Urban areas often expand into surrounding forestland, rangeland, or agricultural land areas because these areas are adjacent to existing urban areas. Prime farmland is vanishing at a alarming rate in certain regions of the United States because of urban expansion and development (figure 1.6). We must balance the increasing size of urban areas with our need for food and fiber.

Urban areas occur all across the USA, from coastal areas to areas high in the mountains, and soils occur in such areas as parks, playgrounds, lawns, and gardens. These soils are similar in some ways to soils in rural areas, but in other ways they are very different. A basic understanding of urban soils will help you learn more about this valuable resource. As urban areas grow and change, so must the management of natural resources surrounding and within those areas.

We invite you to continue to explore the complex, fascinating, and fun science of urban soils.

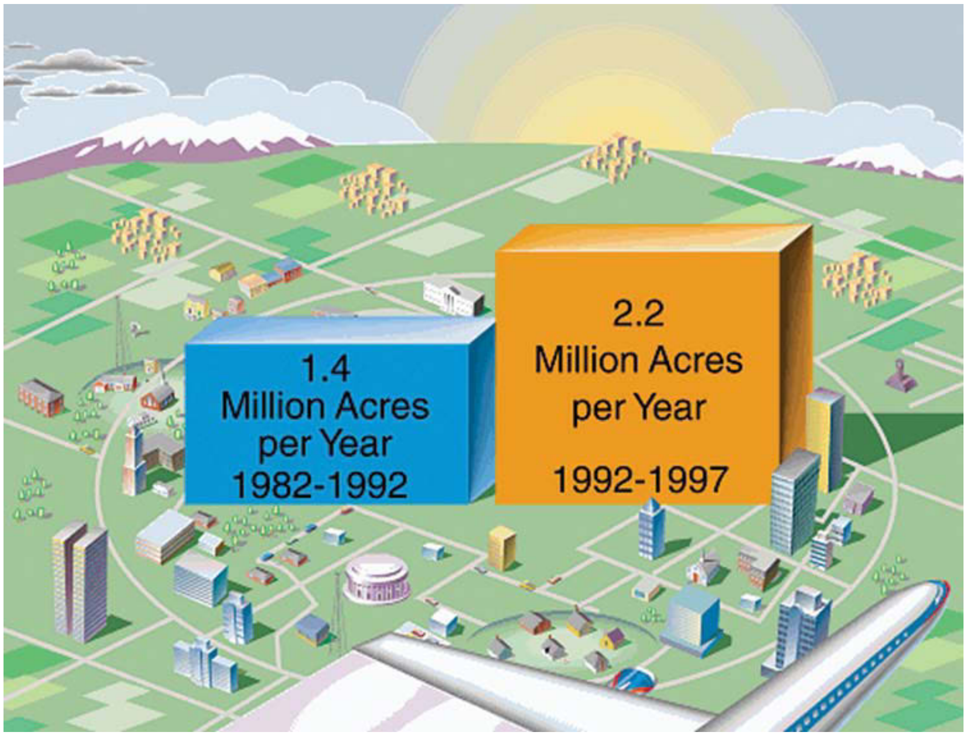

Figure 1.5: Land converted to urban development from 1982 through 1997 (NRCS, NRI).

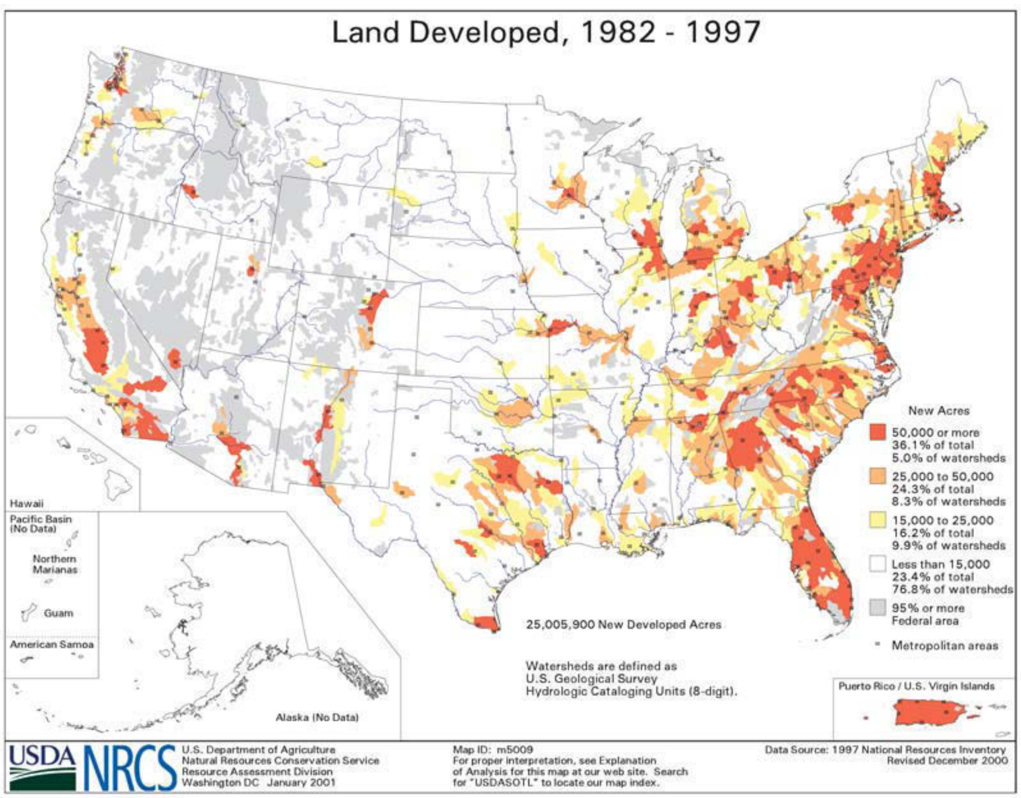

Figure 1.6: Annual rate of urban development from 1982 through 1997 (NRCS, NRI).

Chapter 2: Basic Soil Properties

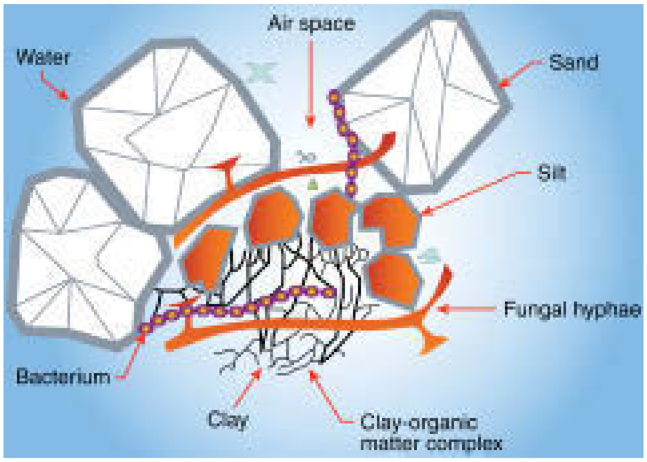

Figure 2.1

Soils in an urban area may share some properties with soils in forests, pastures, cotton fields, or even other urban areas. There are large differences in soils as they naturally occur in forests, farmed fields, and grazing land areas, and these differences are changed when an area is converted to an urban area. Soil scientists have developed conventions and language to communicate among themselves. It is important that we share scientific information with everyone, not just other scientists and professionals. Soil properties, such as soil texture and structure, particle-size distribution, soil reaction, and bulk density, help us to understand and predict how soils react and respond to different uses. Construction activities, compaction, and surface sealing dramatically change soil properties and can sometimes result in a reduced ability to perform the critical functions or activities of natural soil.

Topics in this chapter:

- **Soil variation**
- **Soil components**
- **Soil-forming processes**
- **Soil horizons**
- **Measuring and monitoring soil properties**

Soil Variation

What is soil and why is soil important to each of us? Traditionally, soil is defined as a dynamic natural body that is made up solids, liquids, and gases, occurs on the earth's surface, contains living matter, and supports or is capable of supporting plants. Bockheim (1974) defines urban soil as "soil material having a non-agricultural, man-made surface layer more than 50 cm (20 inches) thick that has been produced by mixing, filling, or by contamination of land surface in urban and suburban areas." In some important ways, soils of urban areas differ from soils of other areas.

Differences in urban soils have been observed and recorded by scientists, engineers, equipment operators, and construction workers for a long time. Even within urban areas, there is a multiplicity of soil conditions, ranging from "natural" soils that are relatively undisturbed to soils in which the natural materials have been mixed or truncated, to soils that formed in added materials, or fill, of varying thickness. Each of these areas, in turn, can be subject to different types of use and management, which can further affect their soil properties. Soils in urban areas can be divided into two general types: *natural* soils, which formed in material naturally deposited by water, wind, or ice or in material weathered from the underlying bedrock, and *anthropogenic* soils, which formed in human-deposited material, or fill (table 2.1). Anthropogenic soils are almost anywhere in the urban environment. The purpose of adding fill to an area may be to alleviate undesirable soil properties or to modify the urban landscape for specific activities.

Table 2.1: Examples of Fill Material in Urban Soils

- Natural soil materials that have been moved around by humans
- Construction debris
- Materials dredged from waterways
- Coal ash
- Municipal solid waste
- A combination of any or all of the above

Characteristics of soil in any urban area depend on many things. They depend on how deep the site has been excavated during construction and if new materials were brought in and mixed with the original soil materials. They depend on the properties of the original natural soil and the past uses of the site. Many times topsoil is removed from the site prior to construction and may or may not be returned to the site. After excavation, subsoil may be placed as fill over topsoil. Changing the order of the soil layers or mixing the topsoil and subsoil can alter soil properties. These variables make predicting soil behavior difficult in urban areas.

Soil Components

All soil is made up of air, water, numerous kinds of living and/or dead organisms (organic matter), and mineral matter (sand, silt, and clay). In the urban arena, it includes many manmade materials. The amount of each of these soil components varies from one place to another in the world or from one kind of soil to another. Soil components can vary dramatically within distances of only a few feet on the same landscape.

Soil composition can be dramatically changed by pedestrian or vehicular traffic, especially when the soil is wet. The soil components most easily changed are the amounts of soil air and water. Imagine the change in soil composition at construction sites after large trucks and heavy construction equipment drive over a soil and compact it. Imagine people walking and playing on wet soils in city parks and recreation areas or yards. Note the differences in percent of soil air and soil water in figures 2.2 and 2.3. Figure 2.2 illustrates the general composition of a natural soil. Figure 2.3 illustrates the general composition of a soil that has been compacted by heavy traffic. As soil particles are squeezed together, pores for air and water are reduced in size and number (figure 2.4). The reduced pore space changes the way a soil handles water intake and water movement throughout its layers, or horizons.

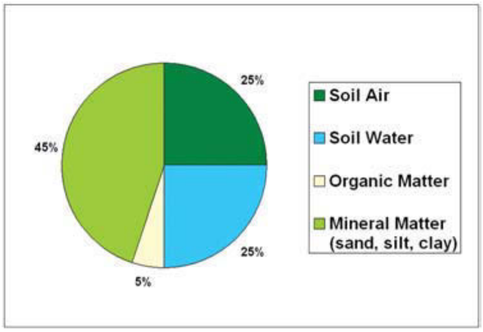

Figure 2.2: Composition of a natural soil, by weight.

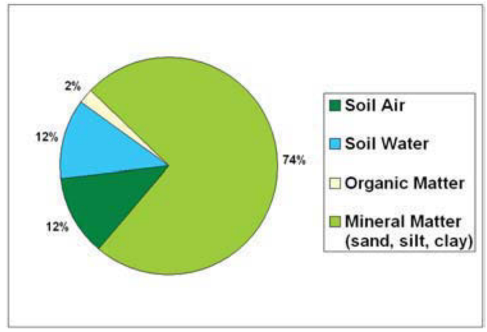

Figure 2.3: Composition of a compacted soil, by weight.

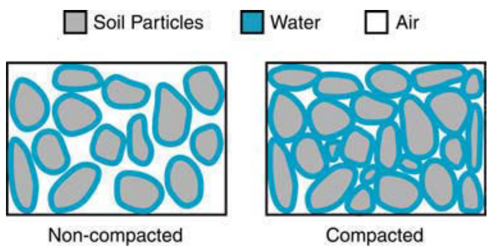

Figure 2.4: Soil pore space.

Soil-Forming Processes

Soils form through a group of processes no matter where they are located or what they are used for. All soils form because of four processes operating along with five basic soil-forming factors. The four processes that operate on soil material are additions, transformations, translocations, and losses (figure 2.5). We are able to map, classify, and interpret soil because a given set of environmental factors produces a predictable kind of soil.

The soil-forming factors are parent material, climate, living and dead organisms, time, and landscape position. When all soil-forming factors are similar, a similar soil is produced. If we change one or more of the soil-forming factors significantly, then a different soil is produced.

Additions to soil generally include organic matter, fertilizer, pollutants, and deposits of soil material. All of the additions change a soil and how it functions. In urban areas new soil material is sometimes added on top of an existing soil. If thick enough, the new layer or layers can change the way the soil develops. When a layer of concrete or asphalt is added to the top of a soil in areas where streets, parking lots, or driveways are built, additions to the soil are suddenly altered, restricted, or even stopped.

Transformations are changes that take place within a soil. In figure 2.5, transformations are illustrated by the letters x and y and the arrows that connect them. During transformation processes, material does not leave the soil but is simply changed from one form to another or from one compound to another. Micro-organisms and earthworms play an important role in soil transformations. Earthworms eat soil and plant materials and transform them into organic material that provides food for plants and other organisms. Chemical weathering changes parent material, such as rocks and sand grains, and creates new minerals and/or smaller particles. Rocks are transformed into sand grains, and sand grains are transformed into silt and clay particles over time. As iron particles change form, they change soil colors from gray to brown or to red and yellow. Applying too much fertilizer of certain kinds can transform a soil into one that is too acidic for plants to grow.

Translocations are movements of soil components from one place to another in the soil. Translocations can move materials from one soil layer to another and can even move the materials completely out of a soil. Water moves through a soil profile and carries clay particles, soluble salts, organic matter, and chemical compounds downward into the soil. Translocations can also be upward or horizontal. As soil dries and water evaporates from the soil surface, minerals and salts may move back toward the soil surface. In dry areas translocations are restricted because there is less water to carry compounds and materials deep into the soil. Compounds and minerals can move only as deep as water moves into a soil. Concentrations of soluble material generally are closer to the surface in dry areas than in other areas. Windthrow and the activity of animals (i.e., ants, termites, groundhogs, and worms) also can move soil components upward.

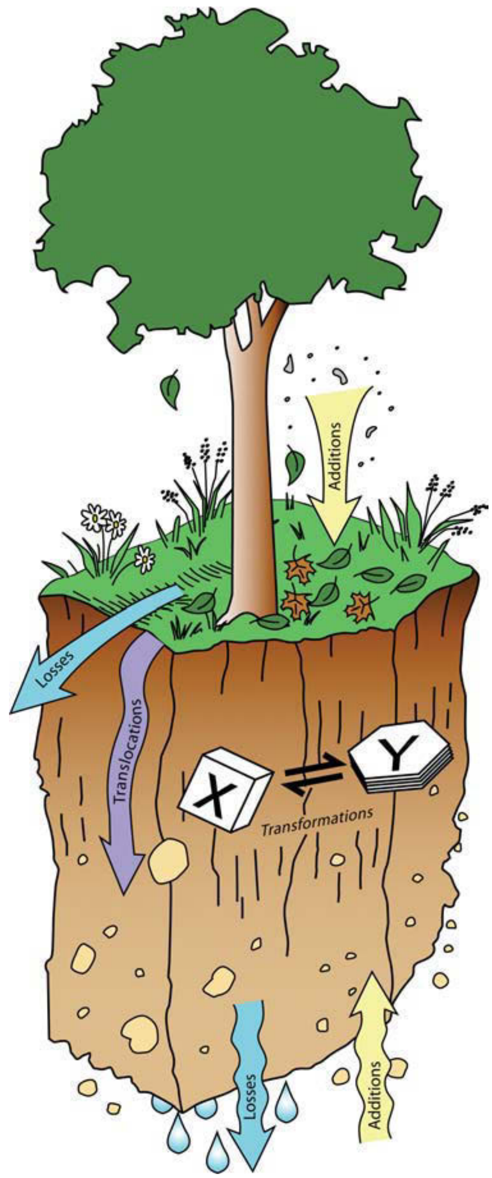

Figure 2.5: Soil-forming processes.

Losses occur when water moves material through and out of a soil profile. If enough water is available, soluble materials, such as sodium and calcium, are removed early in the process of soil formation. Lawn and garden fertilizers are relatively soluble and may be removed from a soil when too much water is applied. Ground-water pollution can occur if too much water is added to a soil that contains contaminates. Erosion by wind or water removes the soil particles and compounds needed for plant growth. Topsoil removed through water erosion in a given area can improve the soil in the area where the sediments are deposited.

Soil Horizons

Soils are made up of soil horizons, or layers, that form as the result of five soil-forming factors. The six major kinds of soil horizons are designated as O, A, E, B, C, and R (figure 2.6). All six of these horizons are not always evident in every soil profile.

For example, most agricultural soils do not have an O horizon because organic horizons are usually mixed with A horizons during tillage. Also, a soil has an R horizon only if bedrock is close to the surface.

O horizons are generally the uppermost layers and form on top of mineral horizons where they occur. They are formed by the accumulation of fresh and decaying plant parts, such as leaves, grass, needles, and twigs. O horizons are dark colored (mainly black or brown) because decomposing plant and animal materials produce humus. They are generally in forested or wet areas.

A horizons are below O horizons and are made up mostly of mineral material. They are characterized by the loss of iron, clay, and aluminum and the addition of organic matter by soil organisms. Hence, they are dark colored in most areas, except for extremely dry areas. A horizons are commonly referred to as topsoil.

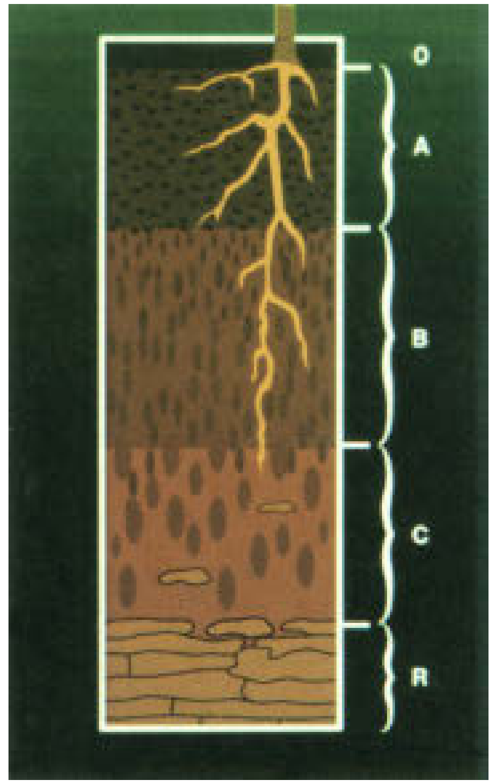

Figure 2.6:Natural soil profile with major horizons.

E horizon*s* are commonly in forested areas. The “E” stands for eluvial, which means that clay, iron, organic matter, and other minerals have been removed from this horizon. E horizons commonly appear white or lighter in color than the horizons above and below them.

B horizons are below A or E horizons and are characterized by the accumulation of iron, clay, aluminum, and other compounds. B horizons are commonly referred to as subsoil.

C horizons are below B horizons and are commonly referred to as the substratum. They are made up mainly of partially weathered or disintegrated parent material, but soft bedrock can also occur. Because C horizons are deeper in the profile, the effects of the soil-forming factors are less pronounced than the effects in the overlying A and B horizons.

R horizons are made up of bedrock. The bedrock can be far below or just a few inches below the surface.

Horizons in urban soils may not be fully related to the natural soil-forming factors but instead may be manmade layers formed by the deposition of dredge, fill, and/or mixed materials. Human artifacts, such as bricks, bottles, pieces of concrete, plastics, glass, pesticides, petroleum products, pollutants, garbage, and disposable diapers, are often components of urban soils. Manmade materials may be added to raise a landscape to a higher level, backfill ditches or foundation walls, or construct berms. In urban areas, human activity is often the predominant activity in making soil instead of the action of the natural agents of wind, water, ice, gravity, and heat.

Urban soils differ from natural soils because they have been altered to some degree. They have been excavated, compacted, disturbed, and mixed and may no longer possess their natural soil properties and features. Many highly disturbed soils in urban areas or on construction sites have not been in place long enough for soil-forming factors to significantly change them and to form soil horizons. In areas where

Figure 2.7: Urban soil profile.

fill materials have been in place for a considerable time (e.g., 50 years or so), the formation of A horizons and sometimes weakly expressed B horizons has been documented. Figures 2.7 and 2.8 show soil horizons in urban and natural soil profiles.

Measuring and Monitoring Soil Properties

Soil properties are measured at specific sites or sampled for laboratory analysis. The properties that can be described in the field include horizonation and layering, color, texture, structure, consistence, depth to bedrock, and drainage class. The properties that generally are measured in the laboratory include content of organic matter, particle-size distribution, clay mineralogy, reaction, exchangeable cations, and concentrations of contaminants. The soil characteristics that are estimated or calculated from the measured properties include engineering classification and erodibility.

Physical Soil Properties

Soil is a mixture of mineral matter, organic material, air, and water. The texture of a mineral soil is based on the amounts of sand, silt, and clay in the soil. Sand, silt, and clay are defined on the basis of the size of each individual soil particle. These size

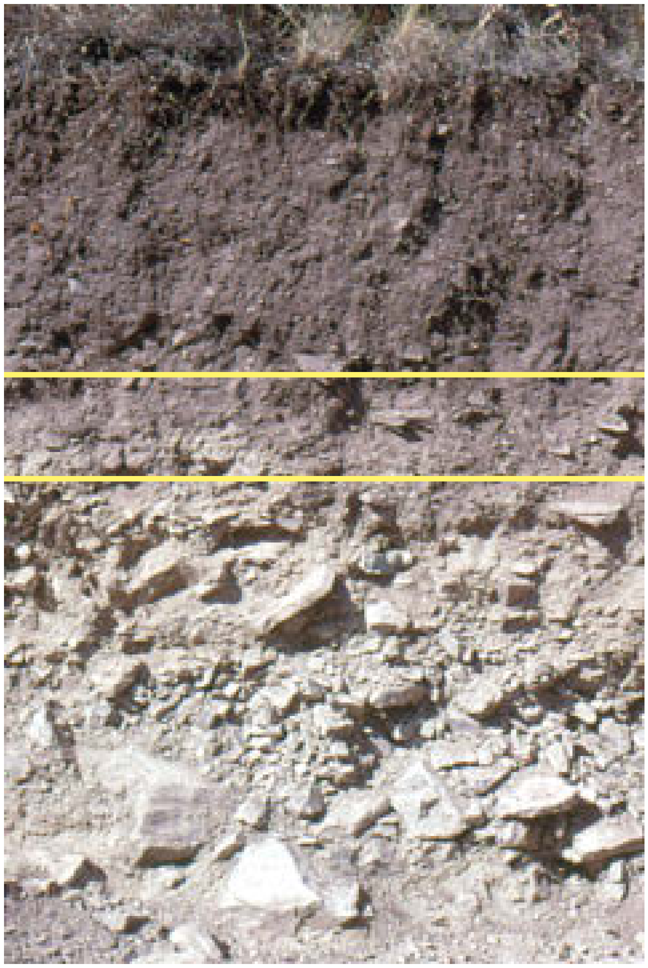

Figure 2.8: Natural soil profile.

relationships can be demonstrated by imagining that a sand particle is the size of a basketball, a silt particle is the size of a baseball, and a clay is the size of an aspirin tablet (figure 2.9).

Soil texture and other soil properties vary significantly within short distances on urban or natural landscapes. This variation is caused by the movement and mixing of soil materials during construction activities or changes in any of the soil-forming

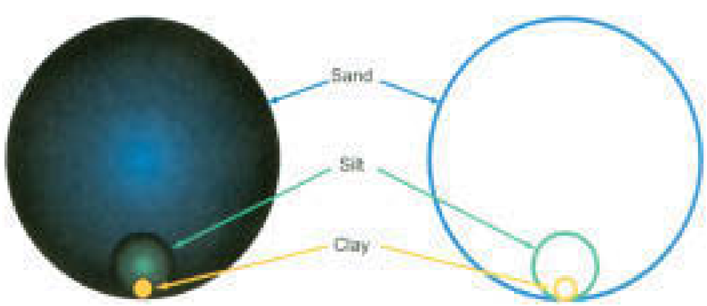

Figure 2.9: Relative sizes of sand, silt, and clay particles.

factors**.** The combinations of different textures may improve or limit the soil for a specific use.

Soil texture affects water and air movement through the soil as particles of different sizes pack together and thus determine the size and spacing of pores and channels. Sand particles have the largest pore spaces and allow water to drain through the pores most freely. Silt particles have smaller pore spaces, so water moves through them more slowly. Clay particles have very small pores, and so they tend to adsorb and hold more water. The mixture of particle sizes affects water, nutrient, and contaminant absorption. The specific type of mineral influences engineering properties, such as shrink-swell potential and excavation difficulty, especially in expanding clays (smectite), which behave like plastics.

The soil textural triangle (figure 2.10) can be used to determine soil texture from the relative amounts of particles of any two sizes. For example, a clay percentage of 15 with a silt percentage of 70 gives a soil texture of silt loam.

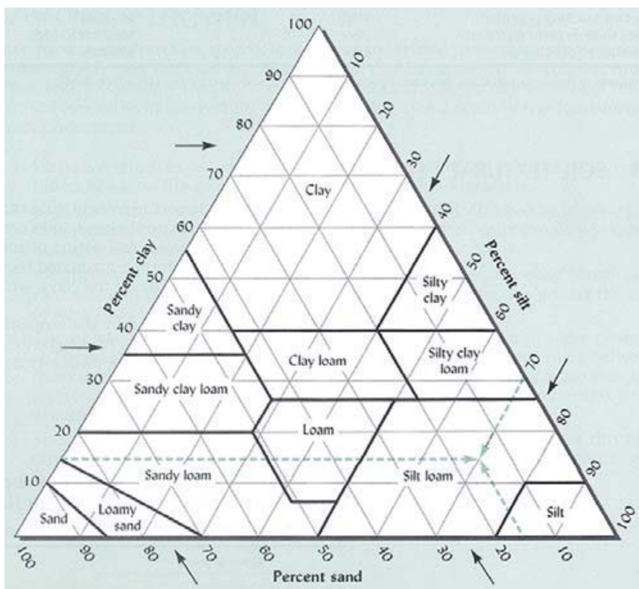

Figure 2.10: Soil textural triangle.

Measures of Water Movement

Water movement in urban soils is described in three ways (figure 2.11):

- infiltration into the soil surface, especially from rainfall
- percolation within the soil drain lines from septic systems, which is especially important in the soil below the drain line and above a restrictive layer
- permeability within the soil from the surface to a restrictive layer

Key terms in understanding water movement in soils are “restrictive layer” and “water table.” Restrictive layers have high density (high weight in a given volume of soil) and low porosity (limited space between particles), so that water cannot flow into or through them. Restrictive layers at the surface can cause surface sealing and limit

Figure 2.11: Comparison of descriptive terms for water movement in soils.

infiltration of water into the soil. Restrictive layers within the percolation zone reduce the drainage rate of fluids in septic drain lines and can cause septic systems to back up and fail. Compaction of soil materials can occur if heavy weight is on the surface when the soil is wet, resulting in dense restrictive layers below the surface.

A "perched" water table occurs when a restrictive layer anywhere in the soil limits waterflow deeper into the soil. Water drains down from the soil surface and builds up, or "perches," above the restrictive layer and above the expected water table depth. An "apparent" water table is fed from below by ground water, streamflow, or subsurface lateral flow as water moves across a restrictive layer below the soil surface.

Soil Color

Soil color differences in a profile reflect soil-forming processes and can be an indicator of soil wetness. These differences help to distinguish fill from natural soil. Important coloring agents in soil include parent (geologic) material, soil wetness, extent of leaching, content of organic matter, and the chemical form and content of iron.

Organic matter darkens the soil to a degree, depending on the content and the extent of decomposition. *Iron* gives soil a brown, yellow, or red color. Shades of blue or green may also appear, depending on iron amount, oxidation state, and hydration state. When soil is saturated, iron can become soluble and can be removed, leaving the soil with "mottled" brown and gray colors or completely gray colors, depending on the extent of the wetness.

Soil Structure

Soil structure is the combination or arrangement of primary soil particles into secondary units or aggregates. Organic materials and clay are important binding agents. Wetting and drying cycles are important in creating structure. Soil structure influences pore space and water movement in soils.

The principal forms of soil structure are—*granular* (roughly spherical)*; platy* (laminated); *angular or subangular blocky* (roughly cube shaped, with more-or-less flat surfaces); *prismatic* (vertical axis of aggregates longer than horizontal); and *columnar* (prisms with rounded tops). See figures 2.12 to 2.15.

Structureless soils are either *single grained* (each grain by itself, as in dune sand) or *massive* (the particles adhering without any regular cleavage, as in many hardpans).

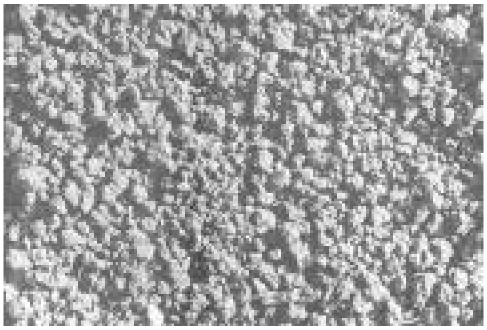

Figure 2.12: Granular structure.

Figure 2.13: Blocky structure.

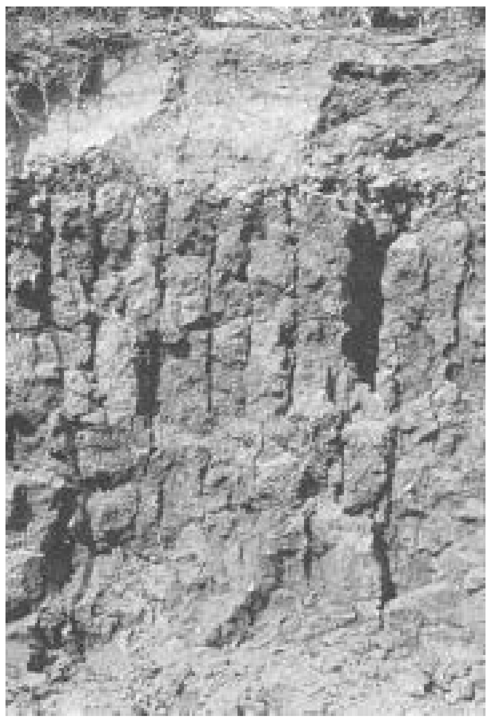

Figure 2.14: Prismatic structure.

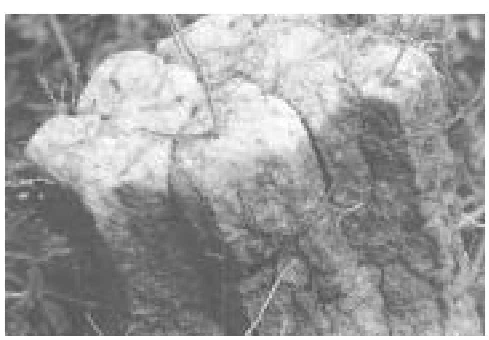

Figure 2.15: Columnar structure.

Chapter 3: Soils Regulate, Partition, and Filter Air and Water

Figure 3.1

Soils play a very important role in storing, regulating, and filtering both air and water resources. As rainwater falls onto the soil surface, it may percolate into the soil or run off the surface, depending on soil properties. Soil particles may hold chemicals and nutrients, making them available for plant roots and keeping them from moving into lakes and streams or entering the ground water. Soil pores that hold and transmit air and water play an important role in the health of the soil environment. All living organisms need both air and water. If all soil pores are filled with water or compacted, then less air is available to plant roots. After site preparation or manipulation, the properties of urban soils differ from those of natural soils and the soil air and water react much differently.

Topics in this chapter:

- **Soil functions**
- **Urban landscapes**
- **Soil and water interactions**
- **Soil temperature**
- **Stream corridors**
- **Storm water management**
- **Urban wind erosion**

Soil Functions

The kinds of activities that soils perform are called soil functions. Soil functions help us sort the extremely complex soil system into smaller parts that can be studied and understood. We depend on soil for more than just producing food. Other soil functions include a) providing building materials and support for structures; b) preserving natural and cultural history; c) regulating, partitioning, and filtering air and water; d) sustaining biological diversity and productivity; e) trapping pollutants; and f) providing sites for recreation. Soils perform specific critical functions no matter where they are located, and they perform more than one function at a time (table 3.1).

Table 3.1: Five Concurrent Soil Functions

- Soils act like *sponges,* soaking up rainwater and limiting runoff. Soils also impact ground-water recharge and flood-control potentials in urban areas.
- Soils act like *faucets,* storing and releasing water and air for plants and animals to use.
- Soils act like *supermarkets,* providing valuable nutrients and air and water to plants and animals. Soils also store carbon and prevent its loss into the atmosphere**.**
- Soils act like *strainers or filters,* filtering and purifying water and air that flow through them.
- Soils buffer, degrade, immobilize, detoxify, and *trap* pollutants, such as oil, pesticides, herbicides, and heavy metals, and keep them from entering ground-water supplies. Soils also store nutrients for future use by plants and animals above ground and by microbes within the soils.

Soil functions occur in spite of the land use. Rainwater must be dispersed or regulated in urban areas, and landscaping plant roots must have air available for growth. When areas are paved over, plans must be in place to handle rainwater. Buildings constructed on fill material must still be supported by the materials on the site. Soils perform the same or similar functions in all areas, including urban ones.

An important task is convincing people living in the urban environment to consider soil information and data before urban projects begin. This information must be part of the planning process for all urban projects. As soil properties change because of construction or other disturbances, major changes occur in the capacity of a soil to function, as predicted by engineering properties. The ability of a soil to support buildings and other structures changes when the soil is disturbed and/or mixed with other materials. Soil materials placed on top of garbage cannot support large buildings and certain other structures. Thus, it is important to know ahead of time what functional changes are expected to result from soil disturbance. Soil maps and soil profile descriptions can help us to understand how the soil at the building site will respond to project management.

Urban Landscapes

Landscapes in urban areas are controlled by underlying geologic landforms; by human activities, such as excavation or other disturbances and removal of water, oil, or minerals; and by microrelief in small areas. Soil movement can result from hazards, such as the formation of sinkholes, soil settling, decomposition of buried trees or landfills, and landslides. Some of these hazards are natural in the environment, and others are caused by human activities, such as excavation and filling for building. These impacts are secondary to the intended soil use. Old geologic formations, such as lava flows and lava tubes, collapse and unexpectedly create large holes. Knowing the underlying geologic formations before building can eliminate the need for costly repairs.

Urban planning for landscape changes requires consideration of fill consistency, soil porosity, internal water movement, surface drainage, and the increased water retention as organic matter is added to the soil. Knowledge of landforms helps us to understand water movement and storage whether the landforms were created by geologic forces or human construction. Some human-constructed soil layers dramatically impact water movement in soils. Geologic landforms lie beneath areas of urban development and may not be visible on the landscape (figure 3.2).

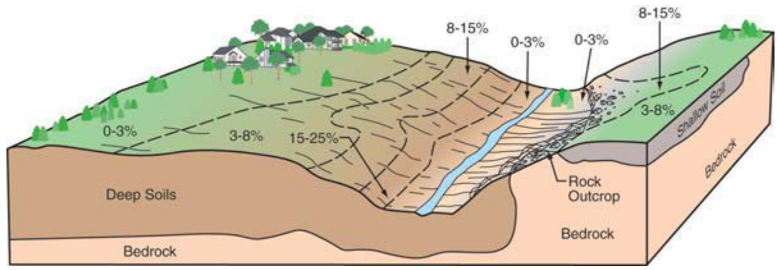

Figure 3.2: Soil slope and underlying geology.

Table 3.2: Summary of Inputs Useful in Identifying Urban Soil-Landscape Units

• Infrastructure	Storm drains, building heights, housing density, and road types
• Soil catenas	Interrelated drainage, soil texture, soil depth, and geologic deposits
• Block diagrams	Geologic material, relief, and spatial patterns of cuts and fills
• Site data	Measured erosion, infiltration, streamflow, and waste filtration
• Soil science	Chemical, physical, and biological interactions and discontinuities
• Vegetation	Seasonal variation, opportunistic species, and adapted physiology

Soil and Water Interactions

Maps with contour lines, called topographic maps, show the direction of waterflow from landforms (figure 3.3). The contour lines are drawn around landforms. Each line represents the same elevation. Contour lines generally show 10- or 20-foot intervals. They run side by side across a slope, and water moves perpendicularly (at a right angle) to the lines to get downhill. The contour lines are closest together where the slope, or downhill gradient, is steepest.

When contour lines form a V shape and elevation increases as you follow the point of the V, the V points upstream. The lines for flat areas or gentle slopes are spaced farther apart than the lines for steeper areas. A closed circle indicates a hilltop or knoll. A closed circle with hatch lines inside indicates a closed depression or sinkhole at the lowest point on a landscape. Map unit symbols on soil survey maps commonly

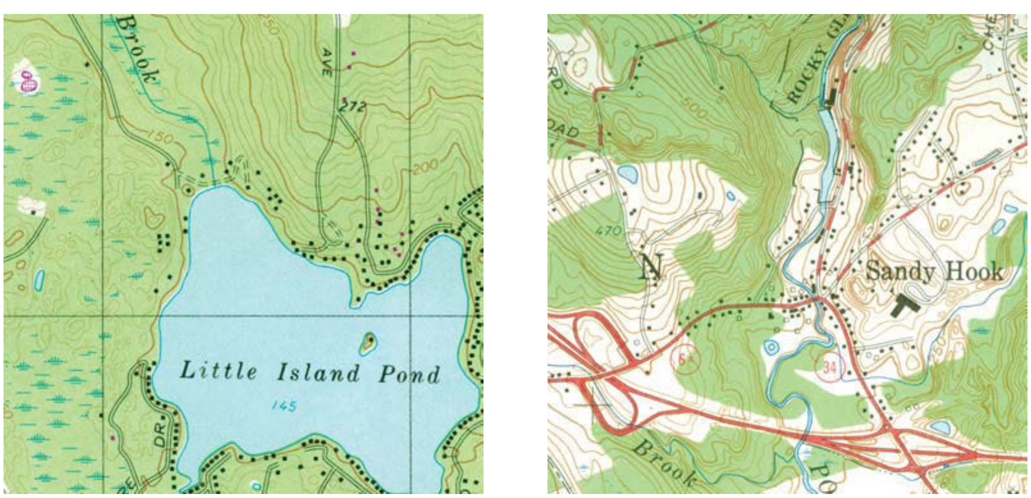

Figure 3.3: Topographic map detail.

indicate the relative steepness of slope. They tie the map unit delineation in soil survey reports to the name of the soil, the texture of its surface layer, and its slope. An example is Ridgebury loam, 3 to 8 percent slopes.

Water tables are underground supplies of water that generally occur closer to the surface during wet periods and are deeper during dry periods. Land use impacts water tables and runoff. An area of wetland may occur where the land surface slopes to an elevation below the water table. Where the underground water does not rise to the surface, it is called an aquifer. Water tables can be identified by observing and recording soil color and soil wetness in urban project excavations or in test holes.

The movement of water into a soil depends heavily on soil texture, soil structure, slope, bulk density, compaction, surface loading, and vegetation. Figures 3.4 and 3.5 demonstrate that more water moves into the soil on natural landscapes than on

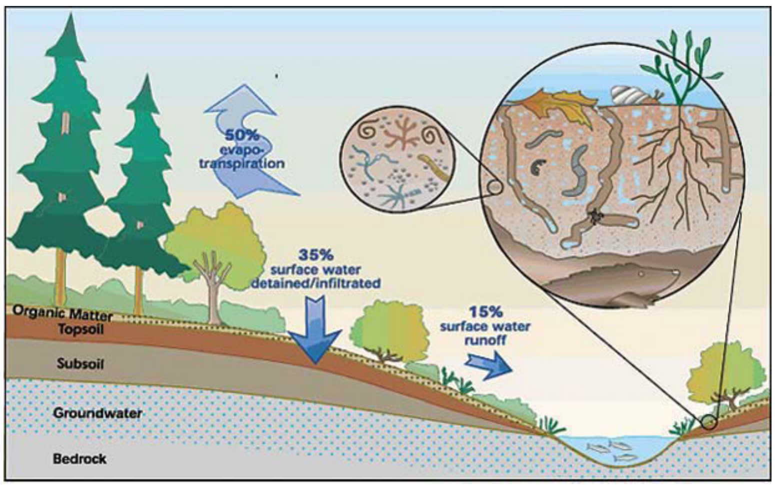

Figure 3.4: Water movement on a natural landscape with a plant cover. This landscape is in a humid area. In the drier regions, the stream level is higher than the surrounding land.

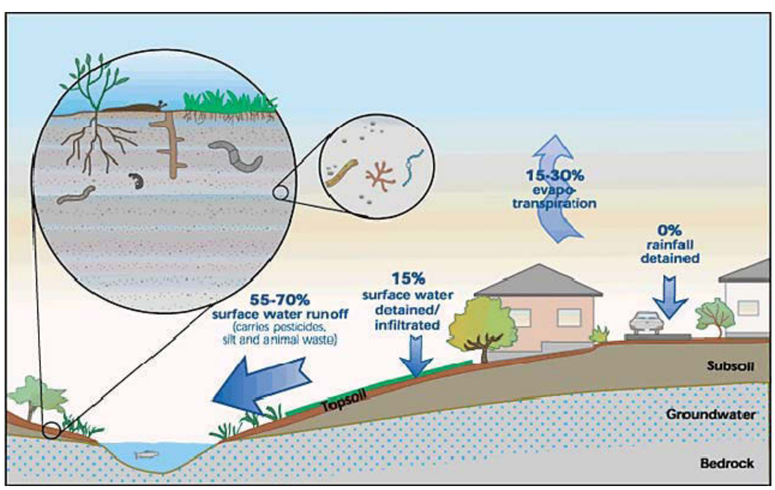

Figure 3.5: Water movement on a disturbed urban landscape with limited vegetation and impervious surfaces. This landscape is in a humid area. In the drier regions, the stream level is higher than the surrounding land.

disturbed landscapes, such as those in urban areas. More water evaporates into the air on natural landscapes than in areas covered by streets, roads, homes, garages, and other buildings. More water runs off urban areas because of the impervious nature of pavement, compacted soil layers, and urban buildings. Water containing sediment clogs lakes and reservoirs. Removing this sediment is costly (figure 3.6).

Figure 3.6: Removing sediment from a flood-control lake. A dam is in the background.

Oil, gas, lawn fertilizer, pesticides, and other pollutants often run off from urban areas and into lakes, streams, or reservoirs and reduce water quality. Some of the fertilizer, pesticides, and herbicides can run through the soil and into ground water, also impacting urban water quality.

Geologic formations, the kinds of rocks that occur below soils, affect water movement in soils and their landscapes. An example of an unstable geologic formation is a shale bed, which is prone to slippage and landslides (figures 3.7 and 3.8). The weight of excess water in the soil can reduce slope and soil stability, especially in urban areas where expensive urban projects are built.

Figure 3.7: A home damaged by slippage of shale beds.

Soil Temperature

Soil temperature may be higher in urban areas than in the surrounding forests and fields. Heat islands form where extensive pavement and large buildings absorb and return heat and restrict airflow within a city. The water supply may be limited in the heat islands as roof runoff and rainwater are piped to storm drains in the streets. Heat stress can occur in plants in excessively dry soils. Soil water and microbial activity within the soil have a significant impact on subsurface soil temperature (figure 3.9).

Figure 3.8: Soil slump on a steep slope below a mall.

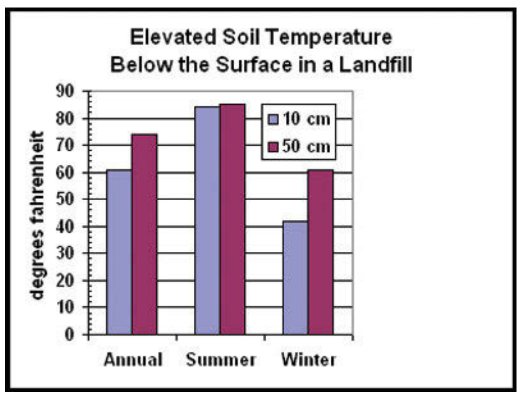

Figure 3.9: Increased microbial activity results in elevated soil temperature in a landfill.

Stream Corridors

Stream corridors provide opportunities for recreational green space, flood control, and wildlife habitat in urban areas. Urban and suburban soil ecosystems are similar to rural ones but have the added dynamics of heat islands, channeled storm water, and transportation systems for urban residents. In some areas, streets interrupt normal surface drainage and ponds or lakes form. Many urban projects restore streams that were piped underground in the past and create riparian stream corridors. These areas may connect with retrofitted parking lots of porous pavement, so that more rainwater eventually returns to the ground water or surface rivers and lakes.

The filtering function of soils is critical in areas within stream corridors and under parking areas. Soils require an active biological community for the chemical reactions that draw toxic materials out of runoff water and hold them in less reactive forms within the soils.

Because of a high population density and the resulting intensive land use, urban soils commonly are disturbed. This disturbance can be small and involve only the soil profile. Examples are mixing of soil horizons, removal of topsoil, and additions of soil material for plant growth. Other disturbances, such as shaping and grading activities, can be more dramatic and can change the shape of the landscape itself. Cutting and filling activities change the surface characteristics that impact water movement into and through soil, site erosion characteristics, and soil fertility. Shaping and grading activities may improve a project site, but they may also change the direction and flow of water, causing problems on adjacent sites. Planning is required prior to construction to minimize the problems in adjacent areas and the impacts on ground water, erosion, and sedimentation. Silt fences can keep sediment from reaching streams and other water bodies (figure 3.10).

Figure 3.10: Silt fences collect sediment and keep it from reaching water bodies near construction sites. Construction is just starting on this site.

Watersheds in urban areas can be defined by the type of boundary between landscape features that forces water to move in a different direction. We can differentiate between an urban watershed, or "sewer shed" (defined by storm drains), and a "natural" watershed, defined by topographic watershed divides.

Landscape disturbance may also have positive effects. It sometimes introduces additional plant and animal species or helps to minimize the effects of the less favorable traits of natural landscapes. Soil reconstruction can take advantage of different soil textures and boundary conditions between soil layers to manage waterflow, structural stability, and nutrient storage.

Storm Water Management

Construction activities can be major contributors to poor water quality from sedimentation and dust in urban areas. Changes in water quality in adjacent streams and wetlands commonly indicate poor management of urban soils. For example, a lower abundance of organisms, such as crayfish and dragonflies, in streams can be an indicator of poorly managed urban soils nearby.

Runoff is water that cannot infiltrate the soil and flows across the land surface, picking up soil particles and any other objects that can be moved as sediment during rainstorms and periods of flooding (figure 3.11). Sediment can clog streets and storm drains with mud, and floodwater can carry excess phosphorus, nitrogen, and other contaminants to streams or lakes. Excess nutrients, attached to soil particles in sediment, may cause algae blooms and poor underwater visibility. Algae blooms are sometimes health hazards and impact swimming and fishing. Algae blooms and sedimentation also decrease water quality, usually by reducing the oxygen content.

Figure 3.11: Street flooding submerges cars.

Erosion- and sediment-control plans are used where large land areas are to be disturbed or where activity is expected to last through a number of rainfall or windstorm events. Two major components of these plans are control of runoff and windblown dust and maintenance of the flow rate and amount of water (hydrology) at preconstruction levels. Preventative measures that slow the flow of sediment to waterways include silt fences staked on contours across hillsides and hay bales anchored at intervals within runoff ditches.

Some urban areas have rapid soil infiltration rates of approximately 2.5 inches per hour. A negative effect of the high infiltration rate is that if fertilizer is applied immediately before a severe thunderstorm, then a great deal of the fertilizer may be leached through the soil into ground water or washed directly into the storm drains. Soil scientists have called these nutrient-rich storm drains human-made wormholes. Wormholes in the soil fulfill a similar function of carrying nutrients rapidly to distant places in the soil.

More often, storm water management in highly developed areas is needed to prevent flooding and emergency discharge of untreated sewage into rivers (figure 3.12). The amount and flow of storm water depend on how much rainfall can infiltrate into the soil. The amount of rainfall varies greatly in urban areas across the Nation. Construction practices that disturb the soil may differ from one State to another because of local and State ordinances. Increased runoff resulting from decreased water infiltration (from compaction or land shaping) is a high priority in urban planning.

"Urban Hydrology for Small Watersheds" (Technical Release 55, USDA, NRCS, 1986) is still widely used as a tool for planning and monitoring water movement, especially in urban areas where soils have been disturbed. Water infiltration plays a critical role in the calculation of the amount of water that will flow from a site in a certain amount of time. Relative infiltration rates for different housing densities and varying degrees of lawn vigor are expressed as runoff curve numbers (RCN) in TR-55 (table 3.3). The hydrologic soil group (HSG), which is an indicator of infiltration, is predetermined for each soil. The letter A indicates rapid infiltration, and the letter D indicates that rainwater generally runs off the surface. Soil management in urban areas can focus on decreasing runoff (RCN) by increasing the area of "good" open lawn, where more than 75 percent of the surface is covered with grass. Each addition of pavement will increase the amount and speed of water leaving the site.

Figure 3.12: A flooded parking lot and street.

Table 3.3: TR-55 Runoff Curve Numbers by Housing Density and Vigor of Cover

Cover type	Increasing runoff (RCN) by decreasing infiltration (HSG)				Soil condition
	A	B	C	D	
Paved driveway	98	98	98	98	impervious
Commercial district	89	92	94	95	85% impervious
Newly graded area	77	86	91	94	no vegetation
Housing lot <1/8 acre	77	85	90	92	65% impervious
Housing lot 1/4 acre	61	75	83	87	38% impervious
Housing lot 1/2 acre	54	70	80	85	25% impervious
Housing lot 2 acres	46	65	77	82	12% impervious
"Poor" open lawn	68	79	86	89	<50% grassed
"Good" open lawn	39	61	74	80	>75% grassed

Excerpt from table 2.2a in TR-55, "Urban Hydrology for Small Watersheds." RCN is the runoff curve number (30-98). The number 30 indicates the least runoff. HSG is hydrologic soil group (A-D). Group A consists of soils characterized by rapid infiltration.

Urban Wind Erosion

Wind erosion is the movement of soil particles by wind. It occurs when land surfaces lack vegetation and the soil dries out. Windspeeds must reach a certain velocity (in most cases more than 12 miles per hour at 1 foot above the land surface) to move soil particles, depending on the size of the particles. The smaller soil particles (silt and clay) require lower windspeeds, and individual particles of organic matter move most easily and with the lowest windspeeds because of their low weight. “PM-2.5” dust refers to soil particles less than 2.5 microns in size. It can enter human lungs and cause respiratory problems. These small particles form when construction vehicles pulverize soil under dry and windy conditions. There is a high potential for dust blowing on large construction sites and in other disturbed areas (figures 3.13 and 3.14).

Figure 3.13: A cut on a construction site. This site is subject to wnd erosion.

Figure 3.14: A dust cloud along a highway. Windblown particles are measured by the meter in the foreground.

There are three kinds of wind erosion based on particle size and weight (figure 3.15). "Soil creep" occurs when very high wind moves coarse sand particles by rolling them along the soil surface. "Saltation" occurs when wind moves soil particles by bouncing them along the soil surface. Medium-sized sand particles usually are moved by this process. A "dust storm" occurs when wind detaches small soil particles from the land surface and suspends them in the air. Wind erosion is most visible during the suspension stage of dust storms.

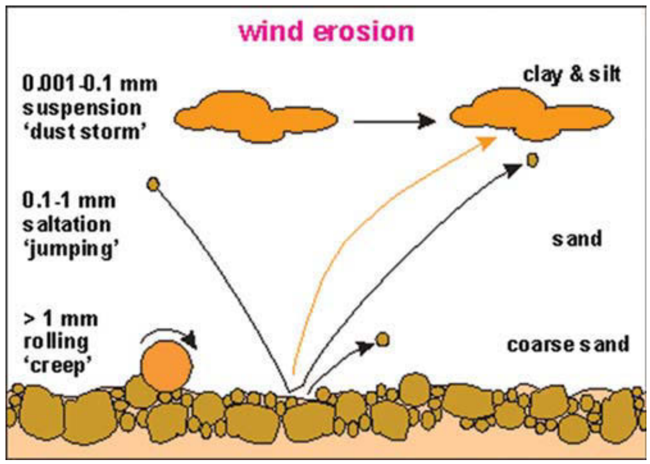

Figure 3.15: Process of wind erosion.

Flat areas in dry climates are likely to have serious wind erosion problems. Certain areas of the United States are more prone to high-velocity winds than others. Construction activities usually disturb the land surface by removing plants and pulverizing soil aggregates, making the site more likely to dry out. Reducing traffic over the land surface, keeping the surface rough by maintaining soil clods or aggregates, watering construction site surfaces, applying mulch to disturbed sites, and maintaining windbreaks or barriers reduce the risk of urban wind erosion. Establishing grasses and other plants as soon as possible after construction is completed also helps to control wind erosion.

Chapter 4: Soils Sustain Plant and Animal Diversity and Productivity

Figure 4.1

Whether they are in urban or natural areas, soils provide living space and supply air, water, and nutrients for micro-organisms, plants, animals, and humans. In most areas, soil properties determine which plants and animals can live in and on the soil. Urban soils that have been disturbed and mixed may no longer possess the natural characteristics needed to support life. Soil amendments may be required to reestablish plants. In many urban areas, the remaining soil materials must be modified before they can support plant and animal life.

Topics in this chapter:

- **Soil fertility and plant nutrition**
- **Soil acidity**
- **Soil organisms and biochemistry**
- **Soil as a filter and buffer for waste**
- **Identifying problem sites from historical records**
- **Identifying problem sites by visual clues**
- **Precautions for community gardens, playgrounds, and parks**
- **Historical tidbits on waste management**

Soil Fertility and Plant Nutrition

Management of urban soils for productive gardens requires a basic understanding of physical and chemical soil properties. Local sampling and testing can help gardeners to determine the suitability of urban soils for certain plants and the need for fertilizer, or plant food (table 4.1).

Table 4.1: Examples of the Factors That May Affect the Productivity of Urban Soil

- Little or no addition of organic matter
- Artifacts that disrupt water movement
- Elevated salt content
- Interrupted nutrient cycling and modified activity of micro-organisms
- High soil temperatures that increase the rate of chemical reactions
- Generally higher pH values resulting from additions of cement, plaster, and road salts
- Lateral (sideways) subsurface waterflow resulting from compacted layers

Meeting the nutritional needs of urban plants requires consideration of soil moisture and temperature as well as the chemicals and biological organisms needed to convert fertilizers into useful nutrients. Plant selection may vary according to the grower's nutritional needs, cultural traditions, soil conditions, and the space available. Plants common in different ethnic diets can be successfully grown in urban areas (figures 4.2 and 4.3). Attention must be paid to different plant tolerances for metals and to drainage, the growing season, and weed control.

Figure 4.2: Produce from a Vietnamese home garden.

Figure 4.3: Intensive Vietnamese home garden in an urban area.

Plant growth and nutrition are closely linked to soil properties. The ability of soil particles to hold and release nutrients for plants and micro-organisms to use is called the cation-exchange capacity (CEC). This capacity determines which nutrients stay in solution and are available for uptake by plant roots and which nutrients are moved through the soil and thus are not available for plant and microbe use. Cations in the soil are positively charged nutrients, such as nitrogen, sodium, calcium, and potassium. Different plants and microbes require different kinds and amounts of nutrients. Trace metals also are nutrients in the soil. They generally are used in very small amounts. Such trace metals as iron and manganese are necessary for plant growth. Also, they help plants to fight diseases. Metal mobility and potential toxicity in soil occur at the lower pH levels and depend on metal binding through cation exchange.

Various kinds of clay in the soil attract and hold cations onto negatively charged parts of their surfaces. Certain clays internally bind some chemicals very tightly. As a result, it is difficult for plants to obtain the necessary nutrients from the soil solution. In areas of these highly active clays, we often add lime (calcium carbonate) to reduce the acidity of the soils and facilitate release of the nutrients from the clays into soil solution.

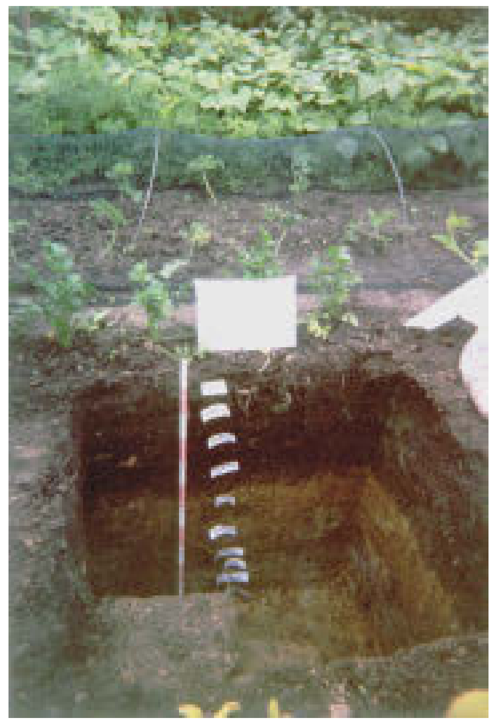

Figure 4.4 Soil profile in a long-term garden.

Organic matter has many active sites that bind chemicals in a manner similar to the way clay particles bind the chemicals in the soil. Organic matter is often visible in a thick, dark surface layer, in which plants begin to grow and take up nutrients. Clays and other soil materials are mixed with the organic matter in each soil layer to form a chemical system. Intensive vegetable gardening over many years during which unused plant materials and organic waste are returned to the soil can produce a thick, dark surface layer of organic matter. The color of the resulting dark surface layer may contrast with the color of the underlying soil, as is shown in figure 4.4, which pictures a 100-year-old continuous vegetable garden.

Soil Acidity

An acid is a substance that has a positive charge and usually yields hydrogen ions when dissolved in water. Hydrogen ions are positively charged. The stronger the acid, the better it dissolves in water. The pH scale (1-14) is a common measure of soil reaction. The lower the number, the greater the acidity. The midpoint of the pH scale is neutral (7.0), a good level for the growth of most plants.

Changes in soil reaction, as measured by pH, have significant effects on metals in soil. Metal toxicity to plants and animals increases in strongly acid soils with a low pH (3.5). Metals in these soils are released from negative sites back into soil solution. At a higher pH (8.5), the metals often are sequestered in the soil. The term “sequestered” indicates that the positively charged metal ions are bound tightly to negatively charged sites in the soil. These sites may be on clays, mineral compounds, or organic matter, including the surfaces of some micro-organisms. These strong, tight bonds restrict the availability of metals for plant uptake and reduce the risk of animal consumption or human skin contact.

Soil Organisms and Biochemistry

Soil is made up of mineral particles and organic matter, the decomposed remains of living things. Bacteria, fungi, and other micro-organisms are largely responsible for breaking down dead plants and animals in the soil. Small organisms (microbes) have negatively charged sites where soil nutrients and metals can bind to form soil aggregates and compounds. Earthworms and larger animals eat and digest organic materials and minerals, transform them into soil aggregates, and deposit them as waste. Soil aggregates are loose groupings of many different soil components in a structure allowing water and air movement as well as biochemical reactions for energy production and nutrient cycling (figure 4.5).

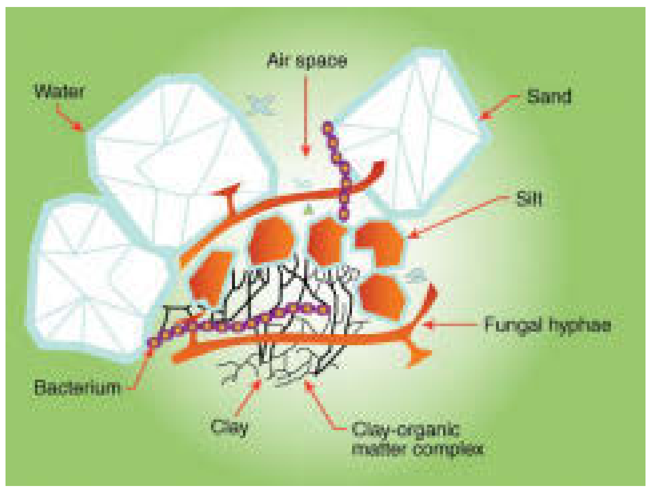

Figure 4.5 : Soil components at a microbial scale.

Soil as a Filter and Buffer for Waste

Managing compost and organic waste is important for plant nutrition and for the biological degradation and conversion of contaminants into inactive forms in the soil. Two key ways to manage waste are filtering and buffering. Waste is filtered when it flows through the soil and is slowly trapped and bound to soil particles. Soil buffering traps waste particles and transforms them into inactive forms.

Composting and using septic systems are examples of waste management in urban soils. Organic materials are needed to hold water and nutrients in the soil for plant growth. In urban parks and community gardens, as well as suburban home gardens and yards, composting can recycle most of the leaves and grass clippings (figure 4.6). This management alternative provides inexpensive soil conditioner that increases porosity and improves the rooting environment for plants.

The major considerations in applying yard and garden waste after composting are plant nutritional needs and the potential of the compost to contain weed seeds or contaminants. Existing resources from the Cooperative Extension Service provide guidelines for managing compost in a manner that maximizes the nutrient content and minimizes the transfer of diseases or contaminants. The same practices work for

Figure 4.6: Composting barrels or traditional fenced piles fit different management intensities in home gardens.

organic waste whether from urban or agricultural sources, and the economic benefits of recycling apply to both.

Understanding the role of soils in septic systems helps residents of small towns or remote housing developments to manage the return of some nutrients to the soil. The liquid septic effluent can provide nitrogen and phosphorus for use by the roots of lawn grasses. Lawn areas receiving liquid drainage from poorly designed or failing septic systems may appear darker green and have thicker grass than surrounding lawn areas. Lakes surrounded by intensive development using septic systems may have water-quality problems, such as algae blooms or high phosphorus levels, if the systems become overloaded.

Conversion of summer cottages to year-round homes may lead to septic system failure or excessive drainage of nutrient-rich septic effluent to lakes or streams. Upgrades, cleanouts, and enlargements of septic systems are needed to accommodate the amount of human waste produced and to make sure that the waste does not pollute surface water or the ground-water supply for wells. Soil properties affecting septic system design and installation include slope, depth to bedrock, permeability, depth to the water table, plasticity of the soil (possible expansion when the soil is wetted and then dried), soil texture and structure, and potential for corrosion of steel or concrete pipe.

Identifying Problem Sites From Historical Records

Metals in soils come from various sources. They may have been present in the geologic rock, or they may occur as atmospheric additions of copper, mercury, lead, and zinc. Metals also may have been deposited by past industrial activities, such as battery production, brass and steel manufacturing, mining, and many different processes involving nickel, cadmium, copper, and lead. Lead is especially evident near roadways because of automobile emissions before the availability of unleaded gasoline, and automobile demolition areas may contain a variety of metals that were commonly used in older cars. As lead paints and some window blinds and soldered pipes used in houses before 1978 wear out and deteriorate, they add lead to nearby soils.

Other ongoing sources of metals and organic waste material are landfills and dump areas that are poorly maintained or unregulated. Landfill materials eventually decompose and form a highly variable type of urban soil. The volunteer vegetation may be dominated by phragmites, as is shown in figure 4.7. These sites can be reclaimed for limited recreational or industrial use.

Figure 4.7: An older landfill with phragmites.

Areas affected by city fires may have concentrated metals buried in the soils. These concentrations are discovered only by referring to historical records or by digging into the soils (figure 4.8). Major fires may leave surface residue high in contaminants. A variety of plants may still grow well, but careful evaluation of each site is needed to determine the risk to human health.

Marine sediments may be dredged and used as fill in low-lying urban areas. Contaminants in the dredged material may be moved onto a site. Other problems with water movement and root resistance may result from compaction of a subsurface layer of very fine sand.

Figure 4.8: Soil profile with a buried layer of ash and refuse. This site was burned by a city fire.

Identifying Problem Sites by Visual Clues

Metal contamination on a site may be evidenced by plant growth, animal behavior, or paint flecks containing lead from older buildings. Many plants simply cannot grow where the level of certain metals is high. Other plants grow well in contaminated soil but fail to set seed or do not grow as well as expected. Absence of any plant growth is a warning sign that a site may be severely contaminated. Caution during sampling is needed.

Metals may be present at a site but not be a high risk for gardening or recreation, depending on the soil properties, drainage, and vegetation at the site. A human health risk from mosquitoes can occur not only in areas of standing water but also in any areas near homes or on city streets with stagnant water. Compaction is often the main problem causing water to pool on the surface without infiltrating into the soil. Mixing the soil when it is just a little moist can increase the porosity (air space between particles) and allow water to soak in. Other options are to divert the water away from low spots and to create channels for storm water to flow around the site or in specific streams or ditches across the site.

Precautions for Community Gardens, Playgrounds, and Parks

Outdoor recreation and gardening are popular activities on urban soils. The risk to human health varies among the sites used for these activities and even between the soils on the same site. A careful study of the area and consideration of key soil properties are needed (table 4.2)

Community and home gardens on contaminated soils may not be a health risk if the garden vegetables supply a very small proportion of the vegetables in the overall human diet. Caution is advised, however, when produce grown in contaminated soils is eaten. Often, the garden supplements the produce bought at grocery stores and for most of the year the nutritional needs of the growers are met elsewhere. Buying vegetables at farmer's markets or school fundraising gardens is another way to dilute the dietary intake of contaminated plants by any one person

Caution is needed in areas of bare ground or leaking water near past industrial sites, dumps, or older homes. Gloves should be worn during soil sampling. Dust from contaminated sites may be dangerous if inhaled by humans or animals. Extended skin contact or hand-to-mouth activities may allow metals to enter children's bodies and interfere with growth and mental development. Pets may collect contaminated dust or mud and carry it into the home.

Prolonged skin contact with contaminated gardens can endanger young children. Raised bed gardens built with a liner on the soil surface and carefully selected fill materials provide a relatively safe and productive alternative. For many residents of urban areas, a community garden is a desirable opportunity for physical exercise, visiting with neighbors, supplementing vegetables, and relaxation.

Table 4.2: Human Health Risks

potential health risks
- **dust inhaled**
- **soluble lead for plant intake**
- **mud puddles that attract children and increase skin contact**

soil chemical properties influencing relative risks
- **strongly bound and insoluble forms of contaminants**
- **prevalence of active clay surfaces for binding**
- **organic carbon in various active forms for binding**
- **other cations, electrical conductivity, pH, and salts**

soil physical properties influencing relative risk
- **drainage**
- **infiltration and permeability**
- **erosion potential for runoff and sediment loss**
- **particle sizes and water in soil pore space**

Historical Tidbits on Waste Management

Night soil was a traditional material in monasteries and in urban areas without sewer systems. Human waste was recycled into gardens and agricultural areas as fertilizer. It was usually emptied from storage pots each morning. Thus, it was called "night soil."

Kitchen gardens were located near cooking areas to provide vegetables and herbs convenient for food preparation. These often were fertilized with night soil. Many historical discard areas are uncovered by the efforts of archaeology and give us insight into the foods people ate, the cooking vessels they used, and the ways they recycled waste materials.

Chapter 5: Soils as Building Material and Structural Support

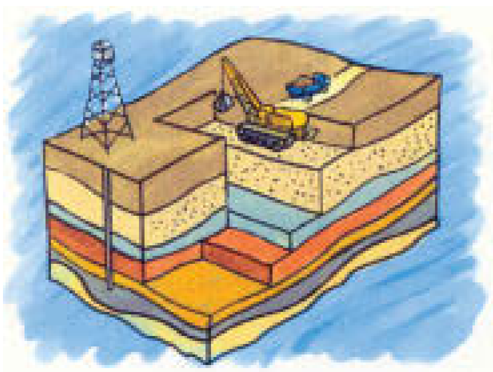

Figure 5.1a

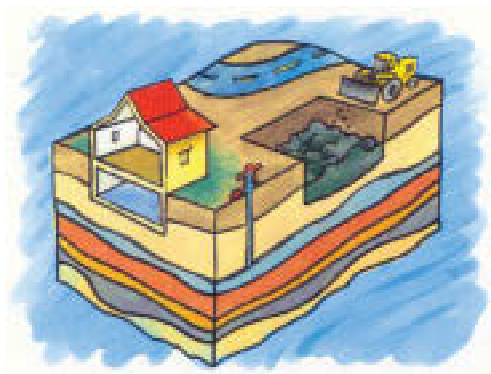

Figure 5.1b

Soil is used as raw material in urban construction activities. Sand, gravel, and clay are mined and used as important materials for many purposes, such as constructing foundations and roadbeds, leveling and filling building sites, and lining ponds and lakes where porous materials require sealing. Soil provides structural support for the houses, schools, shopping malls, churches, industrial parks, and parks and recreation fields that are part of urban areas. Not all kinds of soil are suitable for the many urban uses that are required. Sandy soils are better drained than clayey soils, and some soil layers that are exposed during construction have low strength and are easily compacted. When exposed, bedrock and hardpans are difficult to manage. Knowledge of the soils on the site is needed prior to construction.

Topics in this chapter:

- **Site preparation**
- **What happens when soil is disturbed?**
- **Management after disturbance**
- **Special care of plants in islands within paved areas**
- **Sinkholes**
- **Artificial landscapes**
- **Building material**
- **Materials that allow water to infiltrate**
- **Open space in planned developments**
- **Reclaiming contaminated sites and vacant lots**

Site Preparation

One goal of construction activities in urban areas is to provide material that supports buildings, streets and roads, ballfields, tennis courts, golf courses, parks, and gardens. Another goal is to use soil and other land resources wisely. Each construction site has different needs from the standpoint of supporting structures to be built and then providing materials for landscaping the site after construction is completed. Some sites are left in their natural condition, but many are leveled, drained, shaped, and compacted. These activities help to overcome the engineering and construction limitations affecting building foundations or concrete slabs for building floors, parking lots, athletic fields, or other uses. Soil or even bedrock must be moved or removed when a construction site is leveled or graded. When bedrock or hardpans are involved, drilling and blasting may be needed to loosen the materials. Large machinery, such as an earthmover (figure 5.2), is used to move soil material from one place to another on the site.

Figure 5.2: An example of construction machinery.

Soil materials that are moved from one construction site to another or to a different location on the same site must be compacted if they are to support the weight of buildings. Machinery is used to reduce the number and size of soil pores and increase soil strength (figure 5.3). When soils are not compacted or when sites are unstable, project failures occur. Figure 5.4 shows a house foundation that is unstable. The electric meter was torn from the house as the soil next to the foundation settled. In figure 5.5 settling around a house has torn the outside step away from the patio doors. The red line on the foundation is the original level of the patio. Figure 5.6 shows damage to a road built on an unstable soil.

Soil compaction often occurs in areas where sidewalks were not built along the preferred footpaths (figure 5.7). This compaction is unintentionally caused by people after construction is completed. Because of soil sealing at the surface, vegetation cannot grow in compacted areas. Compaction below the surface may be evidenced by puddles on the surface or trees that are blown over by heavy winds because of shallow root systems. Compaction often is caused by the heavy machinery used by builders and contractors (figure 5.8). The use of large machinery to move materials around on a building site when the soil is wet compacts surface and subsurface horizons in the soil. These compacted horizons, which are characterized by reduced pore space and increased density, alter soil drainage, root penetration, and even microbial communities on the site.

Unintentional soil compaction is a symptom of soil mismanagement and can be a cause of excessive runoff, with or without sedimentation. Compaction occurs when soil particles are packed tightly together as heavy forces (including vehicles, foot traffic, or even glaciers) are applied to wet soils. Compaction is reflected in decreased

Figure 5.3: Sheepsfoot rollers compact soil.

Figure 5.4: An electrical service box torn from a home because of soil settling.

Figure 5.5: A home damaged by soil settling.

Figure 5.6: A road constructed on an unstable soil.

Figure 5.7: Compaction in a footpath.

Figure 5.8: Compaction caused by the use of heavy machinery during wet periods.

water infiltration, limited internal water movement, and the inability of plant roots to grow through a restrictive soil layer.

After soils are modified and used for urban projects, the landscape must still function as a natural system. In other words, the soils must still regulate, partition, and filter air and water; sustain biological diversity and productivity; and support structures. This is the challenge. Soils in densely populated urban areas are dramatically different from soils naturally occurring in forests, on rangeland, in agricultural areas, or at the urban fringe. The functions of urban soils often are modified (figure 5.9), sometimes in a positive way and sometimes in a negative way.

Urban soils range from slightly disturbed to completely manmade. Natural soils can occur in urban areas where site preparation has not been extensive. Urban soils present unique challenges to landscape architects, horticulturalists, engineers, and urban planners. The general types of soil disturbance in urban areas include intentional cutting and filling; vehicular or foot traffic, which can cause compaction; introduction of manufactured soils for raised bed gardens and containerized plantings; and special preparation of sites for parks, gardens (figure 5.10), athletic fields, and golf courses (figure 5.11). Large-scale soil disturbance includes leveling through cutting

Figure 5.9: A modified urban landscape.

Figure 5.10: A garden near a home foundation.

Figure 5.11: Golf course.

and filling or through grading in certain areas, such as sites for buildings or athletic fields; filling of wet areas or areas that have undesirable soil characteristics; and filling of unused or abandoned areas in preparation for waste disposal.

Disturbed soils differ from soils in natural areas because their horizons have been mixed, destroyed, or removed; natural soil structure has been destroyed; compaction has occurred because of heavy machinery use; water transmission rates have probably been reduced because of soil compaction and loss of soil structure; and runoff and soil erosion rates typically have been increased.

What Happens When Soil is Disturbed?

Humans are probably the most important organisms of the soil-forming factors in urban areas. Urban soils have been disturbed by human activity in some manner and to some degree. This disturbance has changed the properties of the soils, and the soils should now be managed in a different manner. Mixing different parts of more than one soil can result in a new soil that may be better suited to a certain use than the original soils. Some soils have to be altered before they are suitable for certain uses. An example is a soil in an area where preparing a roadbed requires mixing and deliberately compacting soil material. Topsoil commonly is piled up and then spread on top of the altered soil after construction. In some strongly sloping areas, soil may be moved from one area to another to fill low-lying areas and level the site for construction. In some areas soil material is created on the site by mixing manmade and/or natural materials from various sources. The materials may be mixed as they are moved by heavy construction equipment.

Soils in urban areas are used for many purposes even if they are compacted and/or contaminated. Contaminated soil material is sometimes buried because of the need to protect those who work or play on the site. This contaminated material may be exposed during construction activities. Old dump sites for petroleum and chemicals are now being exposed as urban redevelopment occurs in many cities. The buried materials have leached into other soil layers or even into the ground water, and cleanup coasts are extremely high. In some areas cleanup may be impossible. Some soils are unintentionally compacted prior to their use. This compaction causes problems after construction. Soils that have been compacted or contaminated create special problems for certain uses or for the people who live or work on them. A soil scientist and specialists in other disciplines can provide valuable information to help people use soils properly and to address existing problems in urban areas. It is important to get advice and help from soil scientists before projects are started.

These facts help us begin to understand that urban soils are very different from soils in natural areas. Even in undisturbed areas, no two soils are exactly alike. Thus, it is important to know all one can about a soil before it is used for any purpose, including urban projects. Most soil-related limitations can be overcome if enough money is available to correctly design, install, and maintain a project. Costs to overcome project errors are often higher than the original project costs.

Management After Disturbance

After disturbance, the surface layer of urban soils should have the characteristics needed for good plant growth. Management includes overcoming physical and chemical root restrictions, providing nutrients by managing soil fertility and acidity (pH), and reducing the likelihood of contamination or disease problems. In areas where the climate is dry, a water supply for the site also is needed.

Special Care of Plants in Islands Within Paved Areas

Urban plants may grow on small islands within disturbed or paved areas. Overland waterflow to the vegetation is limited on these islands. Large soil pores that connect to the surface are critical if water is to move to the deep roots of the plants. The soil in the island of vegetation should extend below the pavement and should provide enough volume for root growth in proportion to the above-ground height of the trees and shrubs. Trees and flowerbeds along streets may require more frequent applications of fertilizer and water than backyards or gardens.

Sinkholes

Sinkholes severely limit urban uses. They form where water has been pumped from underlying geologic formations, leaving the surface soil without support; where limestone bedrock is dissolved in water and removed below the soil during geologic weathering; and where underground volcanic lava tubes collapse after geologic weathering (figure 5.12).

Figure 5.12: A sinkhole where a lava tube has collapsed.

Artificial Landscapes

Many urban parks were once deep ravines. These ravines were filled with construction materials and refuse during the process of land leveling. Examining a pit dug into the soil under the vegetation helps soil scientists to determine the soil properties controlling the way water moves through the soil and the way nutrients are released to plants (figure 5.13).

Figure 5.13: Soil scientists examining urban soils.

Building Material

Soils in urban areas are more often the recipients of excavated and dredged materials than the source of those materials. Some areas do have large deposits of sand or gravel that can easily mined and transported to other areas. The pits left behind when quarries in urban areas are closed are sometimes used for water-based recreation or are refilled with other material, such as garbage or road debris.

Fill material can be natural soil (derived locally or moved onsite), waste (e.g., coal ash, dredged spoil, and construction debris), or a mixture of both (figure 5.14). Soils in urban areas may have cultural artifacts (garbage), construction debris, and various waste products.

Figure 5.14: A filled area excavated for a home foundation.

Soil material is sometimes made on a site by mixing manufactured materials with natural materials from various sources as both of the materials are moved around by heavy construction equipment. This process may result in hardpans or compacted layers that impede foundation drainage under extensive fill material added for home construction. The potential problems associated with disturbed urban soils include a scarcity of organic material for plant nutrition and biological soil-building reactions, the presence of artifacts that damage construction equipment or release contaminants, and significant variability between soil layers. The variability between the soil layers affects water movement and the stability of the soil under weight.

Materials That Allow Water To Infiltrate

Urban renewal may include removing old culverts and pipes and thus restoring a natural stream, as in a park with trees and picnic areas. Restoration of stream corridors for recreation, flood control, and wildlife may require rebuilding of streambanks with such material as rock or gabions (rock baskets, as shown in figure 5.15) that can withstand the erosive force of floodwater (FISRWG, 1998). Pavement may be removed from parking lots near the reconstructed stream so that more water can infiltrate into the soil and thus raise the stream level. Porous building materials may be added to the surface of streets (figure 5.16), parking lots, or sloping areas that require greater stability. The porous materials permit water to move into the soil instead of running off the site. Also, plants growing through the materials help to control erosion (figure 5.17).

Figure 5.15: Rock baskets.

Figure 5.16: Brick street in an historic district.

Figure 5.17: Soil surfaces may be covered with products that provide strength for slope stability and still allow water to infiltrate and plants to grow.

Open Space in Planned Developments

Planting beds may be constructed in parking lots, around playgrounds, and near nature trails to allow a wider variety of plants to flourish with frequent watering and intensive fertilizing. Urban planning can combine housing and open space needs for a community through consideration of the soil resources of the larger urban area (figures 5.18 and 5.19).

Figure 5.18: Aerial view of planned development.

Figure 5.19: A subdivision.

Building suburban houses on slight or moderate slopes and establishing lawns minimize erosion. The houses generally have gutters that channel runoff from roofs into storm drains. Very little space is left between houses, but larger lawn areas are in the backyards, where mowing and fertilizing can be coordinated among suburban owners. The soils around the houses should be characterized by good infiltration. They should slope away from the foundation, so that basements are not flooded. A level soil with moderate infiltration and good drainage is desirable in areas near swimming pools and play structures.

Reclaiming Contaminated Sites and Vacant Lots

In the more densely populated urban areas, a vacant lot may be the only site available for recreation and gardening. This restriction forces residents to use soils that may be compacted and contaminated or filled with unknown materials. Reclaimed mine areas provide land for urban housing and recreation after soil reconstruction measures are applied for water movement, structural stability, and plant growth. Raised bed gardens built with composted leaves and grass provide a plant rooting space of minimal risk to children and adults in many urban areas (figure 5.20).

Figure 5.20: A raised bed garden.

Chapter 6: Soils Preserve Natural and Cultural History

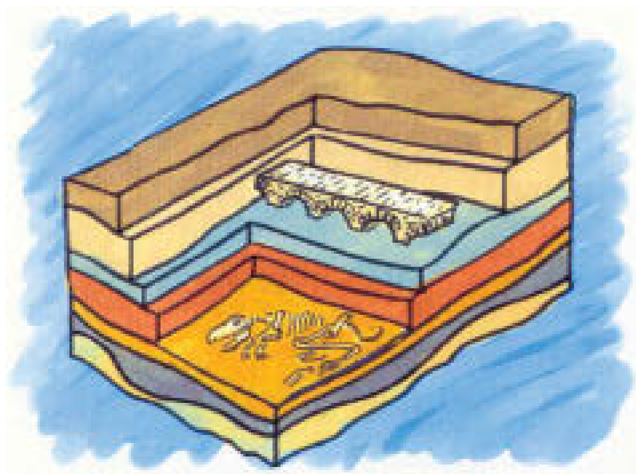

Figure 6.1

Soils can tell us much about our past. They are derived from a variety of parent materials and are transported by wind, water, ice, gravity, or humans. Soil material has been transported to its present location over very long to very short periods of time. What occurs in or under a soil can indicate how old a buried soil layer is and even how it got to its present location. For example, glaciers from the Canadian ice sheets moved down into the northern part of the United States about 12,000 to 15,000 years ago. Rocks otherwise found only in Canada are within the soils impacted by these glacial events. Soils can be dated by the plant pollen or artifacts within them. Layers of garbage or dredge material also can indicate the age of the soils. In addition, they help to preserve artifacts of culture and history.

Topics in this chapter:

- **Urban site preparation**
- **Intentional burial**
- **Catastrophic events**

Urban Site Preparation

When most sites for urban projects are prepared, soil excavation is required to allow the construction of building foundations, roads, and streets and to shape the lot for construction activities. Excavations vary in depth and size, depending on the building project. Very deep excavations are required when skyscrapers or other large buildings are constructed or when roads and streets are built on strongly sloping land. As soil material is removed by excavation, objects that have been buried, either by natural processes or by humans, are sometimes uncovered and must be dealt with before construction begins.

The objects that are discovered in the soils during excavation may have been accidentally lost, intentionally discarded or buried, or buried by catastrophic events. Coins and jewelry are examples of the buried items that are discovered. Old dumps, hazardous materials, fossils, or artifacts of past civilizations also may be exposed during site preparation.

Intentional Burial

Landfills and garbage dumps are examples of intentional burial sites (figure 6.2). Construction debris, garbage, and other items are often placed in dumps or low-lying areas and then covered by soil or dredge materials. Operators of most landfills are required to cover each layer of garbage with a layer of soil on a daily basis. When old landfills are discovered during project excavations, the content may appear to be a stack of debris and soil in layers. In the past, old dumpsites and burial areas were not marked on maps. Radioactive materials or carcinogens may have been buried in some areas before landfill regulations were in place. These areas can be avoided if their location is known, but the location is not always known. The buried materials can be very dangerous when exposed during construction activities. If areas such as these are discovered on a homesite or building lot, the discovery should be reported to the proper authorities.

Figure 6.2: Bulldozers working in a landfill.

Liquid materials, such as oil and oil products, pesticides, and other pollutants also have been placed in landfills and garbage dumps. These materials are in various kinds of containers that eventually corrode, degrade, and begin to leak (figure 6.3). The pollutants may leak into the ground water or out onto the surface in areas downslope from the landfill or dumpsite. In our Nation's past, dumpsites in many rural areas were unregulated. Toxic or hazardous waste material was deposited on these sites along with household garbage. As towns and cities grow and expand, these sites are often uncovered and must be cleaned up before use.

Small towns or a few buildings are sometimes intentionally covered by water impounded by large dams. Over time, sediment that settles out of the water buries the buildings and streets. The dam may be filled with sediment and abandoned. If the site is later used for another purpose, the buildings and debris material may be exposed during site preparation.

Figure 6.3: Barrels containing hazardous material.

Current technology helps us to design safe dumps and landfills. Liners made of impervious materials are now used under garbage and waste materials in dumps to contain the waste materials and keep the by-products of decomposition from leaving the site and leaking into ground water. Cover material placed on top of the garbage can keep odors and hazardous gases from escaping into the atmosphere. Most dumps now require permits. Strict monitoring helps to ensure that hazardous material is not deposited in the dumps. When dumps and landfills are closed, monitoring plans require that the sites be checked on a regular basis.

Catastrophic Events

Catastrophic events, such as earthquakes, volcanoes, landslides, dust storms, and large floods, bury objects unintentionally (figures 6.4, 6.5, and 6.6). An object discovered during urban development is sometimes a surprise. The exposed objects may be skeletons of prehistoric plants and animals, old buildings, human artifacts from earlier civilizations, footprints, leaf imprints, or even pollutants and contaminants that were buried during past disposal activities. Some project sites must be altered when pollutants or contaminants are exposed during excavation. On other sites, changes in project and/or construction plans are needed because of artifacts or hazardous materials uncovered during construction.

Figure 6.4: Human artifacts buried by windblown dust.

Soil horizons are important time markers and are used to help date items discovered when sites for urban projects are excavated. Newspaper articles tell of human and animal bones that were disturbed during excavations in urban areas. In some areas excavation is stopped until the bones can be identified so that the remains of members of ancient civilizations are not disturbed prior to study and cataloging. When the conditions and soil properties are right, buried artifacts and remains are well preserved for long periods of time. Not all kinds of soil, however, preserve artifacts and plant and animal remains. Some soils are so acid that they dissolve the buried materials. In some areas of wet soils, organisms living in the water consume the buried materials as food.

Figure 6.5: Animal skeletons buried by volcanic ash.

Figure 6.6: 1994 landslide (USGS photo).

Locating existing information about a site before site preparation begins can save the owner a great deal of time and expense. Soil survey reports commonly provide information about historic sites and past land use activities as well as information about soils. Soil survey information regarding slope stability, restrictive layers in the soils, and water transmission rates can help builders and landowners to avoid problems and save money. The costs of repairing, rebuilding, or relocating structures can be avoided, and the life expectancy of projects can be enhanced.

Chapter 7: Soil Management for Recreation and Renewal

Many cities and towns maintain botanical gardens or arboretums for use by their citizens and visitors. Some of these gardens and arboretums are very well known and draw people from all over the United States and the world. Some are used for large gatherings of people celebrating special community or holiday events. Unmanaged use of parks, gardens, and arboretums can cause damage to plants and severe soil compaction, which restricts the movement of water into the soil. The result is increased soil erosion, poor plant vigor and growth, increased runoff and offsite sedimentation, and renovation costs.

The most common kinds of urban parks and gardens are meditation gardens, rooftop gardens, rain gardens, butterfly gardens, outdoor classrooms, desert gardens, kitchen gardens, victory gardens, pocket parks, riverfront parks, green space, open space, medicine circles, labyrinths, and peace parks (figures 7.1, 7.2, 7.3, 7.4, and 7.5). The kinds of plants in these areas vary because of differences in soil properties. Additions of special types of nutrients (plant foods or soil conditioners) to the soil or containers in which the plants can grow may be needed.

Figure 7.1: Butterfly garden at an elementary school.

Schoolyards are ideal spots for building butterfly gardens and outdoor classrooms. These areas can also serve as small neighborhood parks. The soil and site history in the areas can show whether contamination is likely and whether protective measures are needed to minimize exposure. Soil testing is needed before the projects begin.

Applications of basic environmental science in urban areas can quickly become complicated and may require special contributions from scientists in many fields. A garden site surrounded by buildings may be hotter and drier than expected because rainwater is channeled in roof gutters and street drains away from the site, nearby concrete walls and streets stay hot longer, and the buildings cut off breezes. In some parts of the country, the added heat can extend the short growing season for

Figure 7.2: An urban pocket park under development.

Figure 7.3: A developed urban pocket park.

Figure 7.4: An urban riverfront park.

Figure 7.5: Intensively managed ballfields after soil reconstruction.

vegetables, but in the warmer regions, it can make a garden site undesirable for some plants.

Careful planning of lawns and picnic areas is needed because of the possibility of heavy foot traffic during wet periods. Urban parks commonly have a combination of paved areas and manufactured soils that can withstand trampling.

Conversion of a vacant lot into a ballfield or picnic area may be delayed if the site was used in the past as a garbage dump. Soil contamination, bad smells, uneven ground surfaces, and other problems may be caused by buried garbage that is slowly decomposing. Some former landfills provide space for parks and ballfields, but they must be carefully planned and managed for intensive use by many people in variable weather.

A few basic soil management practices can help to maintain existing parks or reclaimed recreation areas over time. A soil-based site management plan might include ways to balance water content and movement. Compost leaves and grass add organic materials and thus increase the supply of plant nutrients. Also, they help to maintain soil porosity and thus reduce the likelihood of compaction. In general, gardens and parks in urban areas require careful initial site selection followed by intensive maintenance of the vegetation in lawns and landscaped areas. A soil scientist may need to dig a pit so that the soil properties that affect management can be investigated (figures 7.6 and 7.7).

Figure 7.6: A backhoe used for digging a soil pit.

Figure 7.7: Human artifacts buried in a soil pit.

Schools, parks and recreation departments, and garden centers often employ people with training in soils and landscaping. Many recreation areas and parks are heavily used for more than one purpose throughout the year (figure 7.8). Maintenance plans are needed in these areas. These plans can be used as templates for planning smaller pocket parks and gardens that comply with local regulations.

Figure 7.8: High school playing fields are used for sports and for band and music competitions or performances.

Chapter 8: Help Is Nearby

Many of the conservation practices used in agricultural and forested areas can be adapted to work in urban areas or small towns. The Backyard Conservation Program of the Natural Resources Conservation Service (NRCS) helps urban people to plan, establish, and maintain simple waterways and plantings around homes, schools, and small parks. Team-building skills across disciplines, among generations, and among cultural groups are essential for successful urban conservation programs. These skills have been combined with the science behind NRCS field-office conservation planning. The Backyard Conservation Program has improved the ability of NRCS to serve customers using ecosystem concepts in urban areas.

Topics in this chapter:

- **Soil surveys in urban areas**
- **Naming soil series and soil map units**
- **Help in evaluating your soil and urban site**

Soil Surveys in Urban Areas

The program responsible for mapping all soils in the United States is called the National Cooperative Soil Survey (NCSS). It has been ongoing for more than 100 years. The NCSS is a partnership that combines the resources of Federal agencies, including the Natural Resources Conservation Service (NRCS), the U.S. Forest Service (USFS), the National Park Service (NPS), and the Bureau of Land Management (BLM), and the resources of State and local agencies and universities. In the earliest years of the soil survey program, soil surveys were focused on lands that were or could be important for agriculture. At that time, urban areas were broadly mapped or sometimes even ignored as soil surveys were completed.

The NCSS program has nearly completed the initial mapping of all nonurban land within the Nation and is now turning its attention to updating and maintaining existing soil survey data, to mapping lands managed by certain Federal and State agencies, and to mapping urban areas. Some urban areas have already been mapped, while others are just beginning soil surveys. Table 8.1 lists several completed and published

Table 8.1: Examples of Soil Surveys in Urban Areas

Soil Survey of the San Diego Area, California, 1973
Soil Survey of Suffolk County (Long Island), New York, 1975
Soil Survey of Washington, District of Columbia, 1976
Soil Survey of St. Louis County and St. Louis City, Missouri, 1982
Soil Survey of Charlotte County, Florida, 1984
Soil Survey of Cumberland and Hoke Counties, North Carolina, 1984
Soil Survey of Montgomery County, Maryland, 1985
Soil Survey of Nassau County (Long Island), New York, 1987
Soil Survey of South LaTourette Park, Staten Island, New York,1997
Soil Survey of Baltimore City, Maryland, 1998

soil surveys of urban areas. Soil survey activities currently are either planned or underway in several other urban areas.

Mapping urban areas can be difficult because the present land use restricts the access to sites needed for observation of soil profiles and because land use can quickly change. Observing the soils in these areas is difficult because impervious layers of concrete and asphalt are commonly on the surface and because most people do not want holes dug in their yards or gardens.

An urban soil classification scheme based mostly on the use or intended use of the soils could be developed. Urban soils can be investigated for commercial, residential, industrial, and greenbelt uses. For a satisfactory design of each use, there are key soil properties that must be known and understood. The NCSS program maps and classifies soils according to National standards and collects soil property data to be used in developing soil interpretations helpful in wise land use planning.

The emphasis on mapping urban areas results from the increasing size and density of the urban areas, a more environmentally aware clientele, the fact that nearly all rural areas have already been mapped once, and the need for more and better land resource data within and adjacent to urban areas.

NCSS soil survey information is useful for general planning activities. Because of the map scale, however, this information is not adequate for most site-specific activities. Most activities in urban areas are site specific, apply to areas of land smaller than those generally shown on soil maps, and involve highly intensive uses. Site-specific examinations are needed to provide the accurate and detailed data needed for most urban projects.

Naming Soil Series and Soil Map Units

Table 8.2 lists some soil series in urban areas and the type of material in the upper part of the soils and in the underlying substratum. Each soil that is mapped in the NCSS program is given a name that distinguishes it from other soils. Each has a set of chemical and physical soil properties that are different from those of other soils. Groups of soils having profiles that are almost alike, except for differences in the

Table 8.2: Examples of Urban Soil Series

Series	Survey area	Depth and type of surface fill	Substratum
Harvester	St. Louis, MO	12-40" fill or reworked loess	< 20% glass, brick
Fishpot	St. Louis, MO	up to 48" fill or reworked loess	< 20% glass, brick
Matlacha	Charlotte Co., FL	35" dredge spoil	natural sand
St. Augustine	Charlotte Co., FL	30" dredge spoil	natural sand
Bragg	Cumberland and Hoke Cos., NC	20-81" sandy clay loam fill	buried loamy sand
Greatkills	Staten Island, NY	7-24" mod. coarse texture	garbage
Canarsie	Staten Island, NY	10-39" mod. coarse texture	dense glacial till
Foresthills	Staten Island, NY	10-39" mod. coarse texture	buried soil
Greenbelt	Staten Island, NY	40-80" mod. coarse texture	same fill
Centralpark	Staten Island, NY	40-80" very gravelly material	same fill

texture of the surface layer, are called soil series. For example, the soils of one series may have bedrock or a layer of garbage at a depth of 24 inches, while the soils of another series may have bedrock or a layer of garbage at a depth of 75 inches. Other soil series are separated on the basis of chemical properties or, more often, on the basis of a combination of physical and chemical properties. Soils usually are named by the soil scientists who map them. Most are named after landmarks, geographic areas, rivers, mountain peaks, cities, or towns. Examples are the Centralpark series (named after Central Park in New York City) and the Seattle series (named after Seattle, Washington). In a few instances, the names are simply made up.

Urban soils form in different types of human-deposited material, including a) loamy fill over natural sand, b) dredged spoil, c) coal ash, and d) construction debris (figures 8.1a, 8.1b, 8.1c, and 8.1d).

Nonsoil areas are given such names as Rock outcrop, Urban land, Dumps, Water, and Rubble land. Urban land is defined as areas with a specific percentage of pavement, driveways, and buildings (impervious cover). Collectively, nonsoil areas are classified as miscellaneous areas.

Soils are mapped either as a single soil series or a group of soil series and/or miscellaneous areas. For example, one group could be mapped as "Urban land-Charlton complex, 2 to 8 percent slopes." A single soil map unit could be mapped as "Seattle loam, 1 to 3 percent slopes." The end of this soil name ("2 to 8 percent slopes") is an example of additional information called "soil phase" criteria. Soil phase criteria may be related to such characteristics as slope, texture of the surface layer (e.g., loam), and flooding.

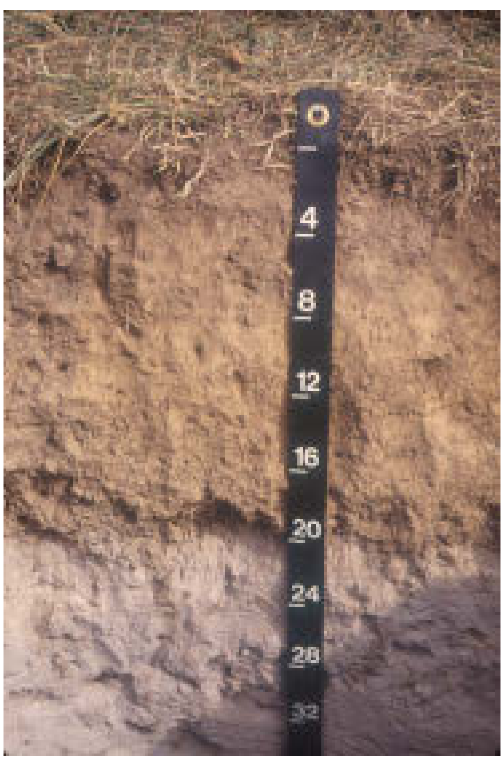

Figure 8.1a: Profile of a Verrazano soil, which formed in loamy fill over natural sand.

Figure 8.1b: Profile of a Big Apple soil, which formed in dredged spoil.

Figure 8.1c: Profile of a Riker soil, which formed in coal ash.

Figure 8.1d: Profile of an Inwood soil, which formed in construction debris.

Soil maps are usually made with aerial photographs as the background. Figure 8.2 is an example of a soil map of a dominantly urban area. By carefully examining the background aerial photograph, one can observe the streets and buildings of the urban area. The light blue areas are lakes or reservoirs. The soils delineated on the map have been separated from one another by black lines. Every delineation on the map has a set of letters that identifies the map unit. Examples of these map symbols are Ur, Urb, UpC, and CrC. The list of map unit symbols and map unit names is called a legend. The legend is very important because it can be used as a link to information or data about the map units. Those who need soil information must have the soil map, the legend, and the soil data or interpretations to make effective use of the soil information in planning onsite investigations for specific projects at the proper scale.

Help Evaluating in Your Soil and Urban Site

Local resource information can be obtained from soil scientists, professional gardeners or garden clubs, science teachers, city planners and planning boards, Master Gardeners, landscape contractors, private soil consultants, and local people with expertise gained through work on schools, outdoor worship areas, and parks. A field tour that involves a combination of these experts can be an effective learning experience (figure 8.3).

Local resource specialists can better assist you when you know some of the vocabulary that applies to urban soils, such as the terms used in this primer. Questions about site planning, landscaping, composting, and urban waste management may lead to a search of city laws and regulations including scientific terms. Management intended to reduce the risk to human health may require micro-engineering for urban sites and selection of certain plants that can grow well on the sites.

Urban Soils

- Uf, Urban land
- UhB, Urban land-Charlton complex, 2 to 8 percent slopes
- UlC, Urban land-Charlton-Chatfield complex, rolling, very rocky
- UlD, Urban land-Charlton-Chatfield complex, hilly, very rocky
- UpB, Urban land-Paxton complex, 2 to 8 percent slopes
- UpC, Urban land-Paxton complex, 8 to 15 percent slopes
- UrB, Urban land-Ridgebury complex, 1 to 8 percent slopes
- UvB, Urban land-Riverhead complex, 2 to 8 percent slopes
- UwB, Urban land-Woodbridge complex, 2 to 8 percent slopes

Nonurban Soils

- CrC, Charlton-Chatfield complex, rolling, very rocky
- Ff, Fluvaquents-Udifluvents complex, frequently flooded
- RdB, Ridgebury loam, 3 to 8 percent slopes
- Ub, Udorthents, smoothed

- Water

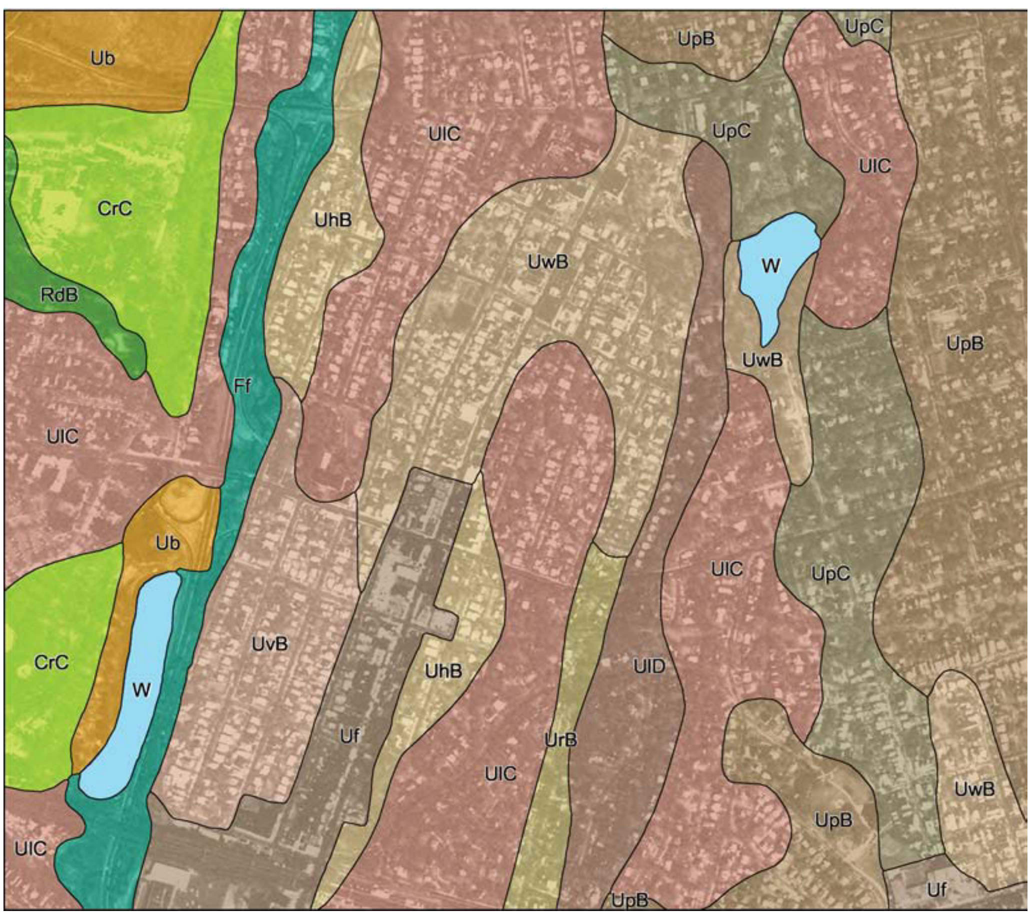

Figure 8.2: A map of dominantly urban soils.

Figure 8.3: A stop on a field tour of soils in Central Park, New York City.

The local Cooperative Extension Service provides brochures explaining how you can collect samples for soil testing and can help you to locate the nearest public university offering soil fertility tests at a low cost. The Cooperative Extension Service also trains Master Gardeners, local volunteers who can help you to manage garden plants and related insects and diseases (figure 8.4).

Figure 8.4: Adult working in a community garden plot.

The Urban Soil Quality Card includes some basic soil tests that you can perform before you plant a garden or vegetation in a park. The card was developed in Connecticut by local community groups with assistance from NRCS soil scientists and community planners. It is designed to be printed and used as written or with changes that you make to help you evaluate your specific site. It is available on the Internet (http://soils.usda.gov/sqi/soil_quality/assessment/cardguide.html).

Other sources of local soil expertise and assistance are youth program leaders and handbooks from organizations, such as Girl Scouts, Boy Scouts, 4H Clubs, Envirothon teams, the Science Bowl, school science fairs, the National Science Teacher’s Association, the Future Farmers of America, and Vocational Agriculture Curriculum (figures 8.5, 8.6, and 8.7). Many of these resources are listed under the heading “References and Resources” in this primer.

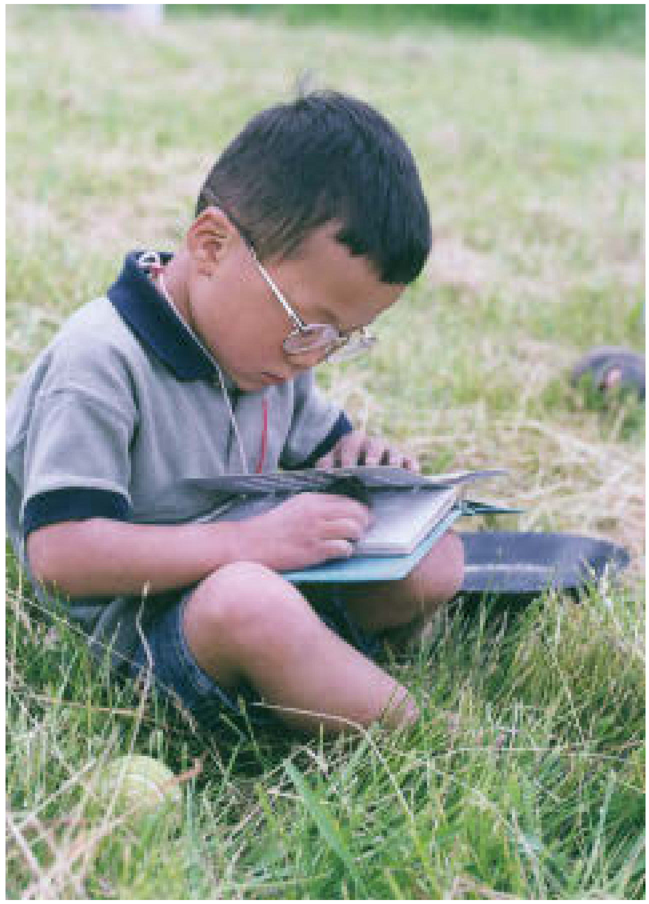

Figure 8.5: A boy with a soil color book.

Figure 8.6: Boys and girls testing soil.

Figure 8.7: Preliminary examination of soil in a backyard.

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Glossary

Aggregate, soil. Many fine particles held in a single mass or cluster. Natural soil aggregates, such as granules, blocks, or prisms, are called peds. Clods are aggregates produced by tillage or logging.

Bedrock. The solid rock that underlies the soil and other unconsolidated material or that is exposed at the surface.

Catena. A sequence, or "chain," of soils on a landscape that formed in similar kinds of parent material but have different characteristics as a result of differences in relief and drainage.

Cation. An ion carrying a positive charge of electricity. The common soil cations are calcium, potassium, magnesium, sodium, and hydrogen.

Cation-exchange capacity. The total amount of exchangeable cations that can be held by the soil, expressed in terms of milliequivalents per 100 grams of soil at neutrality (pH 7.0) or at some other stated pH value.

Clay. As a soil separate, the mineral soil particles less than 0.002 millimeter in diameter. As a soil textural class, soil material that is 40 percent or more clay, less than 45 percent sand, and less than 40 percent silt.

Compaction. Creation of dense soil layers when the soil is subject to the heavy weight of machinery or foot traffic, especially during wet periods.

Composting. Managing the decomposition of organic materials, such as leaves, grass, and garden waste.

Container gardens. Gardens planted in pots, concrete boxes, brick or stone basins, or other isolated rooting areas within paved areas.

Contaminated soil. A soil that has high concentrations of trace metals or organic waste that is toxic or a high risk to people or animals.

Drainage class (natural). Refers to the frequency and duration of wet periods under conditions similar to those under which the soil formed. Alterations of the water regime by human activities are not a consideration unless they have significantly changed the morphology of the soil. Seven classes of natural soil drainage are recognized—*excessively drained, somewhat excessively drained, well drained, moderately well drained, somewhat poorly drained, poorly drained,* and *very poorly drained*.

Drainage, surface. Runoff, or surface flow of water, from an area.

Erosion. The wearing away of the land surface by water, wind, ice, or other geologic agents and by such processes as gravitational creep.

Erosion (geologic). Erosion caused by geologic processes acting over long geologic periods and resulting in the wearing away of mountains and the building up of such landscape features as flood plains and coastal plains. Synonym: natural erosion.

Erosion (accelerated). Erosion much more rapid than geologic erosion, mainly as a result of human or animal activities or of a catastrophe in nature, such as a fire, that exposes the surface.

Fertility, soil. The quality that enables a soil to provide plant nutrients, in adequate amounts and in proper balance, for the growth of specified plants when light, moisture, temperature, tilth, and other growth factors are favorable.

Gravel. Rounded or angular fragments of rock as much as 3 inches (2 millimeters to 7.6 centimeters) in diameter. An individual piece is a pebble.

Hard bedrock. Bedrock that cannot be excavated except by blasting or by the use of special equipment that is not commonly used in construction.

Heat islands. Small areas of artificially drained urban soils surrounded by tall buildings that change soil temperature and moisture patterns. May also refer to an entire city with an artificial microclimate.

Horizon, soil. A layer of soil, approximately parallel to the surface, having distinct characteristics produced by soil-forming processes. In the identification of soil horizons, an uppercase letter represents the major horizons. Numbers or lowercase letters that follow represent subdivisions of the major horizons. The major horizons of mineral soil are as follows:

O horizon.—An organic layer of fresh and decaying plant residue.

A horizon.—The mineral horizon at or near the surface in which an accumulation of humified organic matter is mixed with the mineral material. Also, a plowed surface horizon, most of which was originally part of a B horizon.

E horizon.—The mineral horizon in which the main feature is loss of silicate clay, iron, aluminum, or some combination of these.

B horizon.—The mineral horizon below an A horizon. The B horizon is in part a layer of transition from the overlying A to the underlying C horizon. The B horizon also has distinctive characteristics, such as (1) accumulation of clay, sesquioxides, humus, or a combination of these; (2) prismatic or blocky structure; (3) redder or browner colors than those in the A horizon; or (4) a combination of these.

C horizon.—The mineral horizon or layer, excluding indurated bedrock, that is little affected by soil-forming processes and does not have the properties typical of the overlying soil material. The material of a C horizon may be either like or unlike that in which the solum formed. If the material is known to differ from that in the solum, an Arabic numeral, commonly a 2, precedes the letter C.

Cr horizon.—Soft, consolidated bedrock beneath the soil.

R layer.—Consolidated bedrock beneath the soil. The bedrock commonly underlies a C horizon, but it can be directly below an A or a B horizon.

Humus. The well decomposed, more or less stable part of the organic matter in mineral soils.

Hydrologic soil groups. Refers to soils grouped according to their runoff potential. The soil properties that influence this potential are those that affect the minimum rate of water infiltration on a bare soil during periods after prolonged wetting when the soil is not frozen. These properties are depth to a seasonal high water table, the infiltration rate and permeability after prolonged wetting, and depth to a very slowly permeable layer. The slope and the kind of plant cover are not considered but are separate factors in predicting runoff.

Hydrologic unit or watershed. In urban areas, a catchment area with an outlet in or affecting a densely populated area.

Impervious soil. A soil through which water, air, or roots penetrate slowly or not at all. No soil is absolutely impervious to air and water all the time.

Infiltration. The downward entry of water into the immediate surface of soil or other material, as contrasted with percolation, which is movement of water through soil layers or material.

Landslide. The rapid downhill movement of a mass of soil and loose rock, generally when wet or saturated. The speed and distance of movement, as well as the amount of soil and rock material, vary greatly.

Leaching. The removal of soluble material from soil or other material by percolating water.

Loam. Soil material that is 7 to 27 percent clay particles, 28 to 50 percent silt particles, and less than 52 percent sand particles.

Low strength. The soil is not strong enough to support loads.
Nutrient, plant. Any element taken in by a plant essential to its growth. Plant nutrients are mainly nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, iron, manganese, copper, boron, and zinc obtained from the soil and carbon, hydrogen, and oxygen obtained from the air and water.
Organic matter. Plant and animal residue in the soil in various stages of decomposition.
Parent material. The unconsolidated organic and mineral material in which soil forms.
Percolation. The movement of water through the soil.
Permeability. The quality of the soil that enables water or air to move downward through the profile. The rate at which a saturated soil transmits water is accepted as a measure of this quality. In soil physics, the rate is referred to as "saturated hydraulic conductivity."
pH value. A numerical designation of acidity and alkalinity in soil. (See Reaction, soil.)
Pocket park. A relatively small area reserved for recreation or gardening and surrounded by streets or buildings.
Profile, soil. A vertical section of the soil extending through all its horizons and into the parent material.
Raised bed gardens. Gardens that are planted in boxes made of wood or other materials and have the rooting area above the ground surface. The boxes may be filled with composted materials mixed with uncontaminated soil.
Reaction, soil. A measure of acidity or alkalinity of a soil, expressed in pH values. A soil that tests to pH 7.0 is described as precisely neutral in reaction because it is neither acid nor alkaline.
Relief. The elevations or inequalities of a land surface, considered collectively.
Restrictive layer. A compact, dense layer in a soil that impedes the movement of water and the growth of roots.
Runoff. The precipitation discharged into stream channels from an area. The water that flows off the surface of the land without sinking into the soil is called surface runoff. Water that enters the soil before reaching surface streams is called ground-water runoff or seepage flow from ground water.
Sand. As a soil separate, individual rock or mineral fragments from 0.05 millimeter to 2.0 millimeters in diameter. Most sand grains consist of quartz. As a soil textural class, a soil that is 85 percent or more sand and not more than 10 percent clay.
Sealed soil. Soil that is covered with buildings, pavement, asphalt, or other material. Water and air do not enter the soil from the surface.
Series, soil. A group of soils that have profiles that are almost alike, except for differences in texture of the surface layer. All the soils of a series have horizons that are similar in composition, thickness, and arrangement.
Shale. Sedimentary rock formed by the hardening of a clay deposit.
Shrink-swell potential. The potential for volume change in a soil with a loss or gain in moisture. Volume change occurs mainly because of the interaction of clay minerals with water and varies with the amount and type of clay minerals in the soil. The size of the load on the soil and the magnitude of the change in soil moisture content influence the amount of swelling of soils in place. Shrinking and swelling can damage roads, dams, building foundations, and other structures. It can also damage plant roots.
Silt. As a soil separate, individual mineral particles that range in diameter from the upper limit of clay (0.002 millimeter) to the lower limit of very fine sand (0.05 millimeter). As a soil textural class, soil that is 80 percent or more silt and less than 12 percent clay.
Sinkhole. A depression in the landscape where limestone has been dissolved or lava tubes have collapsed.

Slope. The inclination of the land surface from the horizontal. Percentage of slope is the vertical distance divided by horizontal distance, then multiplied by 100. Thus, a slope of 20 percent is a drop of 20 feet in 100 feet of horizontal distance.

Soft bedrock. Bedrock that can be excavated with trenching machines, backhoes, small rippers, and other equipment commonly used in construction.

Soil-forming factors. Five factors responsible for the formation of the soil from the unconsolidated parent material. The factors are time, climate, parent material, living organisms (including humans), and relief.

Structure, soil. The arrangement of primary soil particles into compound particles or aggregates. The principal forms of soil structure are platy, prismatic, columnar, blocky, and granular. Structureless soils are either single grained or massive.

Texture, soil. The relative proportions of sand, silt, and clay particles in a mass of soil. The basic textural classes, in order of increasing proportion of fine particles, are *sand, loamy sand, sandy loam, loam, silt loam, silt, sandy clay loam, clay loam, silty clay loam, sandy clay, silty clay,* and *clay*. The sand, loamy sand, and sandy loam classes may be further divided by specifying “coarse,” “fine,” or “very fine.”

Topographic maps (USGS). Maps that show terrain, ridges, waterways, contours, elevations, and geographic locations. Also may show roads and buildings.

Trace elements. Chemical elements, for example, zinc, cobalt, manganese, copper, and iron, in soils in extremely small amounts. They are essential to plant growth.

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General Properties of Soil

- Approximately half solids and half pore (non-solid or open) space

- Solids are composed of particles of differing sizes
  - Sand (2.0-0.05 mm diameter)
  - Silt (0.05-0.002 mm diameter)
  - Clay (<0.002 mm diameter)

General Properties of Soil

- Soil water (referred to as 'soil solution') contains dissolved acids, bases, salts and other substances including:
  - Products of soil weathering
  - Atmospheric inputs
  - By-products of plant and animal metabolism
  - Non-natural substances added by man
  - Plant nutrients

General Properties of Soil

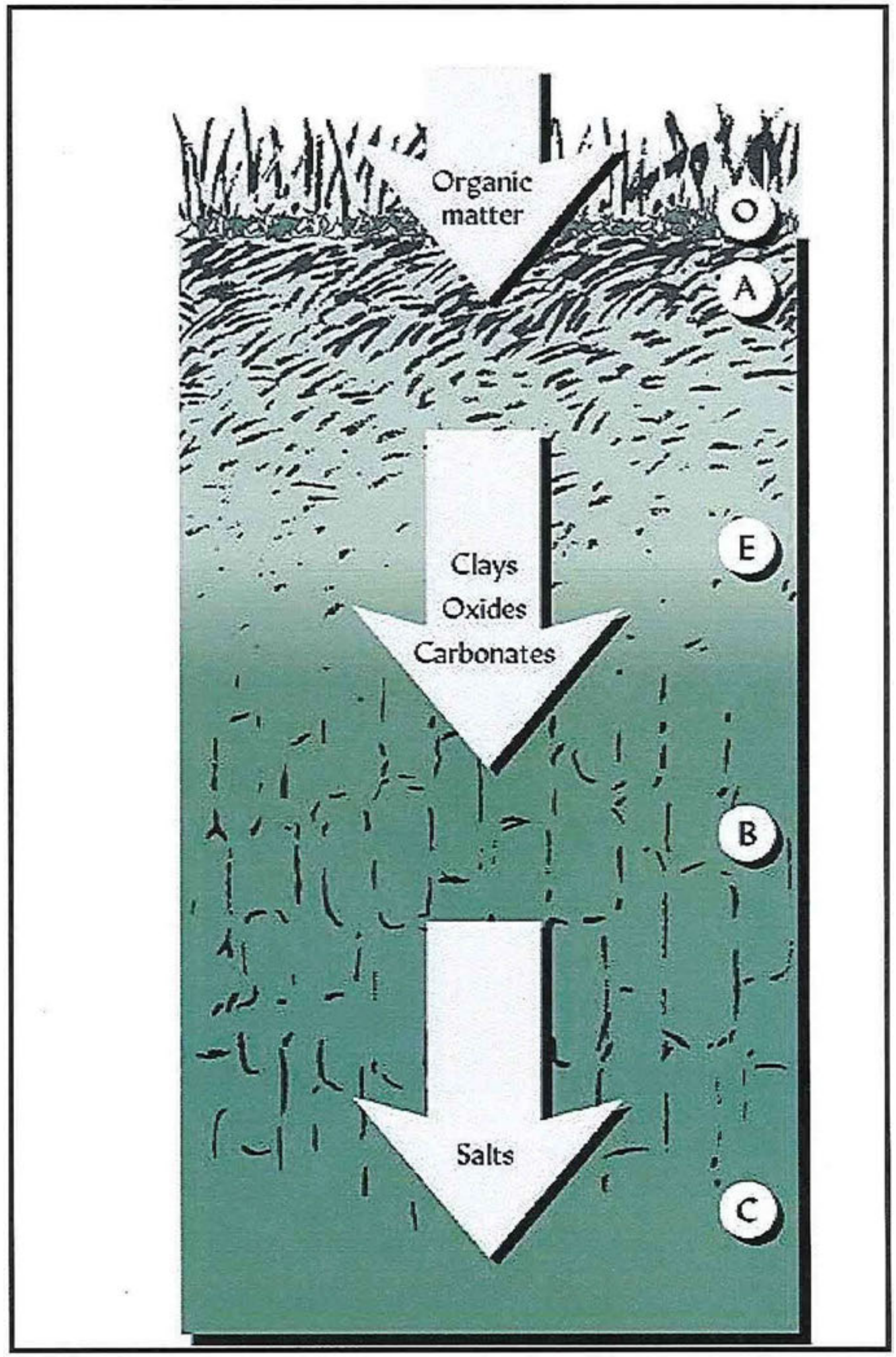
- Soil are usually layered bodies, featuring horizons (the layers)
- The horizons together make up the soil profile
- Soils vary across the landscape, sometimes over very short distances
- Soils vary greatly in their suitability for various land uses

Differences in drainage and topography indicated by light and dark soil areas

Soil as a Natural Body

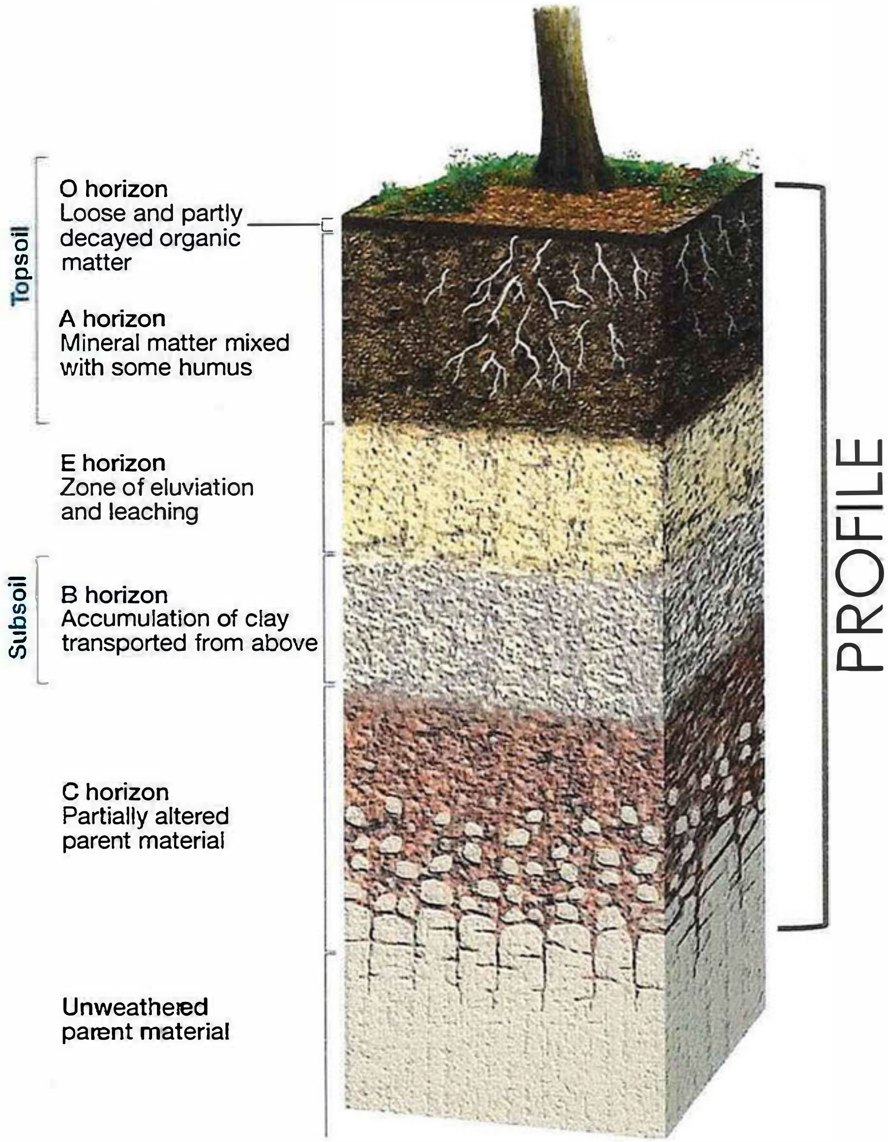
- Three-dimensional natural body
- Forms in the upper part of the regolith (unconsolidated layer of decayed and crumbled rock at the earth's surface)
- Product of destructive and creative (synthetic) processes
- Soil horizons - develop as upper part of the regolith becomes differentiated

Soil horizons begin to differentiate as materials are added to the upper part of the regolith and other materials are translocated to deeper zones.

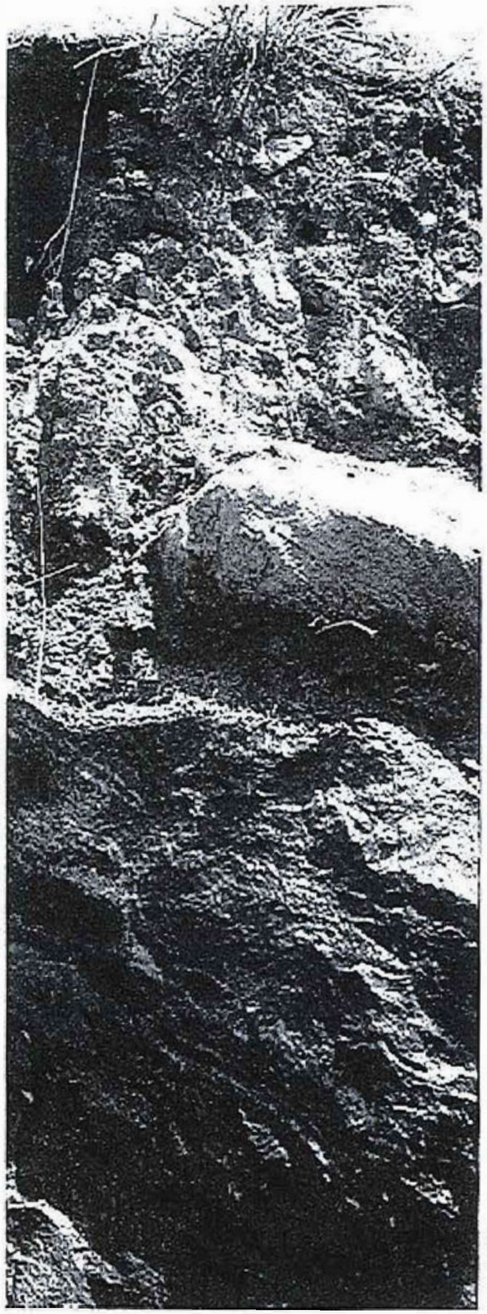


The Soil Profile and Horizons

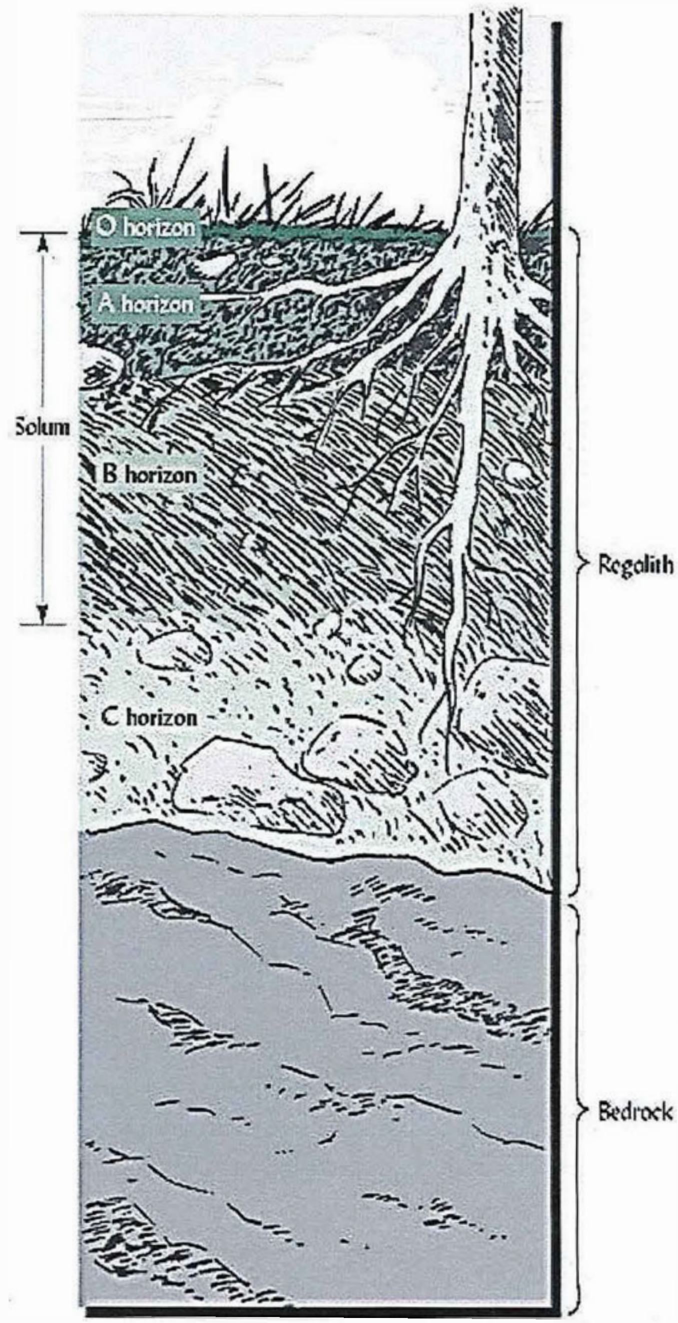
- A set of soil horizons (or layers) exposed in a vertical section (like a road cut) is called a soil profile
- Horizons form from the influences of air, water, solar radiation, and plant material on the upper portion of the regolith.
- Horizons are designated O, A, E, B, C or R



A soil profile includes the sum of all the soil layers



Relative positions of the regolith, soil horizons and the underlying bedrock



The Soil Profile (cont.)

- Horizon designations (letters) indicate something unique about the horizon or layer
  - O -- Organic layer, at the surface
  - A -- Mineral layer, darkened by organic matter, at the surface
  - E -- below A (sometimes), materials removed or leached

The Soil Profile (cont.)

- B -- horizon of accumulation of material from above (clays, iron/aluminum oxides, calcium carbonate or gypsum)

- C -- least weathered or altered horizon

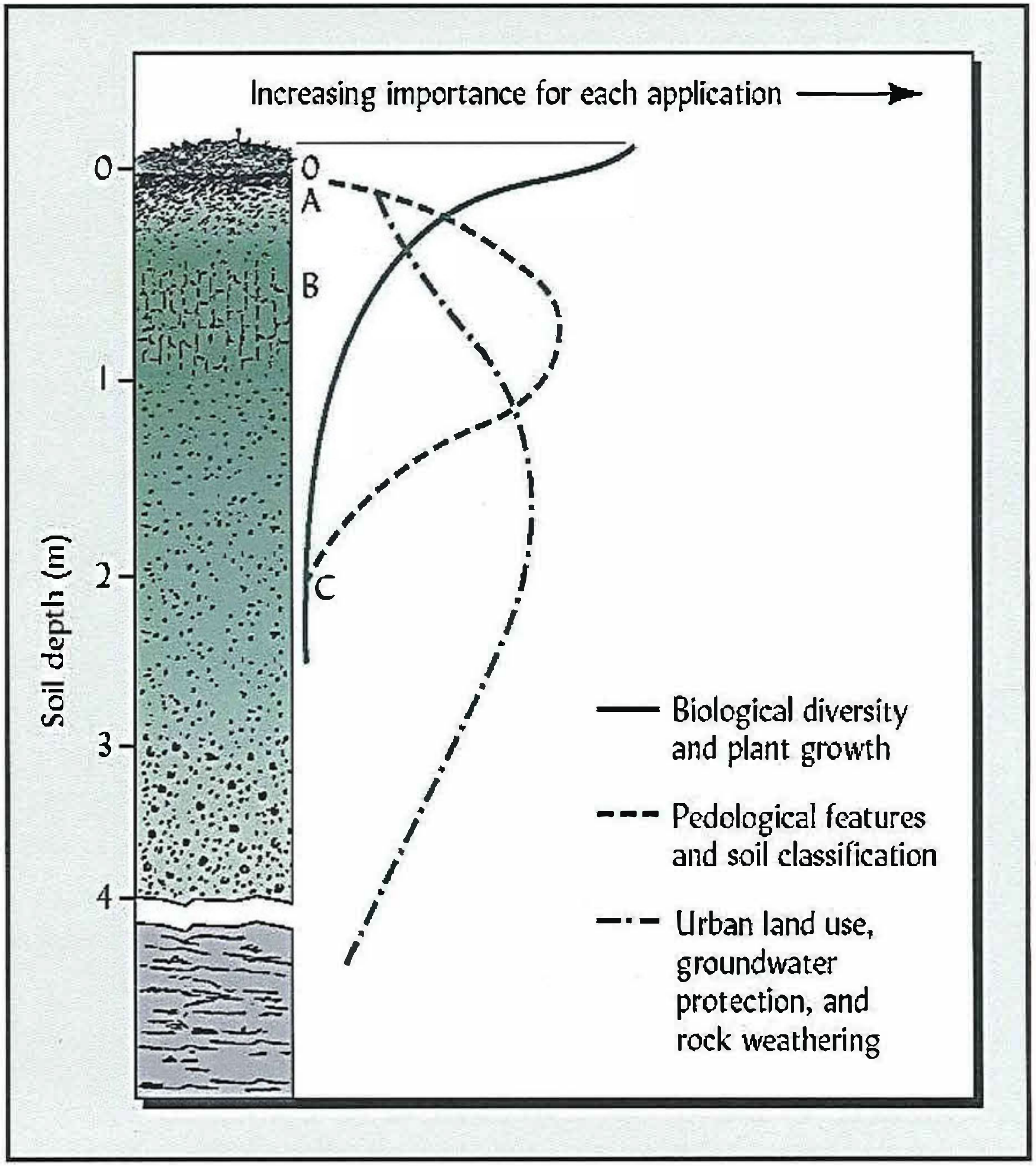
- R -- Bedrock

The Soil Profile (cont.)

- Topsoil (usually about 12 - 18 cm thick)
  - Surface soil, often analogous to A horizon
  - easily altered by erosion or mgmt practices
  - Major source of plant nutrients
  - Zone of root development

- Subsoil (all layers below topsoil)
  - Comprised of E, B, C horizons
  - Subsoil characteristics have greatest impact on land use
  - Management decisions based on subsoil characteristics

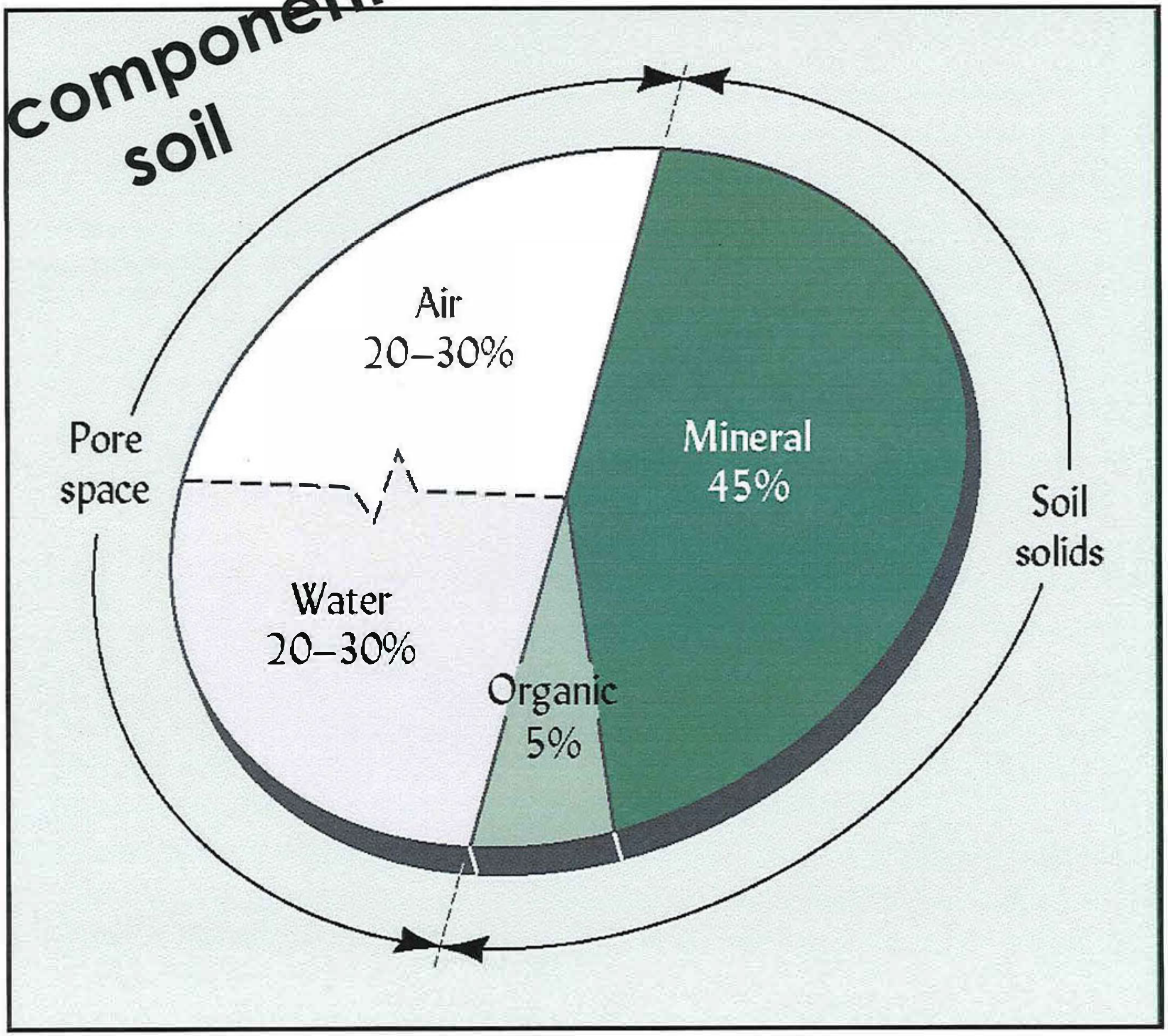
Information relevant to different soil functions and applications can be obtained by studying different layers of the soil profile



4 Major Components of Soil

- Air
- Water
- Mineral matter
- Organic materials

Major components of soil



The "Ideal" Soil - Loam

- By volume, a loam has approximately
  - 45% mineral matter (sand, silt, clay particles)
  - 5% organic matter
  - 50% pore space
    - Pores are filled with 20-30% mixture of air and water

- Considered "ideal" for <u>plant growth purposes</u>

Mineral Component of Soil

- Sand (2.0-0.05 mm diameter)
  - can be seen with eye
  - feel gritty and nonsticky when wet
  - composed of primary minerals
- Silt (0.05-0.002 mm diameter)
  - too small to be seen with eye
  - feel smooth and non-sticky when wet
  - composed of primary & secondary minerals

Mineral Component of Soil

- Clay (<0.002 mm diameter)
  - smallest particle, need electron microscope to see
  - sticky when wet
  - high surface area per unit mass
  - charged surface attracts water, other ions
  - controls physical and chemical activity of the soil

Primary and Secondary Minerals

- Primary Minerals
  - Little change in composition from original
    - Quartz, micas
- Secondary Minerals
  - Formed from further breakdown of primary minerals
  - Continues as soil formation progresses
    - Silicate clays, iron oxides

Soil Organic Matter Component

- Consists of transformed remains of plants, animals and microorganisms
- 1-6% by weight in most soils
- Helps hold water in the soil
- Major source of P, S, and N plant nutrients
- Humus: organic compounds resistant to decay; charged surfaces, attracts other ions and water molecules (like clay)

Soil Water Component

- Called "soil solution" due to dissolved substances present
- Functions as medium by which plant nutrients are brought into contact with roots
- Not all soil water is available to plants
- Soil solution determines soil acidity or alkalinity (pH = conc. of H^+ or OH^- ions)

Soil Air Component

- Composition varies from place to place
- Higher moisture content than atmosphere
- Higher carbon dioxide and lower oxygen content than atmosphere
- Inverse relationship with water content

Introduction

Soil (Pedosphere)

Soils are one of Earth's essential natural resources, yet they are often taken for granted. Most people do not realize that soils are a living, breathing world supporting nearly all terrestrial life. Soils and the functions they play within an ecosystem vary greatly from one location to another as a result of many factors, including differences in climate, the animal and plant life living on them, the soil's parent material, the position of the soil on the landscape, and the age of the soil.

Scientists, engineers, farmers, developers and other professionals consider a soil's physical and chemical characteristics, moisture content and temperature to make decisions such as:

- Where is the best place to build a building?
- What types of crops will grow best in a particular field?
- Will the basement of a house flood when it rains?
- How can the quality of the groundwater in the area be improved?

Using the data collected in the *GLOBE Soil (Pedosphere) Investigation*, students help scientists describe soils and understand how they function. They determine how soils change and the ways they affect other parts of the ecosystem, such as the climate, vegetation, and hydrology. Information about soils is integrated with data from the other GLOBE protocol investigations to gain a better view of Earth as a system.

Why Investigate Soils?

Soils develop on top of Earth's land surface as a thin layer, known as the *pedosphere*. This thin layer is a precious natural resource and so deeply affects every part of the ecosystem that it is often called the "great integrator." For example, soils hold nutrients and water for plants and animals. They filter and clean water that passes through them. They can change the chemistry of water and the amount that recharges the groundwater or returns to the atmosphere to form rain. The foods we eat and most of the materials we use for paper, buildings, and clothing are dependent on soils. Soils play an important role in the amount and types of gases in the atmosphere. They store and transfer heat, affect the temperature of the atmosphere, and control the activities of plants and other organisms living in the soil. By studying these functions that soils play, students and scientists learn to interpret a site's climate, geology, vegetation, hydrology, and human history. They begin to understand soil as an important component of every land ecosystem on Earth and of the Earth System as a whole.

Scientists Need GLOBE Data

The data students collect through the GLOBE soil measurements are invaluable to scientists in many fields. For example, Soil scientists use the data to better understand how soils form, how they should be managed, and what their potential is for plant growth and other land use. Hydrologists use the data to determine water movement through a soil and a watershed and the effect of soils on water chemistry. They also examine the effects of different types of soil on the sedimentation in rivers and lakes. Meteorologists and climatologists use soil data in weather and climate prediction models. Atmospheric scientists want to know the effect of soils on humidity, temperature, reflected light, and fluxes of gases such as CO_2 and methane. Biologists examine the properties of soil to understand its potential for supporting plant and animal life. Anthropologists study the soil in order to reconstruct the human history of an area.

When data are available for many areas of the world, scientists study the spatial patterns of soil properties. When a full set of GLOBE atmosphere, hydrology, land cover and soils data exists at a specific site, scientists can use the information to run computer models to understand how the whole ecosystem functions and to make predictions about what the ecosystem will be like in the future.

The Big Picture

Soil Composition

Soils are composed of four main components:

- Mineral particles of different sizes.
- Organic materials from the remains of dead plants and animals.
- Water that fills open pore spaces.
- Air that fills open pore spaces.

The use and function of a soil depends on the amount of each component. For example, a good soil for growing agricultural plants has about 45% minerals, 5% *organic matter*, 25% air, and 25% water. Plants that live in wetlands require more water and less air. Soils used as raw material for bricks need to be completely free of organic matter.

The Five Soil Forming Factors

The properties of a soil are the result of the interaction between the *Five Soil Forming Factors*. These factors are:

1. *Parent Material:* The material from which the soil is formed determines many of its properties. The parent material of a soil may be bedrock, organic material, construction material, or loose soil material deposited by wind, water, glaciers, volcanoes, or moved down a slope by gravity.
2. *Climate:* Heat, rain, ice, snow, wind, sunshine, and other environmental forces break down parent material, move loose soil material, determine the animals and plants able to survive at a location, and affect the rates of soil forming processes and the resulting soil properties.
3. *Organisms:* The soil is home to large numbers of plants, animals, and microorganisms. The physical and chemical properties of a soil determine the type and number of organisms that can survive and thrive in that soil. Organisms also shape the soil they live in. For example, the growth of roots and the movement of animals and microorganisms shift materials and chemicals around in the soil profile. The dead remains of soil organisms become organic matter that enriches the soil with carbon and nutrients. Animals and microorganisms living in the soil control the rates of decomposition for organic and waste materials. Organisms in the soil contribute to the exchange of gases such as carbon dioxide, oxygen, and nitrogen between the soil and the atmosphere. They also help the soil filter impurities in water. Human actions transform the soil as well, as we farm, build, dam, dig, process, transport, and dispose of waste.
4. *Topography:* The location of a soil on a landscape also affects its formation and its resulting properties. For example, soils at the bottom of a hill will get more water than soils on the hillside, and soils on slopes that get direct sunlight will be drier than soils on slopes that do not.
5. *Time:* The amount of time that the other 4 factors listed above have been interacting with each other affects the properties of the soil. Some properties, such as temperature and moisture content, change quickly, often over minutes and hours. Others, such as mineral changes, occur very slowly over hundreds or thousands of years. Figure SOIL-I-1 lists different soil properties and the approximate time it takes for them to change.

Soil Profiles

The five soil-forming factors differ from place to place causing soil properties to vary from one location to another. Each area of soil on a landscape has unique characteristics. A vertical section at one location is called a *soil profile*. See Figure SOIL-I-2. When we look closely at the properties of a soil profile and consider the five soil forming factors, the story of the soil at that site and the formation of the area is revealed.

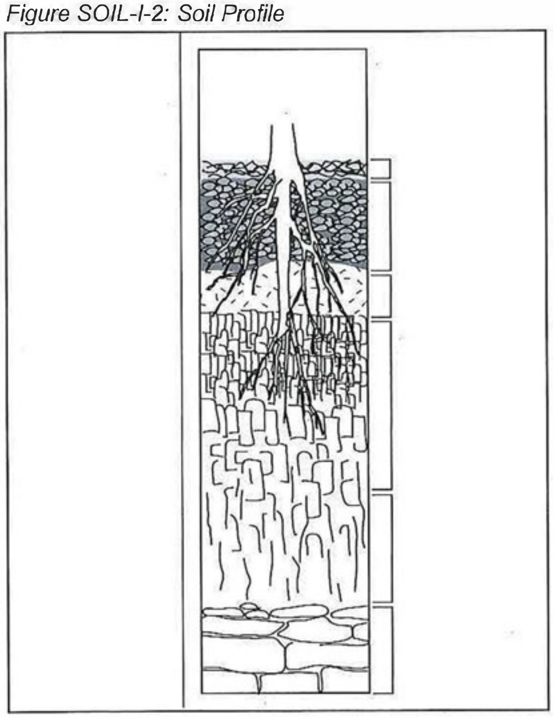
The chapters of the soil story at any location are read in the layers of the soil profile. These layers are known as *horizons*. Soil horizons can be as thin as a few millimeters or thicker than a meter. Individual horizons are identified by the properties they contain that are different from the horizons above and below them. Some soil horizons are formed as a result of the weathering of minerals and decomposition of organic materials that

Figure SOIL-I-1

Soil Properties That Change Over Time		
Properties that change over minutes or hours	**Properties that change over months or years**	**Properties that change over hundreds and thousands of years**
Temperature Moisture content Local composition of air	Soil pH Soil color Soil structure Bulk density Soil organic matter Soil fertility Microorganisms, animals, plants	Mineral content Particle size distribution Horizons Particle density

move down the soil profile over time. This movement, called *illuviation*, influences the horizon's composition and properties. Other horizons may be formed by the disturbance of the soil profile from erosion, deposition, or biological activity. Soils may also have been altered by human activity. For example, builders compact soil, change its composition, move soil from one location to another, or replace horizons in a different order from their original formation.

Figure SOIL-I-2: Soil Profile



Moisture in the Soil

Moisture plays a major role in the chemical, biological and physical activities that take place in the soil. Chemically, moisture transports substances through the profile. This affects soil properties such as color, texture, pH, and fertility. Biologically, moisture determines the types of plants that grow in the soil and affects the way the roots are distributed. For example, in desert areas where soils are dry, plants such as cacti must store water or send roots deep into the soil to tap water buried tens of meters below the surface. Plants in tropical regions have many of their roots near the surface where organic material stores much of the water and nutrients the plants need. Agricultural plants grow best in soils where water occupies approximately one-fourth of the soil volume as vapor or liquid. Physically, soil moisture is part of the hydrologic cycle. Water falls on the soil surface as precipitation. This water seeps down into the soil in a process called *infiltration*. After water infiltrates the soil, it is stored in the horizons, taken up by plants, moved upward by *evaporation*, or moved downward into the underlying bedrock to become *ground water*. The amount of moisture contained in a soil can change rapidly, sometimes increasing within minutes or hours. In contrast, it might take weeks or months for soils to dry out. If a soil horizon is compacted, has very small pore spaces, or is *saturated* with water, infiltration will occur slowly, increasing the potential for flooding in an area. If the water cannot move down into the soil fast enough, it will flow over the surface as *runoff* and may rapidly end up in streams or other water bodies. When the soil is not covered by vegetation and the slope of the land is steep, *water erosion* occurs. Deep scars are formed in the landscape as a result of the combined force of the runoff water and soil particles flowing over the surface. When a soil horizon is dry, or has large pore spaces that are similar in size to the horizon above, water will infiltrate the horizon quickly. If the soil gets too dry and is not covered by vegetation, *wind erosion* may occur.

The surface layer of soil is in direct content with the atmosphere and moisture entering or leaving the soil passes through this layer. Except in hyper arid conditions, the only soil property that can be measured from satellites is the moisture in the top 5 cm. NASA has flown the Soil Moisture Active Passive (SMAP) mission to measure this environmental property. Calibration and validation of SMAP data need in situ measurements of surface soil moisture, and GLOBE and SMAP have partnered to obtain these data from GLOBE participants.

Soil Temperature

The temperature of a soil can change quickly. Near the surface, it changes almost as quickly as the air temperature changes, but because soil is denser than air, its temperature variations are less. Daily and annual cycles of soil temperature can be measured. During a typical day, the soil is cool in the morning, warms during the afternoon, and then cools down again at night. See Figure SOIL-I-3. Over the course of the year, the soil warms up or cools down with the seasons. Because soil temperature changes more slowly than air temperature, it acts as an insulator, protecting soil organisms and buried pipes from the extremes of air temperature variations. In temperate regions, the surface soil may freeze in winter and thaw in the spring, while in some colder climates, a permanent layer of ice, called *permafrost*, is found below the soil surface. In either case, the ground never freezes below a certain depth. The overlying soil acts as insulation so that the temperature of the deeper layers of soil is almost constant throughout the year. Temperature greatly affects the chemical and biological activity in the soil. Generally, the warmer the soil, the greater the biological activity of microorganisms living in the soil. Microorganisms in warm tropical soils break down organic materials much faster than microorganisms in cold climate soils. Near the surface, the temperature and moisture of the soil affect the atmosphere as heat and water vapor are exchanged between the land and the air. These effects are smaller than those at the surfaces of oceans, seas, and large lakes, but can significantly influence local weather conditions. Hurricanes have been found to intensify when they pass over soil that is saturated with water. Meteorologists have found that their forecasts can be improved if they factor soil temperature and moisture into their calculations.

Soils Around the World

Following are examples of six different soil profiles and landscapes. See Figures SOIL-I-4 through I-9.

Figure SOIL-I-3

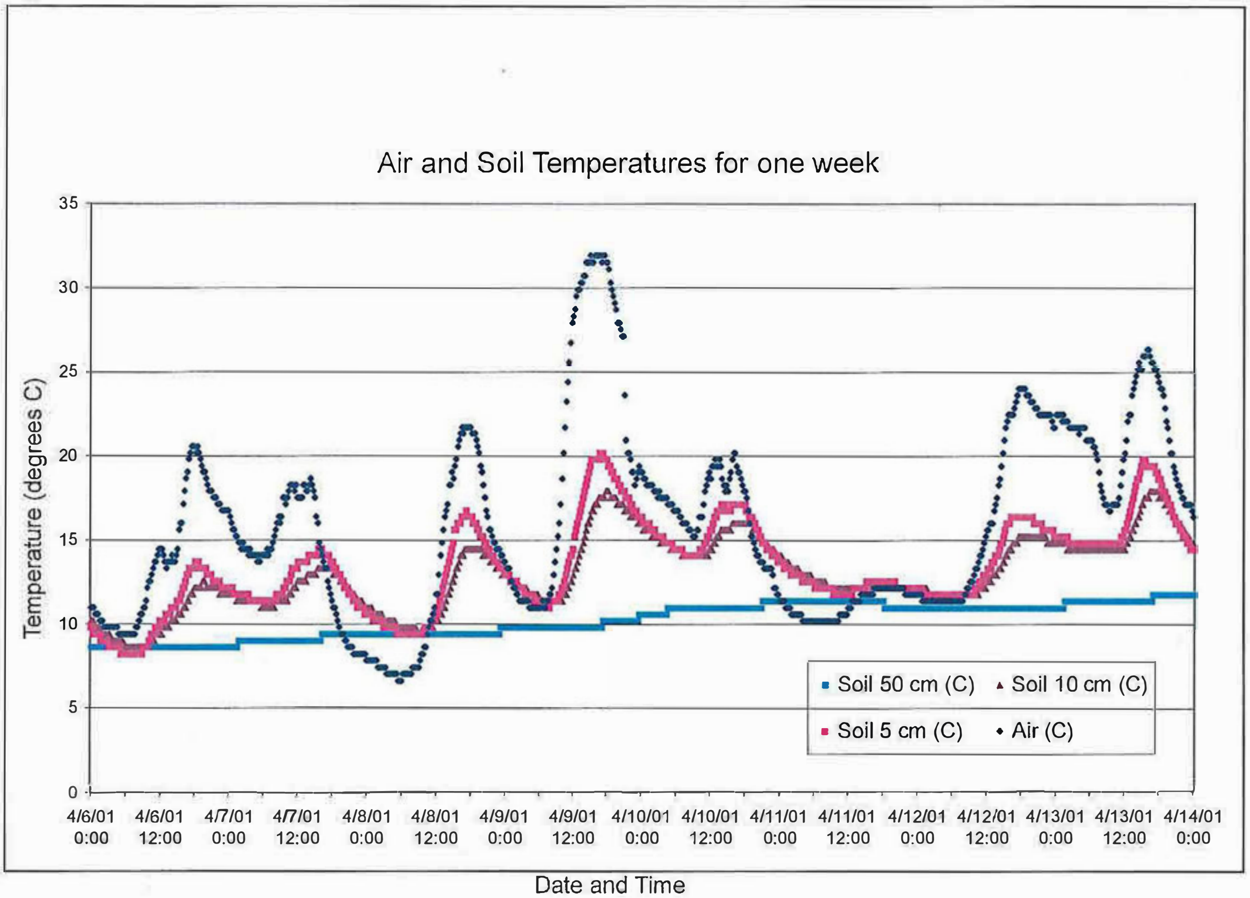
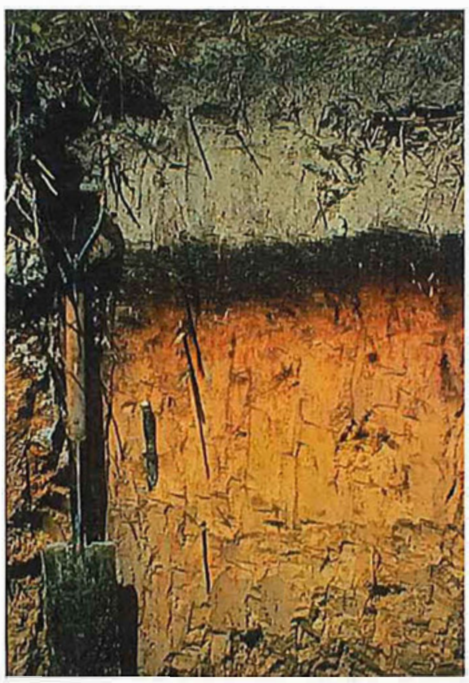


Figure SOIL-I-4: Grassland soils sampled in the southern part of Texas in the USA

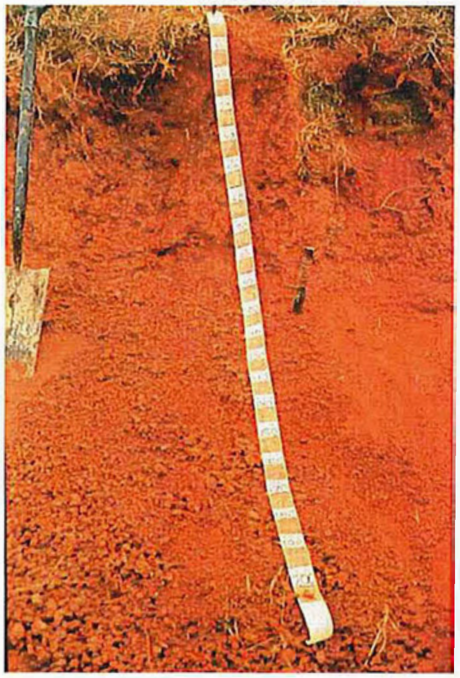
These soils are common in the mid-western USA, and in the grasslands of Argentina and Ukraine. They are usually deep and dark in color, and are among the best soils for growing crops. Their dark color is caused by many years of grass roots dying, decomposing, and building up the organic matter content that allows the soil to hold the water and nutrients needed for excellent plant growth.

Figure SOIL-I-5: Soil formed under a forest in far eastern Russia, near the city of Magadan



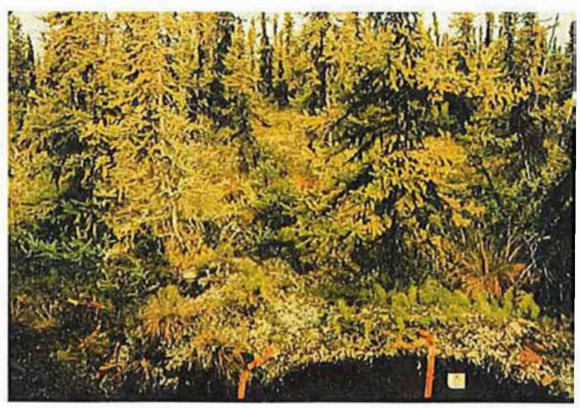
Most of the organic matter in this soil comes from the leaves and roots of coniferous trees that die and decompose near the surface. When this decomposed organic matter mixes with rain, acids form that *leach*, or remove, materials from the top horizons of the soil. The white layer you see below the dark surface layer was caused by organic acids that removed the nutrients, organics, clays, iron, and other materials in the layer and left behind soil particles that are only mineral in composition. Below this horizon is a dark horizon that contains materials that were leached from the horizon above and deposited or illuviated. This horizon has a dark color because of the organic matter deposited there. The next horizon has a red color due to iron oxide brought in from the horizon above and coating the soil particles. The horizon below this one has fewer or different types of iron oxides coating the inorganic soil particles creating a yellow color. The lowest horizon in the profile is the original parent material from which the soil formed. At this site, the parent material is a sandy deposit from glaciers. At one time, the whole soil looked like this bottom horizon, but over time, soil-forming processes changed its properties.

Figure SOIL-I-6: A tropical environment in Northern Queensland, Australia



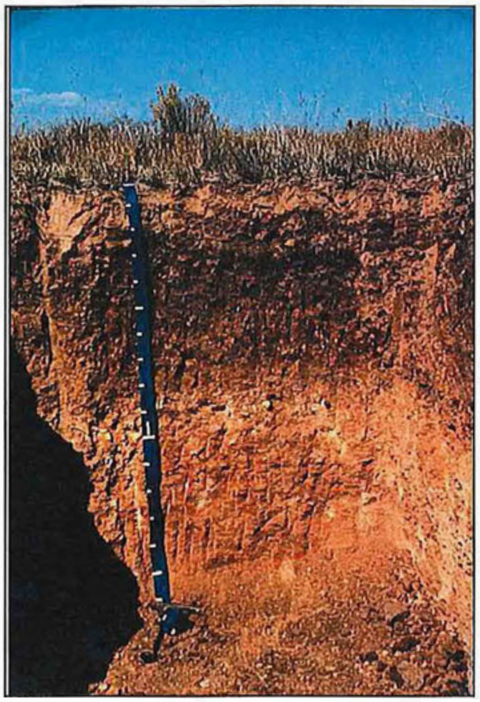
Notice the bright red colors and the depth to which the soil is uniform. It is very difficult to distinguish unique horizons. Hot temperatures and lots of rain help to form weathered soils like this. In tropical climates, organic matter decomposes very quickly and transforms into inactive material that binds with clay. Most of the nutrients have been leached from this soil by intense rainfall. Left behind are weathered minerals coated by iron oxides giving the soil its bright red color.

Figure SOIL-I-7: Soil formed under a very cold climate near Inuvik in the Northwest Territory of Canada



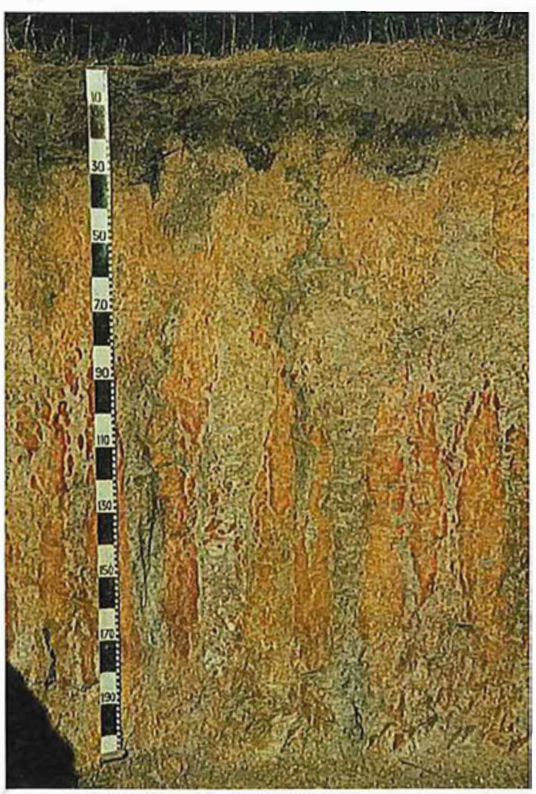
The "hummocky" or wavy surface of this soil is caused by freezing and thawing of water stored in the soil year after year. The black zones indicate places where organic materials have accumulated during freezing and thawing cycles. The process of freezing and thawing and churning of the soil is called *cryoturbation*. This soil is not very developed and has only slight indications of horizons that can be seen by faint color differences. At the bottom of the profile is a layer called *permafrost*, which consists of ice, soil, or a mixture of both. The permafrost layer stays below 0°C throughout the year. The dark, thick organic material in this soil accumulates because decomposition is very slow in cold climates.

Figure SOIL-I-8: Soil formed under very dry or arid conditions in New Mexico, USA



A light brown horizon at the surface is often found in environments where organic matter is limited. High amounts of organic matter form dark soils. In dry places, organic matter is not returned to the soil because very little vegetation grows there. When rainfall does occur in this environment, the sandy texture of the soils allow materials to be carried downward into the lower horizons of the profile. The white streaks near the bottom of this profile are formed from deposits of calcium carbonate that can become very hard as they accumulate over time.

Figure SOIL-I-9: Wet soil sampled in Louisiana, USA



Wet soils are found in many parts of the world. The surface horizon is usually dark because organic matter accumulates when the soil is saturated with water. When these conditions occur, there is not enough oxygen for organisms to decompose the organic material. Colors of the lower horizon are usually grayish. Sometimes, as in this picture, the gray soil color has orange or brown streaks within it, which are called *mottles*. The gray colors indicate that the soil was wet for a long period of time, while the mottles show us where some oxygen was present in the soil.

Dr. John Kimble and Sharon Waltman of the USDA Natural Resources Conservation Service, National Soil Survey Center, Lincoln, Nebraska provided the photographs shown here.

GLOBE Measurements

What measurements are taken?

In the GLOBE Soil Investigation, two sets of soil measurements are made. The first set, known as Soil Characterization, describes the physical and chemical characteristics of each horizon in a soil profile. Some Soil Characterization measurements are carried out in the field, while others are done in a laboratory or classroom. Soil Characterization measurements are carried out one time for an identified site. The second set of measurements are Soil Moisture and Temperature, which determine the water and temperature properties of soil at specified depths. Soil moisture and temperature measurements are carried out repeatedly and can be directly compared with the air temperature and precipitation measurements that are described in the Atmosphere Investigation. Although these two sets of soil measurements are different, having both soil characterization and soil moisture at a given location provides the most amount of meaningful information. For example, differences in soil temperature and moisture between one site and another that have the same air temperature and precipitation may be due to differences in the soil characterization properties. Understanding the physical and chemical properties of the soil will help to interpret patterns in soil moisture and temperature.

Soil Characterization Measurements

Carried Out in the Field

- Site Description
- Horizon Depths
- Soil Structure
- Soil Color
- Soil Consistence
- Soil Texture
- Roots
- Rocks
- Carbonates

*Carried out in the Classroom or Lab**

- Bulk Density
- Particle Density
- Particle Size Distribution
- pH
- Soil Fertility (N, P, K)

Soil Moisture and Temperature Measurements

Carried out in the Field

- Soil Temperature
- Soil Moisture Monitoring

*Carried out in the Classroom or Lab**

- Gravimetric and Volumetric Soil Moisture

Individual Measurements

Soil Characterization

At a soil site, horizons in a soil profile are distinguished from one another by differences in their structure, color, consistence, texture, and the amount of roots, rocks, and free carbonates they contain. Laboratory or classroom analyses of bulk density, particle density, particle size distribution, pH, and soil fertility also reveal differences among horizons.

Structure

Structure refers to the natural shape of aggregates of soil particles, called peds, in the soil. The soil structure provides information about the size and shape of pore spaces in the soil through which water, heat, and air flow, and in which plant roots grow. Soil ped structure is described as *granular, blocky, prismatic, columnar,* or *platy.* If the soil lacks structure, it is described as either *single grained* or *massive.*

Color

The color of soil is determined by the chemical coatings on soil particles, the amount of organic matter in the soil, and the moisture content of the soil. For example, soil color tends to be darker when organic matter is present. Minerals, such as iron, can create shades of red and yellow on the surface of soil particles. Soil in dry areas may appear white due to coatings of calcium carbonate

* Lab measurements use samples collected in the field.

on the soil particles. Soil color is also affected by moisture content. The amount of moisture contained in the soil depends on how long the soil has been freely draining or whether it is saturated with water. Typically, the greater the moisture content of a soil, the darker its color.

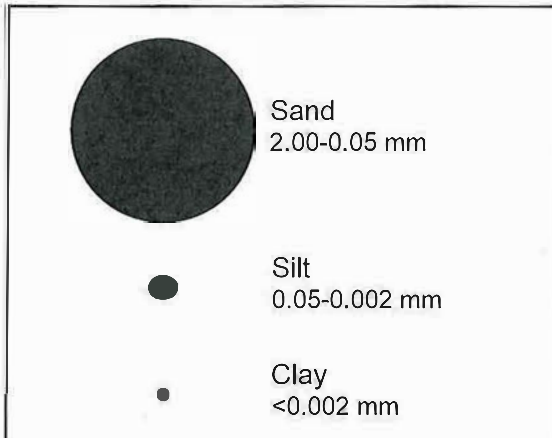
Consistence

Consistence describes the firmness of the individual peds and the degree to which they break apart. The terms used to describe soil consistence are *loose, friable, firm,* and *extremely firm*. A soil with friable consistence will be easier for roots, shovels, or plows to move through than a soil with a firm consistence.

Texture

The *texture* describes how a soil feels and is determined by the amounts of *sand, silt,* and *clay* particles present in the soil sample. The soil texture influences how much water, heat, and nutrients will be stored in the soil profile. Human hands are sensitive to the difference in size of soil particles. Sand is the largest particle size group, and feels gritty. Silt is the next particle size group, and feels smooth or *floury*. Clay is the smallest particle size group and feels sticky and is hard to squeeze. See Figure SOIL-I-10. The actual amount of sand, silt, and clay size particles in a soil sample is called the *particle size distribution* and is measured in a laboratory or classroom.

Figure SOIL-I-10: Particle Size Groups



Relative (not actual) size of sand, silt, and clay particles.

Roots

An estimate of the roots in each horizon in a soil profile illustrates the depth to which roots go to obtain nutrients and water. The more roots found in a horizon, the more water and nutrients being removed from the soil, and the more organic matter being returned. Knowing the amount of roots in each horizon allows scientists to estimate the soil's fertility, bulk density, water holding capacity, and its depth. For example, a very compact horizon will inhibit root development whereas a porous horizon will not.

Rocks

An estimate of the number of rocks in each horizon helps to understand the movement of water, heat, and air through the soil, root growth, and the amount of soil material involved in chemical and physical reactions.

Soil particles greater than 2 mm in size are considered to be rocks.

Carbonates

Carbonates of calcium or other elements accumulate in areas where there is little weathering from water. The presence of carbonates in soil may indicate a dry climate or a particular type of parent material rich in calcium, such as limestone. Free carbonates often coat soil particles in soils that are basic (i.e., pH greater than 7). These soils are common in arid or semi-arid climates. Carbonates are usually white in color and can be scratched easily with a fingernail. Sometimes in dry climates, carbonates form a hard and dense horizon similar to cement, and plant roots cannot grow through it. To test for carbonates, an acid, such as vinegar, is squirted on the soil. If carbonates are present, there will be a chemical reaction between the vinegar (an acid) and the carbonates (a base) to produce carbon dioxide. When carbon dioxide is produced, the vinegar bubbles or *effervesces*. The more carbonates present, the more bubbles or effervescence occurs.

Bulk Density

Soil bulk density is a measure of how tightly packed or dense the soil is and is measured by the mass of dry soil in a unit of volume (g/cm^3). See Figure SOIL-I-11. Soil bulk density depends on the composition of the soil, structure of the soil peds, the distribution of the sand, silt, and clay particles, the volume of pore space, and how tightly the particles are packed. Soils made of minerals (sand, silt, and clay) will have a different bulk density than soils made of organic material. In general, the bulk density of soils ranges from 0.5 g/cm^3 in soils with many spaces, to as high as 2.0 g/cm^3 or greater in very compact mineral horizons.

Knowing the bulk density of a soil is important for many reasons. Bulk density indicates how tightly soil particles are packed and the ease with which roots can grow through soil horizons. Bulk density is also used when converting between mass and volume for a soil sample. If the mass of a soil sample is known, its volume is calculated by dividing the sample mass by the bulk density of the soil. If the volume of a soil sample is known, the mass is calculated by multiplying the sample volume by the bulk density of the soil.

Particle Density

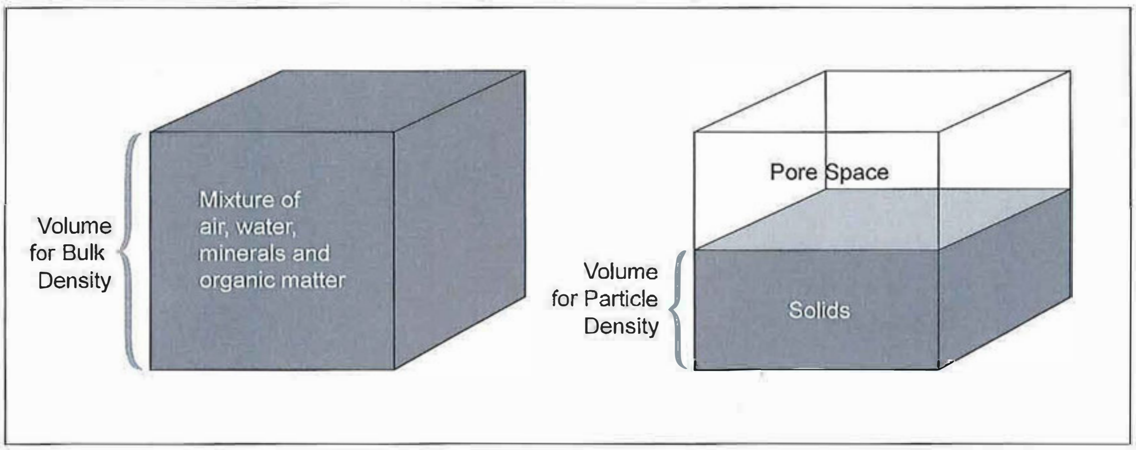
The *particle density* of a soil sample is the mass of dry soil in a particular volume of the soil when all of the air spaces have been removed. See Figure SOIL-I-11. The type of minerals the soil particles are made of affects the particle density. Soils consisting of pure quartz particles generally have a particle density of 2.65 g/cm^3. Soils consisting of particles made of minerals other than quartz will have a different mass for the same volume of particles. By knowing both the particle density and the bulk density, the *porosity* (the proportion of the soil volume that is pore space) can be calculated. Porosity establishes the amount of air or water that can be stored or moved through the soil.

Particle Size Distribution

The proportion of each particle size group (sand, silt, or clay) in the soil is called the soil *particle-size distribution*. Sand is the largest soil particle, silt is intermediate in size, and clay is the smallest. The particle-size distribution of a soil sample determines its exact textural class (which is "estimated" in the field by doing the Soil Texture Protocol). It also helps determine how much water, heat, and nutrients the soil will hold, how fast water and heat will move through the soil, and the structure and consistence of the soil.

The amount of sand, silt, and clay in a soil sample is determined by a settling method using an instrument called a *hydrometer*. A dried sample of soil is first dispersed so that none of the particles stick together, and then it is suspended in water and allowed to settle. The largest particles (sand) settle out in minutes while the smallest particles (clay) stay suspended for days. A hydrometer is used to measure the specific gravity of the soil suspension after settling has proceeded for specific amounts of time.

Figure SOIL-I-11: A Comparison of Bulk Density and Particle Density



Bulk density is a measure of the mass of all the solids in a unit volume of soil including all the pore space filled by air and water. If the volume were compressed so that there were no pore spaces left for air or water, the mass of the particles divided by the volume they occupy would be the particle density.

Soil pH

The *pH* of a soil horizon (how *acidic* or *basic* the soil is) is determined by the parent material from which the soil is formed, the chemical nature of the rain or other water entering the soil, land management practices, and the activities of organisms (plants, animals, and microorganisms) living in the soil. Just like the pH of water, the pH of soil is measured on a logarithmic scale (see the *Introduction* of the *Hydrology Investigation* for a description of pH). Soil pH is an indication of the soil's chemistry and fertility. The activity of the chemical substances in the soil affects the pH levels. Different plants grow at different pH values. Farmers sometimes add materials to the soil to change its pH depending on the types of plants they want to grow. The pH of the soil also affects the pH of ground water or nearby water bodies such as streams or lakes. Soil pH can be related to the water pH measured in the *Hydrology Investigation* and the precipitation pH measured in the *Atmosphere Investigation.*

Soil Fertility

The *fertility* of a soil is determined by the amount of nutrients it contains. Nitrogen (N), phosphorus (P), and potassium (K) are three of the most important nutrients needed by plants for optimum plant growth. Each horizon in a soil profile can be tested for the presence of these nutrients. The results of these measurements help to determine the suitability of a soil for growing plants. Soil fertility can be related to water chemistry measurements carried out in the *Hydrology Investigation.*

Soil Moisture

Soil moisture, also known as *Soil Water Content* (SWC), can be calculated by mass (gravimetric) or by volume (volumetric) and is presented as a ratio of water to soil. When measuring for gravimetric soil moisture, the ratio is of the mass of water contained in a soil sample to the mass of dry matter in that sample. This ratio typically ranges from 0.05 g/g to 0.50 g/g. When measuring volumetric soil moisture, the ratio is the volume of water contained in a volume of soil. The volumetric content of the soil can be as great as 0.5 cc/cc; the volume ratio typically ranges from 0.05 cc/cc to 0.50 cc/cc. Only extremely dry soils that retain a small amount of water, such as those in a desert, have values below 0.05 g/g (gravimetric) or 0.05 mL/mL (volumetric). Only organic-rich soils, peat or some clays absorb large amounts of water and have values above 0.50 g/g (gravimetric) or 0.05 mL/mL (volumetric). The soil moisture measurement helps to define the role of the soil storage in the dynamics of the ecosystem. For example, soil moisture measurements reveal the ability of the soil to hold or transmit water affecting groundwater recharge, surface runoff, and *transpiration* and evaporation of water into the atmosphere. It also describes the ability of the soil to provide nutrients and water to plants, affecting their growth and survival.

Soil Temperature

Soil acts as an insulator for heat flowing between the solid earth below the soil and the atmosphere. Thus, soil temperatures can be relatively cool in the summer or relatively warm in the winter. These soil temperature variations affect plant growth, the timing of bud-burst or leaf fall, and the rate of decomposition of organic materials.

Soil temperatures typically have a smaller daily range than air temperatures and deeper soil temperatures usually vary less. Soil temperature extremes range from 50° C for near-surface summer desert soils (warmer than the maximum air temperature!) to values below freezing in high latitude or high elevation soils in the winter.

Soil Study Site Selection

Soil study sites for carrying out soil characterization measurements and soil moisture and temperature measurements should be carefully selected.

For soil characterization measurements, a site should be considered that allows students to dig a hole with either a shovel or an auger. The purpose is to expose a soil profile that is one meter deep. If this is not possible, students have the option to sample the top 10 cm of the soil profile. It is important to check with local utility companies to be sure there are no pipes or wires buried at the site chosen for digging. A site that is chosen close to the site where soil moisture and temperature measurements are being made will help to understand these measurements better. A soil characterization site chosen near or in the Land Cover study site will help interpret the role that the soil properties play in controlling the type and amount of plant growth.

For soil moisture measurements, a site that is open should be considered. The site must not be irrigated, should have *uniform* soil characteristics, be relatively undisturbed, and be safe for digging. Soil moisture samples are collected from the surface (0-5 cm) and 10 cm depths. Samples may also be collected at depths of 30 cm, 60 cm, and 90 cm to obtain a depth profile. If possible, the site should be within 100 m of a GLOBE Atmosphere Study Site or other location where precipitation measurements are being collected.

For soil temperature measurements, a site should be selected that is adjacent to a GLOBE Atmosphere Study site, or some other location where air temperature measurements are taken. Alternatively, soil temperature can be measured at a soil moisture study site. The site should be in the open and representative of the soils in the area. Soil temperature measurements are made at depths of 5 and 10 cm with all protocols and also at 50 cm with monitoring protocols.

Site Description

After students have selected a site for their soil measurements, they use the following identifying factors to define and describe the location they plan to study: latitude and longitude (using GPS receivers), elevation, slope, aspect (the direction of the steepest slope), type of vegetation covering the soil, parent material, current land use practices, and the position of the soil on the landscape. The students determine some of these properties at the site, while other properties are established using local resources such as maps, soil survey reports, and local experts.

Frequency of Measurements

Soil characterization measurements should be carried out one time for each Soil Characterization Study Site. More than one study site can be used in order to identify soil properties at different locations (such as at the soil moisture and temperature sites, land cover site, or along different parts of the landscape for example).

To help understand the global picture of soil moisture, GLOBE has partnered with the NASA SMAP Mission. The priority is to build a time series of surface soil moisture data. Ideally samples are collected on mornings when SMAP flies over a site – 3 times every 8 days for most locations. Periodic data from 5 cm and 10 cm is useful in characterizing the seasonal and annual patterns of a site. If observations are taken for a limited time period, try to choose a time when soil is drying out or becoming wet.

Daily and continuous soil moisture data from sensors are broadly useful and not generally available.

Soil temperature measurements are carried out at least once each week. The *Digital Multi-Day Max/Min/Current Air and Soil Temperature Protocol* provides for daily measurement of the maximum and minimum soil temperatures from a depth of 10 cm. Optional protocols are available for measuring daily maximum and minimum soil temperatures at 5 cm and 50 cm depths and for collecting soil and air temperature every 15 minutes using a data logger.

Field Considerations

Many teachers find that their students take great pride and satisfaction in digging a soil pit to expose a soil profile. Occasionally, adult volunteers are needed to assist, or someone in the area with a backhoe can be asked to help out. When digging, all necessary precautions should be taken to avoid buried utilities. To keep the hole from being a hazard to both people and animals, the pit should be open only while students are conducting their observations. It should be kept well covered when the class is not working in it.

Managing Students

Depending on the size of the soil pit and the number of students, it might be possible to work on the pit as a class. In other cases, it is better to allow groups of 3-5 students into the pit at a time. There are many strategies for using multiple groups of students to collect data from different horizons or to collect duplicate samples. Teachers should expect the soil characterization measurements and sampling procedures to take several hours. Some teachers choose to carry out the measurements on repeated visits. Experts in Soil Science from local Universities, the USDA Natural Resources Conservation Service, and other agricultural agencies can provide assistance with digging, describing the site, and characterizing the soil.

Soil moisture samples should be collected from as large an area around a school as possible. For comparison to SMAP data 10+ sites within a 20 km radius is ideal. This allows all students (and parents) to participate. Teams of students and parents can work together to collect site descriptions, GPS coordinates, near-surface gravimetric samples, and any other GLOBE data that interests the class. Other groups of students can be responsible for weighing the wet soil as soon after sample collection as possible and then beginning the drying process. It might be useful to contact and work with soil scientists from local colleges, the USDA Natural Resource Conservation Service and other agencies to help dry samples. Generally, a team of two or three students is appropriate for taking soil moisture samples or manually reading soil moisture sensors.

Soil temperature readings from the digital max/min thermometer are taken along with air temperature readings at least once every 7 days. Temperature probe measurements are best made by small teams (2-3 students) on a daily or weekly schedule. One successful strategy is to have one experienced student helping a less experienced student, who later becomes the mentor to new team members. Data collection takes 10-20 minutes.

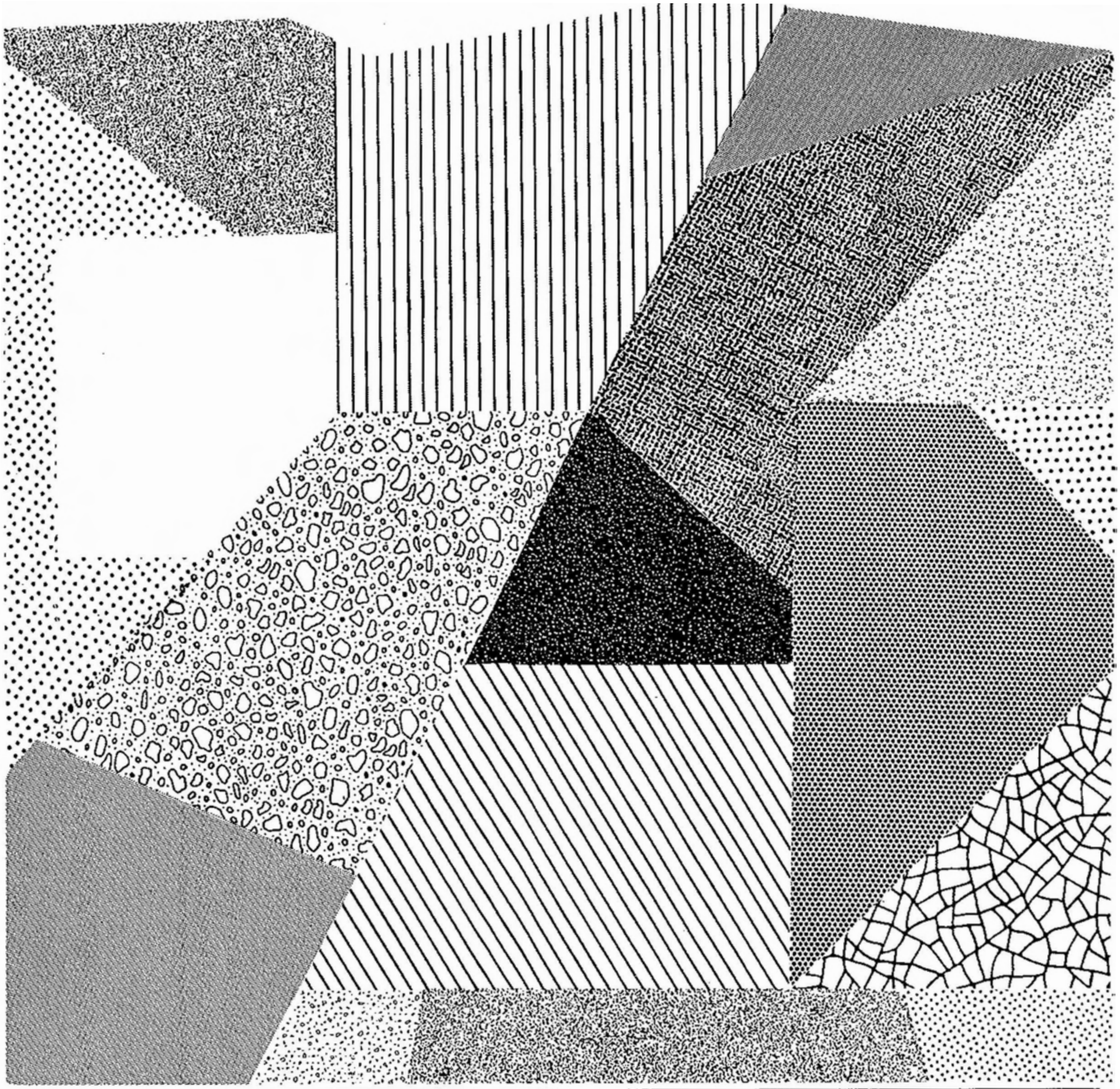
Combining the Measurements

In the GLOBE Soil Investigation, students study both the soil properties that change very slowly (soil characterization), and those that change rapidly (soil temperature and moisture). Without knowing the slowly changing properties of the soil profile, it is difficult to understand the dynamic moisture and temperature changes that occur. In the same way, the patterns in moisture and temperature in the soil over time, affect the formation of the soil. Teachers are encouraged to combine soil characterization measurements with soil temperature and moisture measurements so that students gain a true understanding of the way the pedosphere functions and affects the rest of the ecosystem.

Educational Objectives

Students participating in the activities presented in this chapter should gain scientific inquiry abilities and understanding of a number of scientific concepts. See Figure SOIL-I-12. These abilities include the use of a variety of specific instruments and techniques to take measurements and analyze the resulting data along with general approaches to inquiry. The Scientific Inquiry Abilities listed in Figure SOIL-I-12 and in the grey boxes at the beginning of each protocol are based on the assumption that the teacher has completed the protocol including the Looking at the Data section. If this section is not used, not all of the inquiry abilities will be covered. The Science Concepts included in the figure and grey boxes are outlined in the United States National Science Education Standards as recommended by the US National Research Council and include those for Earth and Space Science and Physical Science. Figure SOIL-I-12 provides a summary indicating which concepts and abilities are covered in which protocols or learning activities.

What on Earth Is Soil?



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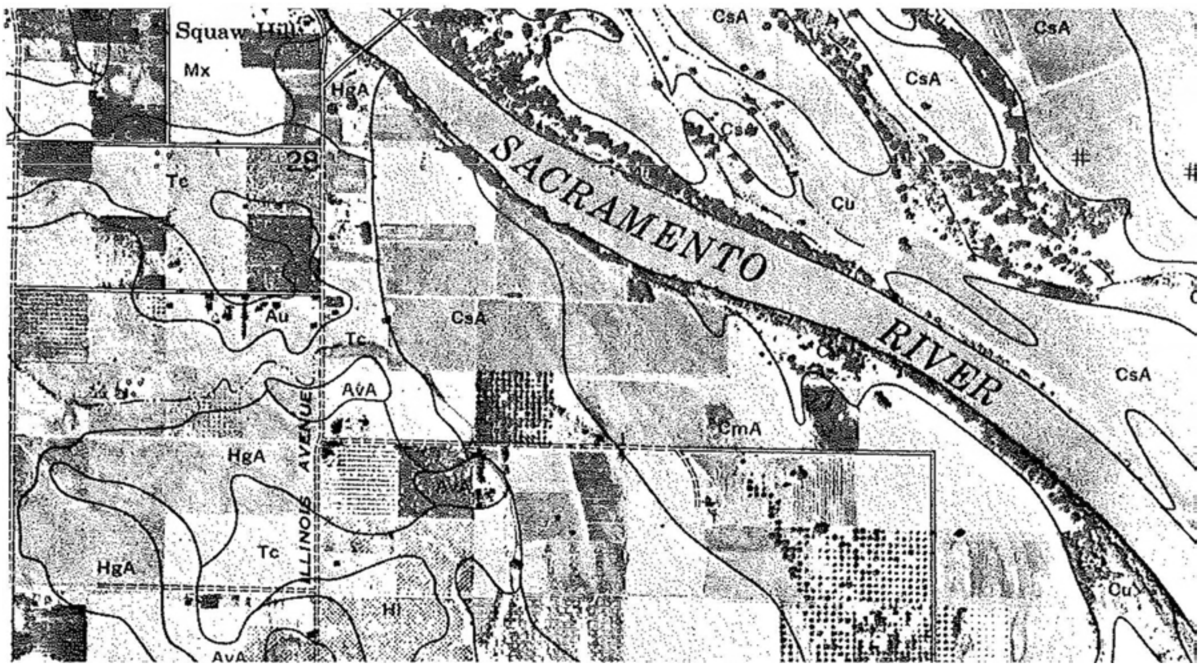
The author is William E. Wildman, Extension Soils Specialist, Davis.



SOIL SURVEYS

At the beginning of this century it was recognized that a map and inventory of the different varieties of soils would be very useful for planning and managing agricultural use of the land. Soil surveys have been made since that time and areas surveyed during the early years have been resurveyed as agriculture has become intensified; concepts in soil classification have changed; and the usefulness of soil surveys in non-agricultural land use planning has become widely recognized. Soil surveys contain a wealth of information in both map and descriptive form about soils, their productivity, and adaptability for cropland, orchard, range, forest, and many other uses.

Soil surveys may be obtained, usually free of charge, at the University of California Farm and Home Advisors' office or the Soil Conservation Service office in the county for which a soil survey is desired. Or they may be requested by writing to:

Department of Soils and Plant Nutrition
University of California
Davis, California 95616

Formerly AXT–n161

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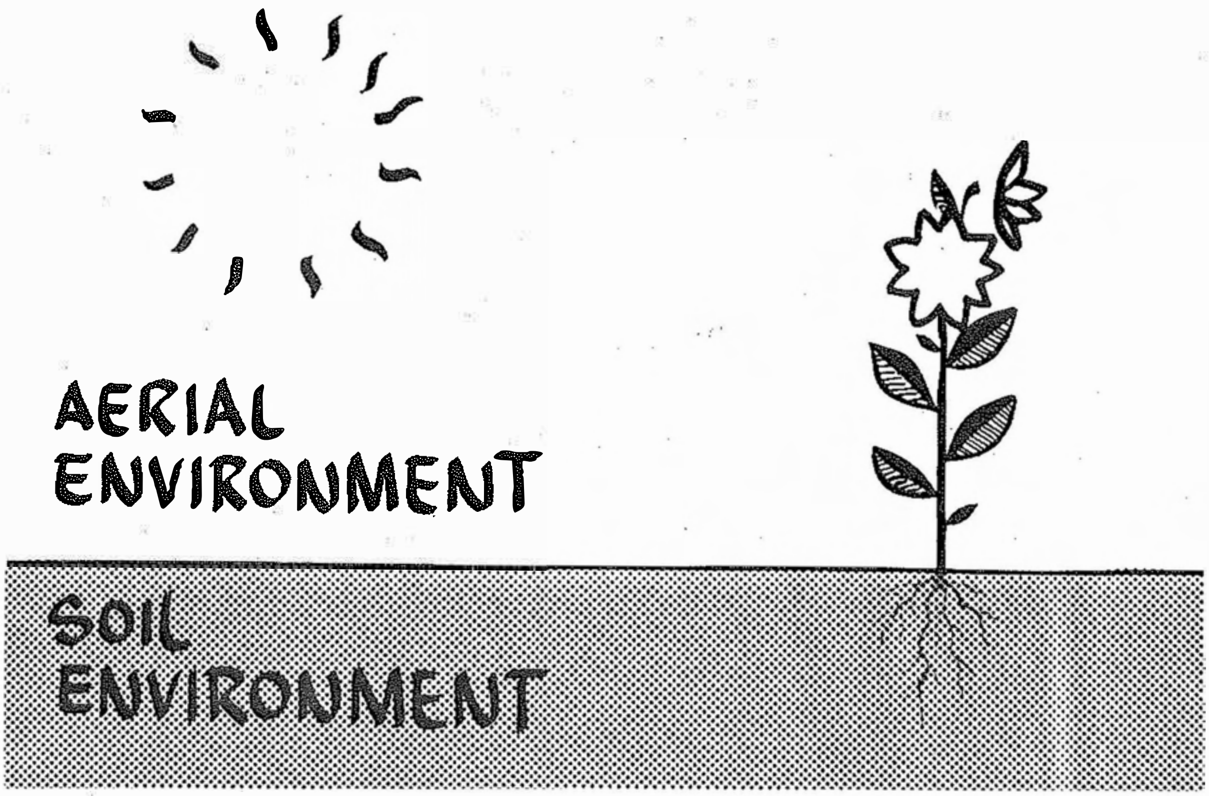
WHAT ON EARTH IS SOIL?

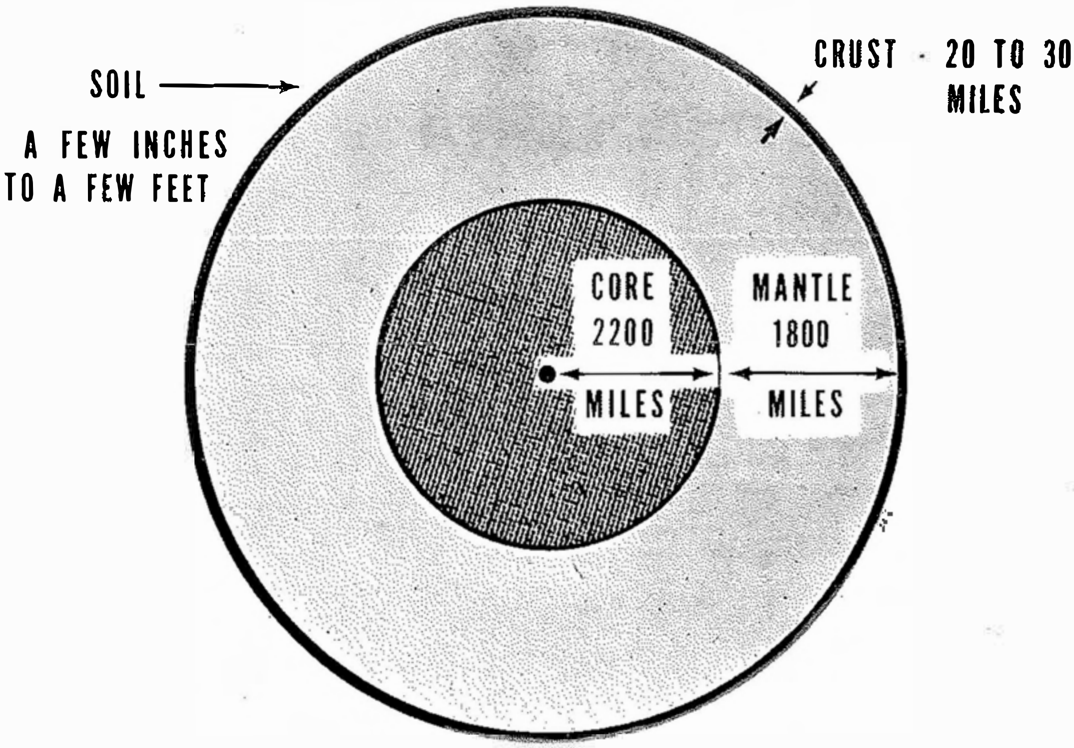


The answer to this question is: just about everything that isn't air or water. The soil is a blanket covering practically all of the earth's land surface. In some places, it is a few inches thick; in others, it may be several feet thick. In either case, it consists of loose material in and upon which plants grow. Without this loose material, land plants could not have evolved. Without land plants, land animals would not exist.

We owe our existence to the soil. It is the meeting place of living and nonliving matter.

How did soil get here? What is it made of? Why do plants grow in it? The answers to these questions can delve deeply into geology, chemistry, physics, and biology. Without getting too technical, we will try to answer these questions in the paragraphs that follow.

THE EARTH

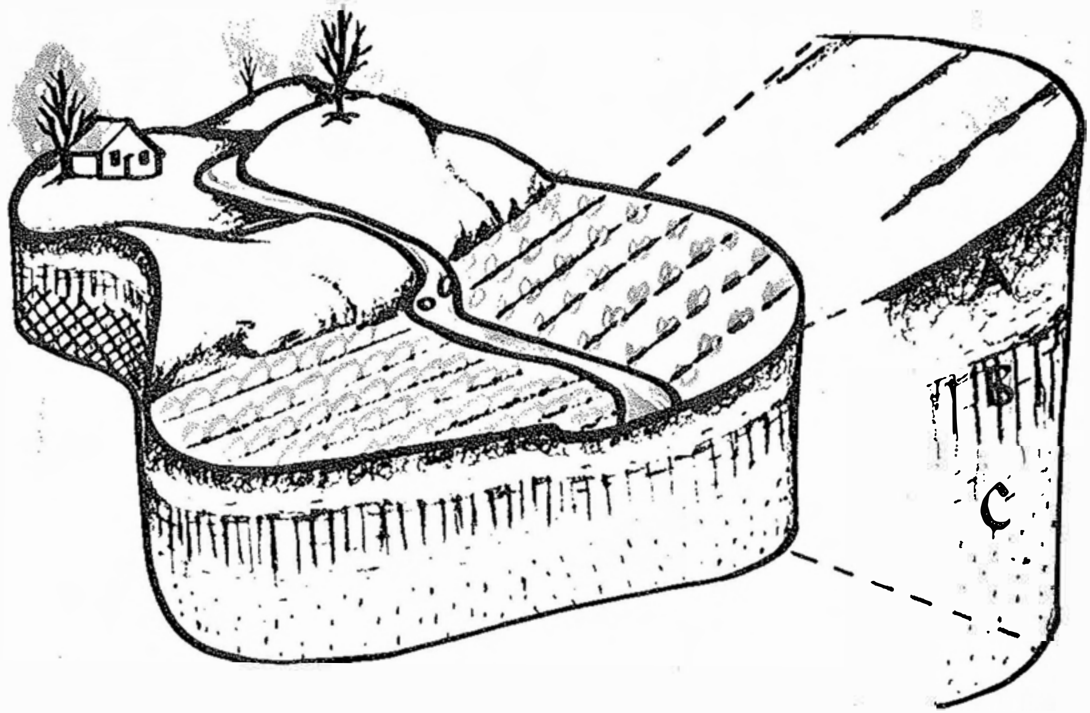


THE EARTH

Geologists are primarily concerned with the earth's crust—a shell of solid rock about 20 to 30 miles thick surrounding the earth. Soil scientists, in turn, study the thin layer of loose material that covers this shell. This layer, the soil, is a few inches to a few feet thick, but without it there would be no land life on earth.

Every solid rock, when it is exposed at the surface of the earth, slowly disintegrates into loose material through a process called weathering. The breaking up of rocks into smaller particles occurs by frost action, expansion and contraction of rocks due to repeated temperature changes, and by the grinding action of streams, glaciers, and wind. This physical weathering is aided by chemical weathering processes, which cause the rock minerals to slowly dissolve and change by the action of water, carbon dioxide, and oxygen. Weathering is so universal that the only land areas of the world that are not covered by soil are those rocky surfaces that are so steep, or subject to such slow weathering, that erosion is able to remove the loose soil material as fast as it forms.

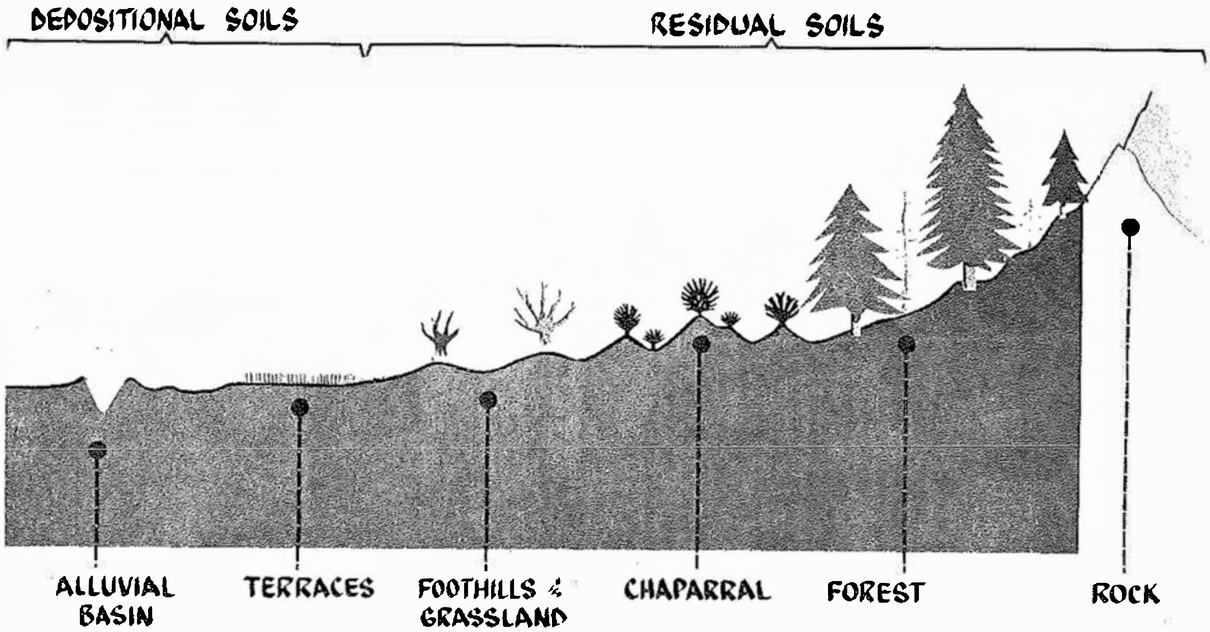
SOIL LANDSCAPE & PROFILE



THE SOIL

When does the loose rock material become soil? There is no clear-cut answer, but it is usually called soil if it is supporting plant growth. There is no minimum or maximum thickness necessary for material to be called soil. What is required is that the material be a medium in which plant roots can grow and from which they can obtain water, air, and the mineral elements essential to plant growth.

Many kinds of soil are found on the earth's surface: soils a few inches to many feet thick; soils made of coarse sand and others of fine clay; soils that mostly contain mineral particles and others made of decomposed plant materials (organic soils); and red, orange, yellow, blue, green, gray, brown, black, and white soils. Soils are complex mixtures of living and nonliving matter and are therefore very difficult to study. During more than a century of scientific study we have learned a great many useful and interesting things about soil. However, there is still much we do not understand.

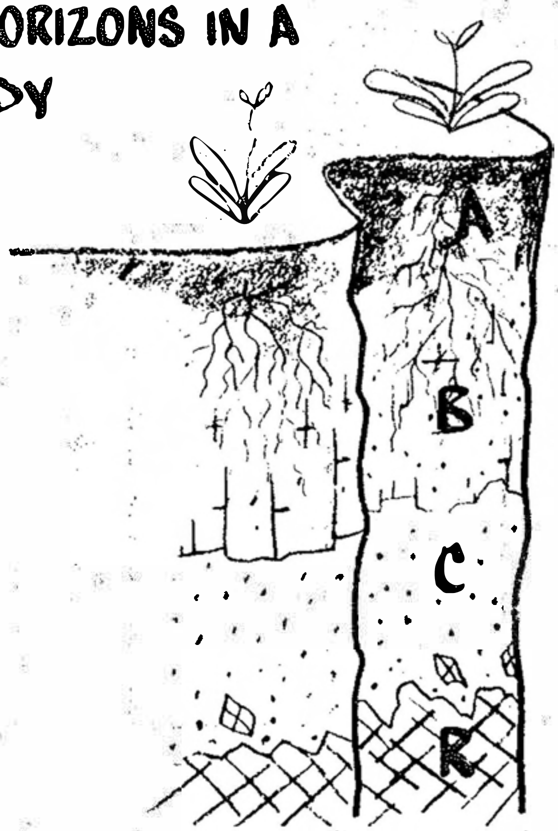


RESIDUAL VERSUS DEPOSITIONAL SOILS

It is useful, particularly in California, to know whether a soil has developed directly above a weathered rock, or if the weathered rock material has been transported and deposited to form a soil many miles from the original parent rock. The former, called **residual soils**, usually occur on mountain slopes and in the foothills. The latter—**depositional soils**—occur in valley locations. Most depositional soils were deposited by streams flowing out of the mountains carrying sand, silt, and clay from the erosion of residual soils and from the breakup of rocks in the stream beds. These are called **alluvial soils**. In some places, sand and silt soil materials have been deposited by wind, and are called **aeolian soils**.

In California, alluvial soils (and some aeolian soils) are usually more intensively farmed and are more productive than residual soils. This is because alluvial soils are usually deeper, more level, more accessible to irrigation water, and more economical to farm than residual soils. Intensive agriculture uses about 10 percent of California's total land area. Over half the land area in the state consists of residual soils of the uplands. These are covered by timber, brush, or grass. Another one-fourth consists of unfarmed desert soils.

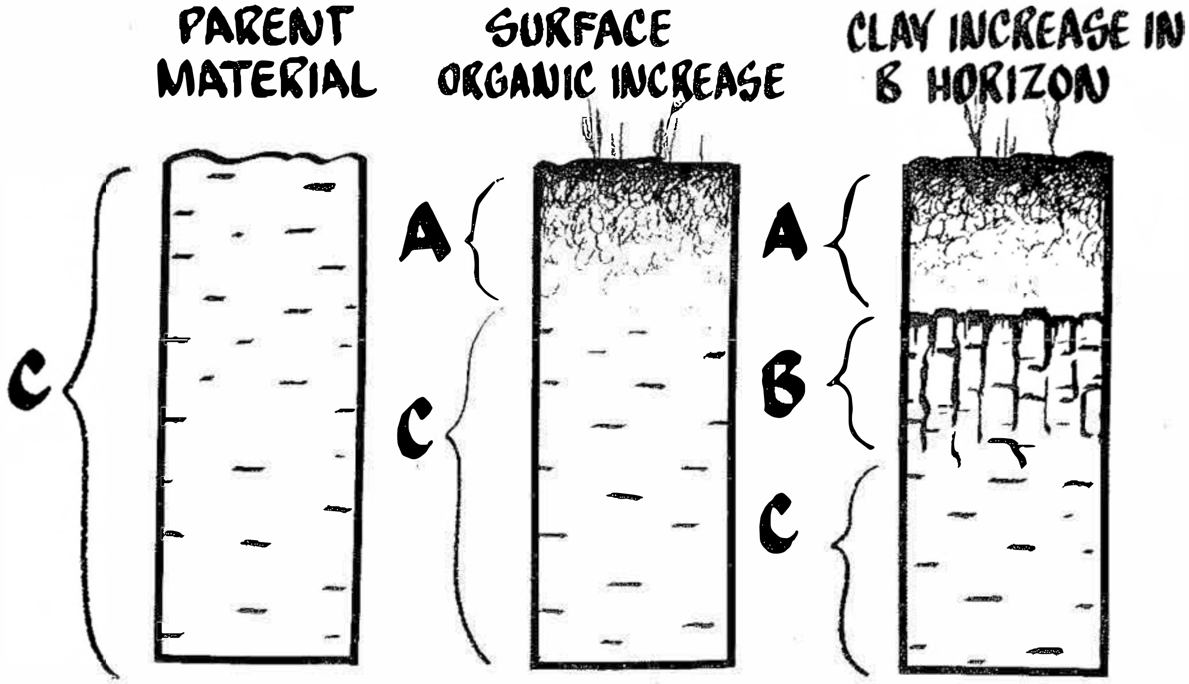
PRINCIPAL HORIZONS IN A SOIL BODY



SOIL PROFILES

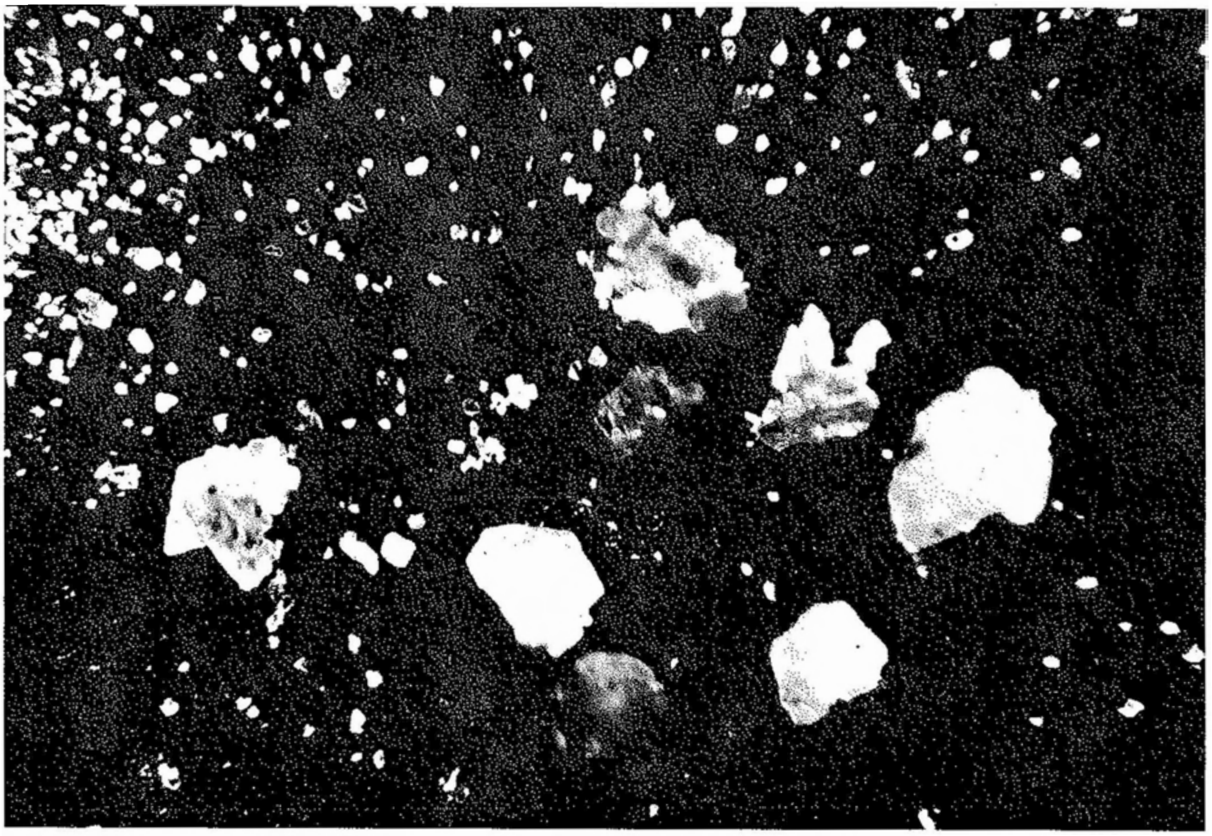
Soils are the product of partial weathering of rocks, but weathering continues in the accumulated soil. A number of changes slowly occur, giving rise to more or less distinctly visible layers below and parallel to the soil surface. These layers are called **horizons** and the sum of all horizons for a soil is called its **profile.** Soil horizons are designated by the letters "A," "B," "C," and "R," going downward from the soil surface. Each lettered horizon may be subdivided, if necessary, by numbers and subscript letters. Not all soils have all the lettered horizons.

SOIL FORMATION



The earliest distinct layer to show up in a recently formed soil is a dark-colored zone that extends downward for several inches from the surface. The dark color is due to the accumulation of well-decomposed organic matter, or humus. A few percent of humus can turn a light-gray or brown soil almost black. More humus is found in soils: 1) in cool climates than in hot climates; 2) in wet climates than in dry climates; and 3) under grassland than under forest. The humus-containing layer forms part of the "A" horizon of soils. It may develop in a few decades.

Young soils usually have "A" horizons and "C" horizons, which consist of loose or weathered rock material, but no "B" horizon. If they are residual soils, they will also have an "R" horizon of unweathered rock. If the soils are depositional, the "C" horizon will extend indefinitely into the loose material. "B" horizons form very slowly in soils that are on stable land positions—i.e., they are neither being lowered by erosion nor raised by deposition. A "B" horizon is an accumulation of clay in a layer beneath the soil surface. It builds up as the result of: 1) the downward movement of fine particles by percolating water; and 2) the formation of new clay particles due to chemical reactions in the soil. Such an accumulation of clay takes thousands of years. Often the clay layer forms a barrier to water penetration and root growth so that these old soils are less well adapted to plant growth than young, deep soils.



SOIL PARTICLES

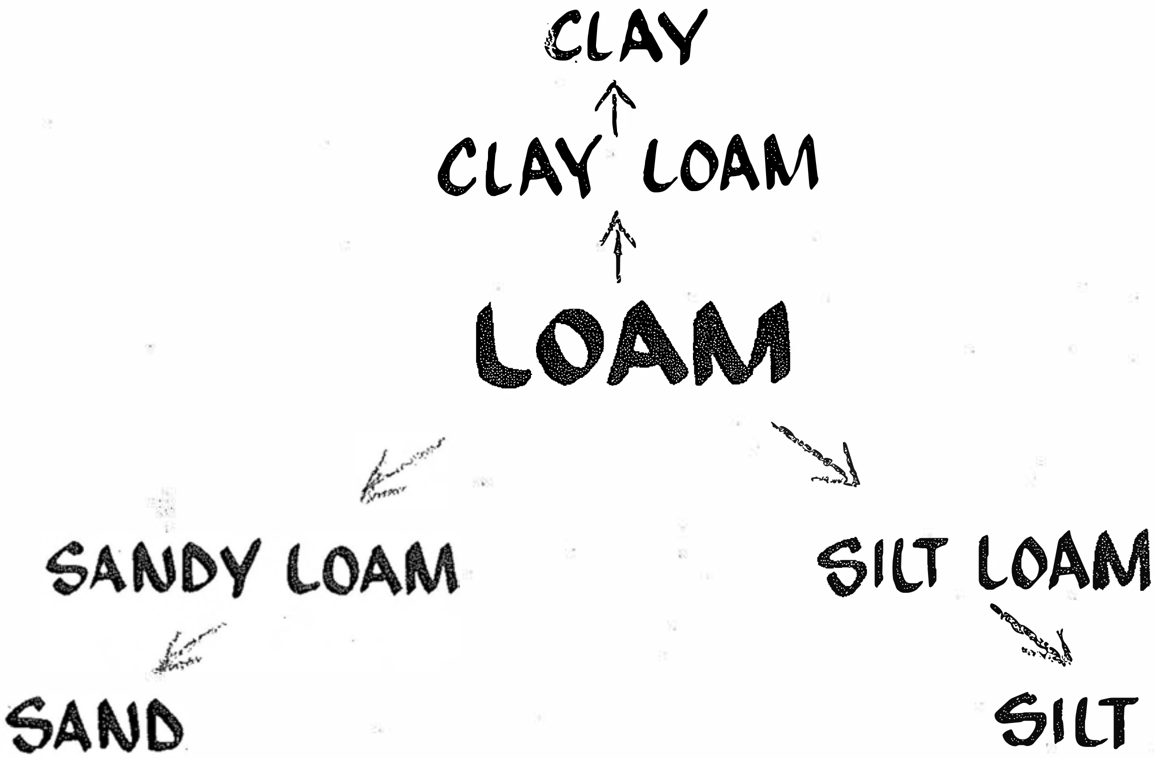
The actual particles that make up soils come in many sizes and shapes. These particles are mixtures of weathered and unweathered mineral grains from the original rocks, new minerals that have formed in the soils, living micro-organisms, and dead organic materials in all stages of decay. The organic fraction in California valley soils is usually less than 5 percent of the soil weight, and often less than 1 percent.

The particles in the picture above are fragments of granitic rocks that have been washed down from the Sierra Nevada and deposited in the San Joaquin Valley to form the **Hanford** soils. These alluvial soils are deep, sandy, and uniform. They are among the most valuable soils for orchard and vineyard production.

SOIL TEXTURE

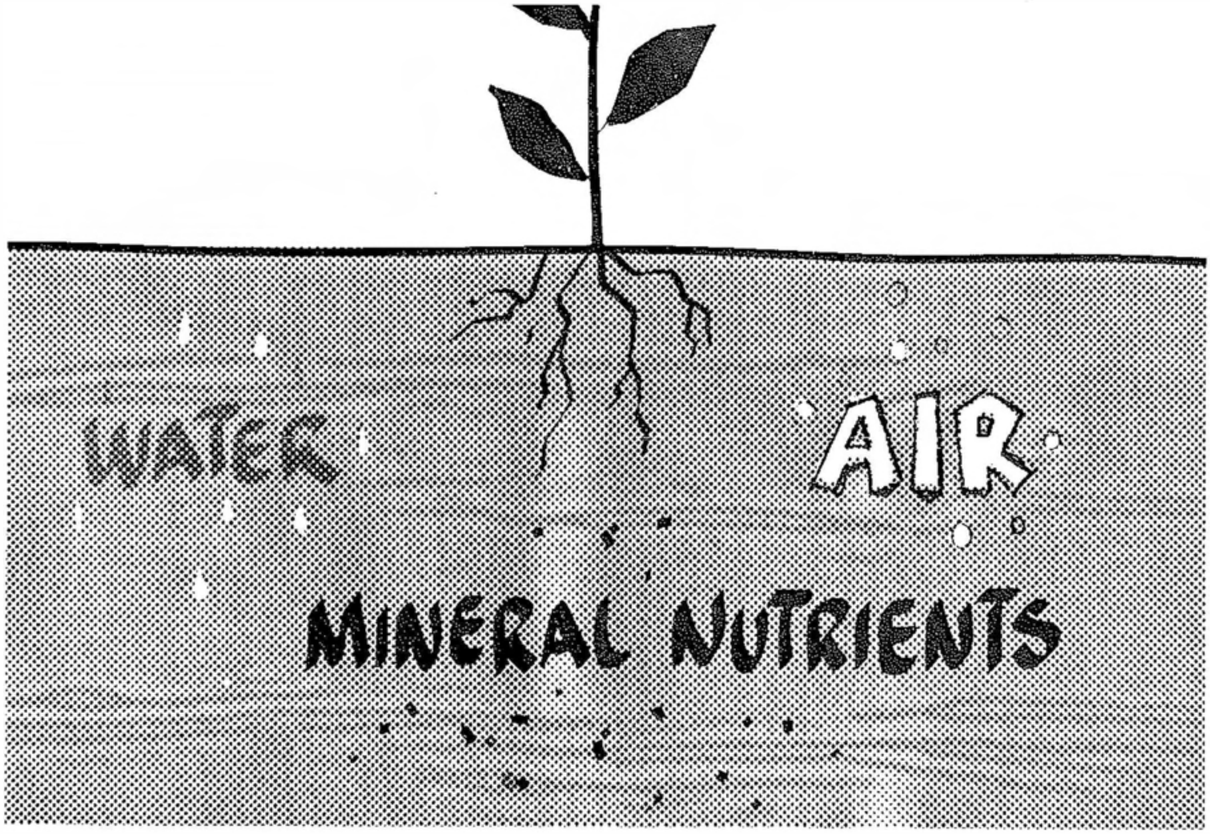
To simplify the description of the mineral portion of the soil mixture, three sizes of particles have been defined. These are called (in order of decreasing size) sand, silt, and clay. All soils are mixtures, in one proportion or another, of these three types of particles. The proportion of each particle type in any particular soil can be estimated by rubbing the moist soil between the thumb and fingers to determine its "feel." Sandy soils are scratchy or gritty. Silty soils are smooth and slippery, but not sticky. Soils high in clay are both slippery and sticky.

In addition to influencing the feel of the soil, each of the particle sizes contributes somewhat different properties to the total soil. The properties affected by particle size are: water percolation, water retention for plant roots, aeration, nutrient supply, and soil strength. In general, sandy soils have faster water percolation and better aeration than finer textured soils, but their ability to retain water and supply nutrients is lower. They also have less strength and are therefore easier to cultivate.



In some soils, called loams, these characteristic properties are intermediate. This is because the particles are in the right proportions to mask the effects of each other on the soil feel and to blend the effects on water retention and percolation, aeration, nutrient supply, and strength. Because of these intermediate properties, loam soils are versatile soils capable of growing a wide variety of crops.

If a soil has somewhat more sand, so that the grittiness begins to be felt, that soil is called a sandy loam and its other properties are dominated more by the coarse sand particles. The name, sandy loam, refers to the texture of this soil. Similarly, there are silt loams and clay loams, sandy clay loams, and silty clay loams, silty clays, and sandy clays, and finally just sands, silts, and clays—all named for different soil textures depending on the predominant size of the particles. The more predominant one size of particle is in a soil, the less versatile that soil is for many crops, and the more exacting are the management requirements for good plant growth.



SOIL AS A MEDIUM FOR PLANT GROWTH

All plant roots need water, air, and certain mineral nutrients. With a few minor exceptions, these plant needs must be obtained from the soil by the roots. So the soil must be able to store water, to provide air, and to release mineral nutrients—all at the same time.

Soil particles attract water and can hold a certain amount in small pore spaces between particles. Plant nutrients from decomposing minerals, organic matter, and fertilizers dissolve in the water held in these pores. Water in large pores drains downward under the influence of gravity, leaving the pores filled with air. And so plant roots are able to get their water and nutrients from the small pores and their air from the larger pores.

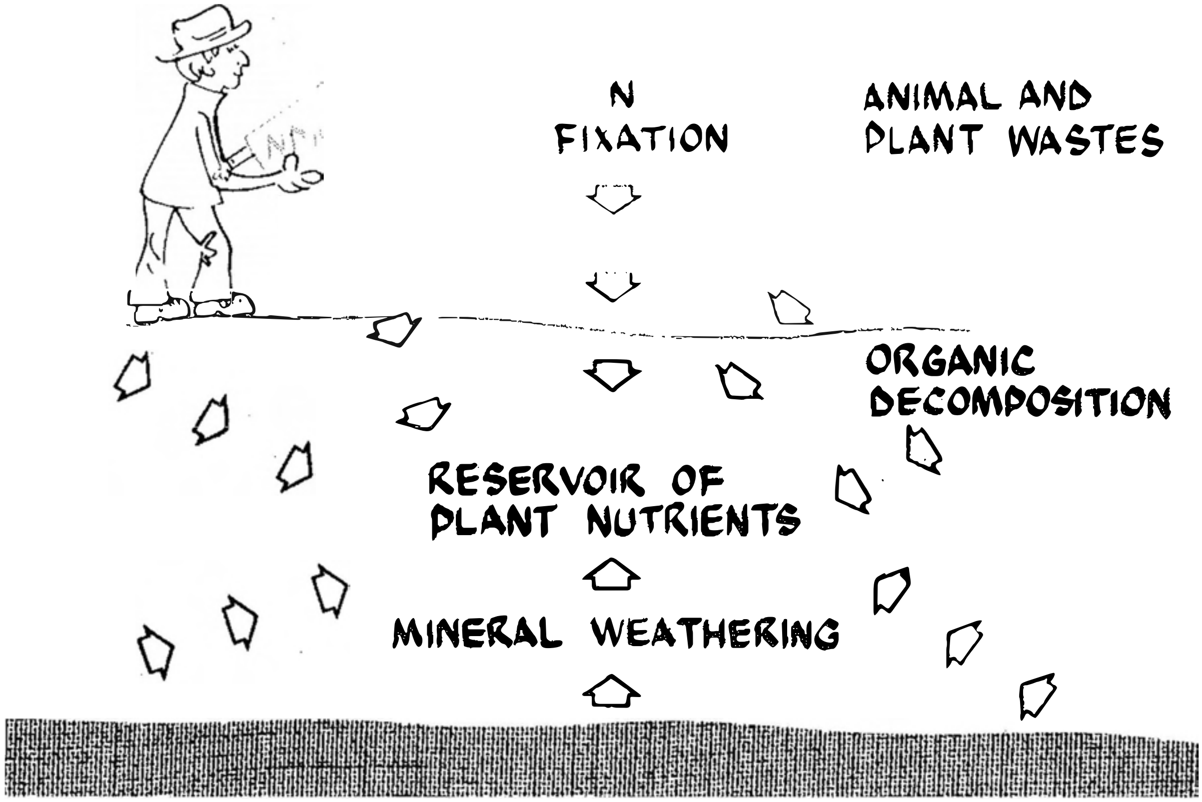
This arrangement works well in soils that have a suitable distribution of large and small pores, such as the medium-textured loams. Sandy soils, however, have many large pores but few small ones. Water percolates through them readily but little is held back for use by roots. For this reason, sandy soils may need to be watered and fertilized more frequently than finer textured soils. At the other extreme, the fine-textured silt and clay soils have many small pores but few large ones. Water and nutrient retention are usually more than adequate for plants, but water often percolates slowly through these soils, providing temporary zones with poor aeration.

ESSENTIAL PLANT ELEMENTS

MAJOR ELEMENTS FROM AIR AND WATER	MAJOR ELEMENTS FROM SOIL	MINOR ELEMENTS FROM SOIL
CARBON	NITROGEN	IRON
HYDROGEN	PHOSPHORUS	ZINC
OXYGEN	SULFUR	MANGANESE
	POTASSIUM	COPPER
	CALCIUM	CHLORINE
	MAGNESIUM	BORON
		MOLYBDENUM

ESSENTIAL PLANT ELEMENTS

Sixteen chemical elements have been proven to be absolutely essential for plant growth and reproduction. The major elements (or macronutrients) are needed in relatively large quantities by plants; the minor elements (or micronutrients) are no less essential but are needed in much smaller quantities. Carbon, hydrogen, and oxygen are the building blocks of carbohydrates and fats. These elements, plus nitrogen and sulfur, are found in proteins. Phosphorus is essential in the energy transfers of cells and also occurs in the cell genetic material. Calcium is a constituent of pectic materials, which help hold cells together. Magnesium is the central atom of the chlorophyll molecule in the cells of green plants. The role of potassium is not yet understood, although it has been clearly demonstrated that plants will not grow without it. Iron is required for the formation of chlorophyll and in the oxidation reactions of the cytochrome chain. Several of the other minor elements function in enzymatic reactions necessary for plant growth

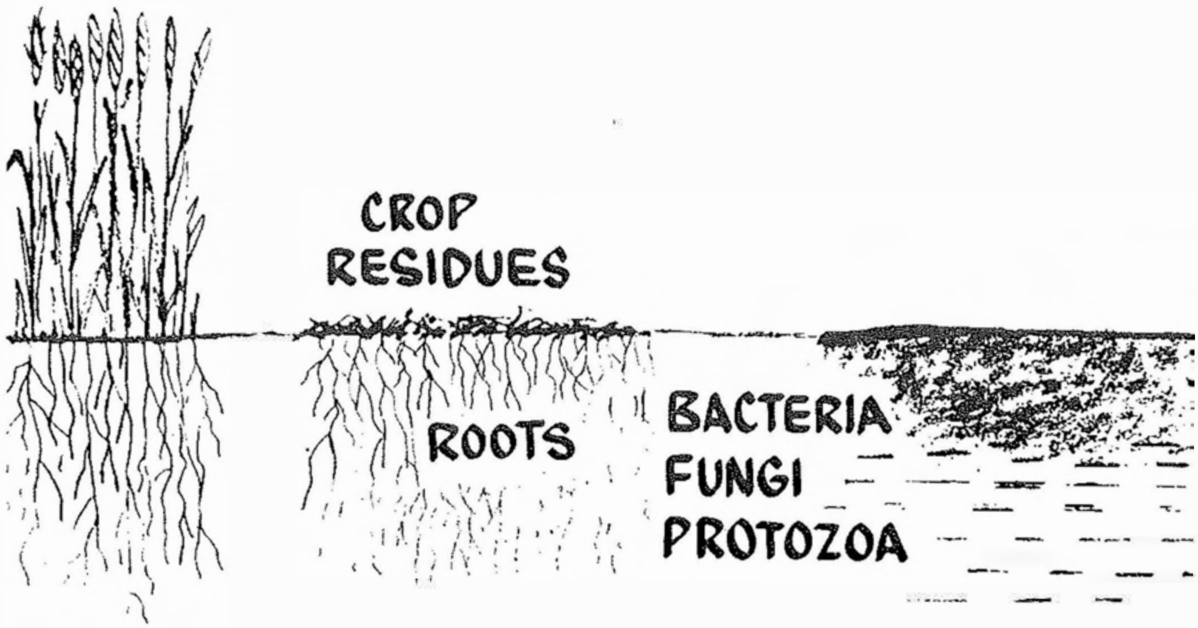


NUTRIENT ABSORPTION AND DEFICIENCY

In the natural environment, most plant nutrients were initially released slowly by the weathering of rocks. An exception was nitrogen, which is found in very low amounts in rocks but is needed in large quantities by plants. Fortunately, blue-green algae, some bacteria, and some higher plants (with the aid of symbiotic bacteria) developed the ability to fix atmospheric nitrogen in the soil. As plants died and decomposed, an accumulation of nutrients was built up in the soil, which was recycled by plants together with the elements released from rocks.

However, the natural accumulation of nutrients in soils was not necessarily balanced in relation to the needs of plants. This became particularly evident when the virgin soils of America were first farmed. At first, crop yields were fairly good without fertilization. But one element, nitrogen, was usually limiting and became deficient after one to a few years. If nitrogen were supplied, another nutrient might become limiting, and so on. The next nutrient that may be limiting in California annual crops is phosphorus; in tree crops, zinc. Potassium is usually in adequate supply in the drier climates, but it and sulfur may become deficient in higher rainfall areas. Iron deficiency is a special case in alkaline soils, where high pH makes the iron present unavailable to some species of plants.

SOIL ORGANIC MATTER



SOIL ORGANIC MATTER

Although the organic fraction of California soils is usually small, it is important in providing a reservoir of nutrients and in improving the tilth of the soil. It is difficult to build up the percentage of organic matter content because it decomposes so rapidly in the hot summer climate. Soil micro-organisms attack the organic compounds and use them for energy. In the process, they convert the carbon, hydrogen, and oxygen into gaseous carbon dioxide and water, at the same time returning the other essential elements to their inorganic form. This process is known as mineralization of the organic matter and must occur before plants can use the essential elements in it. The inorganic elements released from organic matter are identical to the same elements released from weathered rocks or from chemical fertilizer. Plants grown using a balanced mixture of nutrients from any one of these sources are equivalent to each other in growth and quality.

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Conquest of the Land Through 7,000 Years

Agriculture Information Bulletin No. 99
U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

PREFACE

"Conquest of the Land through 7,000 Years" is Dr. Lowdermilk's personal report of a study he made in 1938 and 1939. Despite changes in names of countries, in political boundaries, and in conservation technology, the bulletin still has significance for all peoples concerned with maintaining and improving farm production.

Dr. Lowdermilk studied the record of agriculture in countries where the land had been under cultivation for hundreds, even thousands, of years. His immediate mission was to find out if the experience of these older civilizations could help in solving the serious soil erosion and land use problems in the United States, then struggling with repair of the Dust Bowl and the gullied South.

He discovered that soil erosion, deforestation, overgrazing, neglect, and conflicts between cultivators and herdsmen have helped topple empires and wipe out entire civilizations. At the same time, he learned that careful stewardship of the earth's resources, through terracing, crop rotation, and other soil conservation measures, has enabled other societies to flourish for centuries.

The Soil Conservation Service has reprinted this bulletin without change to meet the continuing demand from teachers, clergymen, writers, college professors, garden clubs, environmental groups, and service organizations for copies of the report as originally written by Dr. Lowdermilk.

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CONQUEST OF THE LAND THROUGH SEVEN THOUSAND YEARS

By W. C. LOWDERMILK, *formerly Assistant Chief, Soil Conservation Service*

Sometime ago I heard of an old man down on a hill farm in the South, who sat on his front porch as a newcomer to the neighborhood passed by. The newcomer to make talk said, "Mister, how does the land lie around here?" The old man replied, "Well—I don't know about the land a-lying; it's these real estate people that do the lying."

In a very real sense the land does not lie; it bears a record of what men write on it. In a larger sense a nation writes its record on the land, and a civilization writes its record on the land—a record that is easy to read by those who understand the simple language of the land. Let us read together some of the records that have been written on the land in the westward course of civilization from the Holy Lands of the Near East to the Pacific coast of our own country through a period of some 7,000 years.

Records of mankind's struggles through the ages to find a lasting adjustment to the land are found written across the landscapes as "westward the course of empire took its way." Failures are more numerous than successes, as told by ruins and wrecks of works along this amazing trail. From these failures and successes we may learn much of profit and benefit to this young Nation of the United States as it occupies a new and bountiful continent and begins to set up house for a thousand or ten thousand years—yea, for a boundless future.

Freedom Bought and Sold for Food

Pearl Harbor, like an earthquake, shocked the American people to a realization that we are living in a dangerous world—dangerous for our way of life and for our survival as a people, and perilous for the hope of the ages in a government of the people, by the people, and for the people. Why should the world be dangerous for such a philanthropic country as ours?

The world is made dangerous by the desperation of peoples suffering from privations and fear of privations, brought on by restrictions of the exchange of the good and necessary things of Mother Earth. Industrialization has wrought in the past century far-reaching changes in civilization, such as will go on and on into our unknown future.

Raw materials for modern industry are localized here and there over the globe. They are not equally available to national groups of peoples who have learned to make and use machines. Wants and needs of food and raw materials have been growing up unevenly and bringing on stresses and strains in international relations that are seized upon by ambitious peoples and leaders to control by force the sources of such food and raw materials. Wars of aggression, long and well-planned, take place so that such materials can be obtained.

These conflicts are not settled for good by war. The problems are pushed aside for a time only to come back in more terrifying proportions at some later time. Lasting solutions will come in another way. We can depend on the reluctance of peoples to launch themselves into war, for they go to war because they fear something worse than war, either real or propagandized.

A just relation of peoples to the earth rests not on exploitation, but rather on conservation—not on the dissipation of resources, but rather on restoration of the productive powers of the land and on access to food and raw materials. If civilization is to avoid a long decline, like the one that has blighted North Africa and the Near East for 13 centuries, society must be born again out of an economy of exploitation into an economy of conservation.

We are now getting down to fundamentals in this relationship of a people to the land. My experience with famines in China taught me that in the last reckoning all things are purchased with food. This is a hard saying; but the recent world-wide war shows up the terrific reach of this fateful and awful truth. Aggressor nations used the rationing of food to subjugate rebellious peoples of occupied countries. For even you and I will sell our liberty and more for food, when driven to this tragic choice. There is no substitute for food.

Seeing what we will give up for food, let us look at what food will buy—for money is merely a symbol, a convenience in the exchange of the goods and services that we need and want. Food buys our division of labor that begets our civilization.

Not until tillers of soil grew more food than they themselves required were their fellows released to do other tasks than the growing of food—that is, to take part in a division of labor that became more complex with the advance of civilization.

True, we have need of clothing, of shelter, and of other goods and services made possible by a complex division of labor, founded on this food production, when suitable raw materials are at hand. And of these the genius of the American people has given us more than any other nation ever possessed. They comprise our American standard of living. But these other good things matter little to hungry people as I have seen in the terrible scourges of famine.

Food comes from the earth. The land with its waters gives us nourishment. The earth rewards richly the knowing and diligent but punishes inexorably the ignorant and slothful. This partnership of land and farmer is the rock foundation of our complex social structure.

In 1938, in the interests of a permanent agriculture and of the conservation of our land resources, the Department of Agriculture asked me to make a survey of land use in olden countries for the benefit of our farmers and stockmen and other agriculturists in this country. This survey took us through England, Holland, France, Italy, North Africa, and the Near East. After 18 months it was interrupted by the outbreak of war when Germany invaded Poland in September 1939. We were prevented from continuing the survey through Turkey, the Balkan States, southern Germany, and Switzerland as was originally planned. But in a year and a half in the olden lands we discovered many things of wide interest to the people of America.

Graveyard of Empires

We shall begin our reading of the record as it is written on the land in the Near East. Here, civilization arose out of the mysteries of the stone age and gave rise to cultures that moved eastward to China and westward through Europe and across the Atlantic Ocean to the Americas.

We are daily and hourly reminded of our debt to the Sumerian peoples of Mesopotamia whenever we use the wheel that they invented more than 6,000 years ago. We do homage to their mathematics each time we look at the clock or our watches to tell time divided into units of 60.

Moreover, our calendar in use today is a revision of the method the ancient Egyptians used in dividing the year. We inherit the experience and knowledge of the past more than we know.

Agriculture had its beginning at least 7,000 years ago and developed in two great centers—the fertile alluvial plains of Mesopotamia and the Valley of the Nile. We shall leave the interesting question of the precise area in which agriculture originated to the archaeologists.

It is enough for us to know that it was in these alluvial plains in an arid climate that tillers of soil began to grow food crops by irrigation in quantities greater than their own needs. This released their fellows for a division of labor that gave rise to what we call civilization. We shall follow the vicissitudes of peoples recorded on the land, as nations rose and fell in these fateful lands.

A survey of such an extensive area in the short time of 2 years called for simple but fundamental methods of field study. With the aid of agricultural officials of other countries, we hunted out fields that had been cultivated for a thousand years—the basis of a permanent agriculture. Likewise, we tried to find the reasons why lands formerly cultivated had been wasted or destroyed, as a warning to our farmers and our city folks of a possible similar catastrophe in this new land of America. A simplified method of field study enabled us to examine large areas rapidly.

In the Zagros Mountains that separate Persia from Mesopotamia, shepherds with their flocks have lived from time immemorial, when "the memory of man runneth not to the contrary." From time to time they have swept down into the plain to bring devastation and destruction upon farming and city peoples of the plains. Such was the beginning of the Cain and Abel struggle between the shepherd and the farmer, of which we shall have more to say.

At Kish, we looked upon the first capital after the Great Flood that swept over Mesopotamia in prehistoric times and left its record in a thick deposit of brown alluvium. The layer of alluvium marked a break in the sequence of a former and a succeeding culture, as recorded in artifacts. Above the alluvium deposits is the site of Kish (fig. 1).

At the ruins of mighty Babylon we pondered the ruins of Nebuchadnezzar's stables (fig. 2), adorned by animal figures in bas-relief. We stood subdued as though at a funeral as we recalled how this great ruler of Babylon had boasted:

FIGURE 1.—Ruins of Kish, one of the world's most important cities 6,000 years ago. Recently, archaeologists excavated these ruins from beneath the desert sands of Mesopotamia.

FIGURE 2.—Ruins of the famous stables of Nebuchadnezzar in Babylon built during the sixth century B. C. Babylon died and was buried by the desert sands, not because it was sacked and razed but because the irrigation canals that watered the land that supported the city were permitted to fill with silt.

> That which no king before had done, I did . . . A wall like a mountain that cannot be moved, I builded . . . great canals I dug and lined them with burnt brick laid in bitumen and brought abundant waters to all the people . . . I paved the streets of Babylon with stone from the mountains . . . magnificent palaces and temples I have built . . . Huge cedars from Mount Lebanon I cut down . . . with radiant gold I overlaid them and with jewels I adorned them.

Then came to mind the warnings of the Hebrew prophets that were thundered against the wicked city. They warned that Babylon would become "A desolation, a dry land, and a wilderness, a land wherein no man dwelleth . . . And wolves shall cry in their castles, and jackals in the pleasant places." Believe it or not, the only living thing that we saw in this desolation that once was Babylon was a lean gray wolf, shaking his head as if he might have a tick in his ear, as he loped to his lair in the ruins of one of the seven wonders of the ancient world—the Hanging Gardens of Babylon where air conditioning was in use 2,600 years ago.

Mesopotamia, the traditional site of the Garden of Eden, out of which come the stories of the Flood, of Noah and the Ark, of the "Tower of Babel" and the confusion of tongues, of the fiery furnace which we found still burning today, is jotted full of records of a glorious past, of dense populations, and of great cities that are now ruins and desolation. For at least 11 empires have risen and fallen in this tragic land in 7,000 years. It is a story of a precarious agriculture practiced by people who lived and grew up under the threat of raids and invasions from the denizens of grasslands and the desert, and of the failure of their irrigation canals because of silt.

Agriculture was practiced in a very

dry climate by canal irrigation with muddy water from the Tigris and Euphrates Rivers. This muddy water was the undoing of empire after empire. As muddy river waters slowed down, they choked up the canals with silt. It was necessary to keep this silt out of the canals year after year to supply life-giving waters to farm lands and to cities of the plain.

As populations grew, canals were dug farther and farther from the rivers. This great system of canals called for a great force of hand labor to keep them clean of silt. The rulers of Babylon brought in war captives for this task. Now we understand why the captive Israelites "sat down by the waters of Babylon and wept." They also were, doubtless, required to dig silt out of canals of Mesopotamia.

As these great public works of cleaning silt out of canals were interrupted from time to time by internal revolutions and by foreign invaders, the peoples of Mesopotamia were brought face to face with disaster in canals choked with silt. Stoppage of canals by silt depopulated villages and cities more effectively than the slaughter of people by an invading army.

On the basis of an estimate that it was possible in times past to irrigate 21,000 of the 35,000 square miles of the alluvium of Mesopotamia, the population of Mesopotamia at its zenith was probably between 17 and 25 million. The present population of all Iraq is estimated to be about 4 million, including nomadic peoples. Of this total, not more than 3½ million live on the alluvial plain.

Decline in population in Mesopotamia is not due to loss of soil by erosion. The fertile lands are still in place and life-giving waters still flow in the Tigris and Euphrates Rivers, ready to be spread upon the lands today as in times past. Mesopotamia is capable of supporting as great a population as it ever did and greater when modern engineering makes use of reinforced concrete construction for irrigation works and powered machinery to keep canal systems open.

A greater area of Mesopotamia thus might be farmed than ever before in the long history of this tragic land. But erosion in the hinterlands aggravated the silt problem in waters of the Tigris and Euphrates Rivers, as they were drawn off into the ancient canal systems. Invasions of nomads out of the grasslands and the desert brought about the breakdown of irrigation that spelled disaster after disaster.

In Egypt's Land

Let's now turn to the other great center of population growth and development of civilization in the Valley of the Nile. Here, the mysterious Sphinx ponders problems of the ages as he looks out over the narrow green Valley of the Nile, lying across a brown and sun-scorched desert.

In Egypt as well as in Mesopotamia, tillers of soil learned early to sow food plants of wheat and barley and to grow surplus food that released their fellows for divisions of labor, giving rise to the remarkable civilization that arose in the Valley of the Nile. Our debt to the ancient Egyptians is great.

Here, too, farming grew up by flood irrigation with muddy waters. But the problems of farming were very different from those of Mesopotamia. Annual flooding with silt-laden waters spread thin layers of silt over the land, raising it higher and higher. In these flat lands of slowly accumulating soil, farmers never met with problems of soil erosion.

To be sure, there have been problems of salt accumulation and of rising water tables for which drainage is the solution. This is especially true since yearlong irrigation has been made possible by the Assuan Dam. But the body of the soil has remained suitable for cropping for 6,000 years and more.

It was perhaps in the Valley of the Nile that a genius of a farmer about 6,000 years ago hitched an ox to a hoe and invented the plow, thus originating power-farming to disturb the social structure of those times much as the tractor disturbed the social structure of our country in recent years. By this means farmers became more efficient in growing food; a single farmer released several of his fellows from the vital task of growing food for other tasks. Very likely the Pharaohs had difficulty in keeping this surplus population sufficiently occupied. For we suspect that the Pyramids were the first WPA projects.

On the Trail of the Israelites

We shall follow the route of Moses out of the fertile, irrigated lands of Egypt into a mountainous land where forests and fields were watered with the rain of Heaven. Fields cleared on mountain slopes presented a new problem in farming—the problem of soil erosion, which, as we shall see, became the greatest hazard to permanent agriculture and an insidious enemy of civilization.

We crossed the modern Suez Canal with its weird color of blue into Sinai where the Israelites with their herds wandered for 40 years. They or someone must have overgrazed the Peninsula of Sinai, for it is now a picture of desolation. We saw in this landscape how the original brown soil mantle was eroded into enormous gullies as shown by great yellowish gashes cut into the brown soil covering. I had not expected to find evidences of so much accelerated erosion in the arid land of Sinai.

On the way to Aqaba we crossed a remarkable landscape, a plateau that had been eroded through the ages almost to a plain, called a peneplain in physiographic language.

This peneplain surface dates back to Miocene times, in the geological scale. In the plain now there is no evidence of accelerated cutting by torrential streams and no evidence that climate has changed for drier or wetter conditions since Miocene times. Here is a cumulative record going far back of the ice age, proclaiming that in this region climate has been remarkably stable.

From this plateau we dropped down 2,500 feet into the Araba or gorge of the great rift valley that includes the Gulf of Aqaba, the Araba, the Dead Sea, and the Valley of the Jordan. At the head of the Gulf of Aqaba of the Red Sea we found Dr. Nelson Glueck excavating Ezion Geber which he calls the ancient Pittsburg of the Red Sea, or Solomon's Seaport. Here, copper was smelted 2,800 years ago to furnish instruments for Solomon and his people. The mud brick used for building these ancient houses looked just like our adobe brick of New Mexico and Arizona.

As we climbed out of the rift valley over the east wall to the plateau of Trans-Jordan that slopes toward the Arabian Desert, we came near Amman upon the same type of peneplain that we crossed west of the Araba. Topographically, these two plains are parts of the same peneplain that once spread unbroken across this region. But toward the end of Pliocene times—that is, just before the beginning of the ice age—a series of parallel faults let down into it the great rift valley to form one of the most spectacular examples of disturbances in the earth's crust that is known to geologists.

From Ma'an we proceeded past an old Roman dam, silted up and later washed out and left isolated as a meaningless wall. At Elji we took horses to visit the fantastic ruins of ancient Petra (called Sela in the Old Testament). This much-discussed city was the capital of the Nabatean civilization and flourished at the same time as the Golden Age of China—200 B. C. to A. D. 200. Rose-red ruins of a great city are hidden away in a desert gorge on the margin of the Arabian Desert.

Petra is now the desolate ruin of a great center of power and culture. It has been used by some students as evidence that climate has become drier in the past 2,000 years, making it impossible for this land to support as great a population as it did in the past. In contradiction to this conclusion, we found slopes of the surrounding valley covered with terrace walls that had fallen into ruin and allowed the soils to be washed off to bare rock over large areas. These evidences showed that food had been grown locally and that soil erosion had damaged the land beyond use for crops.

Invasion of nomads out of the desert had probably resulted in a breakdown in these measures for the conservation of soil and water. Also, erosion had washed away the soils from the slopes and undermined the carrying capacity of this land for a human population. Before ascribing decadence of the region to change of climate, we must know how much the breakdown of intensive agriculture contributed to the fall and disappearance of this Nabatean civilization.

The great buildings used for public purposes are amazing. Temples, administrative buildings, and tombs are all carved out of the red Nubian sandstone cliffs. A fascinating story still lies hidden in the unexcavated ruins of this ancient capital. The influence of Greek and Roman civilization was found in a great theater with a capacity to seat some 2,500 persons. It was carved entirely out of massive sandstone rock that now only echoes the scream of eagles, or the chatter of tourists.

And as we proceeded northward in the Biblical land of Moab, we came to the site of Mt. Nebo. We were reminded of how Moses, after having led the Israelites through 40 years of wandering in the wilderness, stood on this mountain and looked across the Jordan Valley to the Promised Land. He described it to his followers in words like these:

> For the Lord thy God bringeth thee into a good land, a land of brooks of water, of fountains and depths that spring out of valleys and hills; a land of wheat and barley and vines and fig trees and pomegranates, a land of olive oil and honey; a land wherein thou shalt eat bread without scarceness; thou shalt not lack anything in it; a land whose stones are iron and out of whose hills thou mayest dig brass.

The Land of Milk and Honey

We crossed the Jordan Valley as did Joshua and found the Jordan River a muddy and disappointing stream. We stopped at the ruins of Jericho and dug out kernels of charred grain which the archaeologists tell us undoubtedly belonged to an ancient household of this ill-fated city. We looked at the Promised Land as it is today, 3,000 years after Moses described it to the Israelites as a "land flowing with milk and honey."

We found the soils of red earth washed off the slopes to bedrock over more than half the upland area. These soils had lodged in the valleys where they are still being cultivated and are still being eroded by great gullies that cut through the alluvium with every heavy rain. Evidence of rocks washed off the hills were found in piles of stone where tillers of soil had heaped them together to make cultivation about them easier. From the air we read with startling vividness the graphic story as written on the land. Soils had been washed off to bedrock in the vicinity of Hebron and only dregs of the land were left behind in narrow valley floors, still cultivated to meager crops.

In the denuded highlands of Judea are ruins of abandoned village sites. Capt. P. L. O. Guy, director of the British School of Archaeology, has studied in detail those sites found in the drainage of Wadi Musrara that were occupied 1,500 years ago. Since that time they have been depopulated and abandoned in greater numbers on the upper slopes.

Captain Guy divided the drainage of Musrara into 3 altitudinal zones: The plain, 0–325 feet; foothills, 325–975 feet; and mountains, 975 feet and over. In the plain, 34 sites were occupied and 4 abandoned; in the foothills, 31 occupied and 65 abandoned; and in the mountains, 37 occupied and 124 abandoned. In other words, villages have thus been abandoned in the 3 zones by percentages in the above order of 11, 67, and 77, which agrees well with the removal of soil.

It is little wonder that villages were abandoned in a landscape such as this in the upper zone near Jerusalem. The soil, the source of food supply, has been wasted away by erosion. Only remnants of the land left in drainage channels are held there by cross walls of stone.

FIGURE 3.—This is a present-day view of a part of the Promised Land to which Moses led the Israelites about 1200 B. C. A few patches still have enough soil to raise a meager crop of barley. But most of the land has lost practically all of its soil, as observed from the rock outcroppings. The crude rock terrace in the foreground helps hold some of the remaining soil in place.

Where soils are held in place by stone terrace walls, that have been maintained down to the present, the soils are still cultivated after several thousand years. They are still producing, but not heavily, to be sure, because of poor soil management (fig. 3).

Most important, the soils are still in place and will grow bigger crops with improved soil treatment. The glaring hills of Judea, not far from Jerusalem, are dotted with only a few of their former villages. Terraces on these hills have been kept in repair for more than 2,000 years.

What is the cause of the decadence of this country that was once flowing with milk and honey? As we ponder the tragic history of the Holy Lands, we are reminded of the struggle of Cain and Abel. This struggle has been made realistic through the ages by the conflict that persists, even unto today, between the tent dweller and the house dweller, between the shepherd and the farmer.

The desert seems to have produced more people than it could feed. From time to time the desert people swept down into the fertile alluvial valleys where, by irrigation, tillers of soil grew abundant foods to support teeming villages and thriving cities.

They swept down as a wolf on the fold to raid the farmers' supplies of food. Raiders sacked and robbed and passed on. Often, they left destruction and carnage in their path, or they replaced former populations and became farmers themselves, only to be swept out by a later wave of hungry denizens of the desert.

Conflicts between the grazing and farming cultures of the Holy Lands have been primarily responsible for the tragic history of this region. Not until these two cultures supplement each other in cooperation can we hope for peace in this ancient land.

We saw the tents of descendants of nomads out of Arabia. In the seventh century they swept in out of the desert to conquer and overrun the farming lands of Palestine. Again in the 12th century nomads drove out the Crusaders. They with their herds of long-eared goats let terrace walls fall in ruin and unleashed the forces of erosion. For nearly 13 centuries erosion has been washing the soils off the slopes into the valleys to make marshes or out to sea.

In recent times a great movement has been under way for the redemption of the Promised Land by Jewish settlers. They have wrought wonders in draining swamps, ridding them of malaria, and planting them to thriving orchards and fields. These settlers have also repaired terraces, reforested desolate and rocky slopes, and improved livestock and poultry.

Throughout our survey of the work of the agricultural colonies, I was asked to advise on measures to conserve soil and water. I urged that orchards be planted on the contour and the land bench-terraced by contour plowing. We were shown one orchard where the trees were planted on the contour, the land was bench-terraced, and slopes above the orchard were furrowed on the contour and planted to hardy trees.

By these measures all the rain that had fallen the season before, one of the wettest in many years, had been absorbed by the soil. After this work was done, no runoff occurred to cut gullies down slope and to damage the orchards below. We were told that the man responsible for this had learned these measures at the Institute of Water Economy in Tiflis, Georgia, in Transcaucasia.

Across Syria

We crossed the Jordan again into a region famous in Biblical times for its oaks, wheat fields, and well-nourished herds. We found the ruins of Jerash, one of the 10 cities of the Decapolis, and Jerash the second. Archaeologists tell us that Jerash was once the center of some 250,000 people. But today only a village of 3,000 marks this great center of culture, and the country about it is sparsely populated with seminomads. The ruins of this once-powerful city of Greek and Roman culture are buried to a depth of 13 feet with erosional debris washed from eroding slopes.

We searched out the sources of water that nourished Jerash and found a series of springs protected by masonry built in the Graeco-Roman times. We examined these springs carefully with the archaeologists to discover whether the present water level had changed with respect to the original structures and whether the openings through which the springs gushed were the same as those of ancient times. We found no suggestion that the water level was any lower than it was when the structures were built or that the openings were different. It seems that the water supply had not failed.

When we examined the slopes surrounding Jerash we found the soils washed off to bedrock in spite of rock-walled terraces. The soils washed off the slopes had lodged in the valleys. These valleys were cultivated by the seminomads who lived in black goat-hair tents. In Roman times this area supplied grain to Rome and supported thriving communities and rich villas, ruins of which we found in the vicinity.

In the alluvial plains along the Orontes River, agriculture supports a number of cities, much reduced in population from those of ancient times. Water wheels introduced from Persia during or following the conquests of Alexander the Great (300 B. C.) were numerous along the Orontes. There were hundreds, we were told, in Roman times, but today only 44 remain. They are picturesque old structures both in their appearance and in the groans of the turning wheel as they slowly lift water from the river to the aqueduct to supply water for the city of Hama. These wheels are more than 2,000 years old. But no part of a wheel is that old, because the parts have been

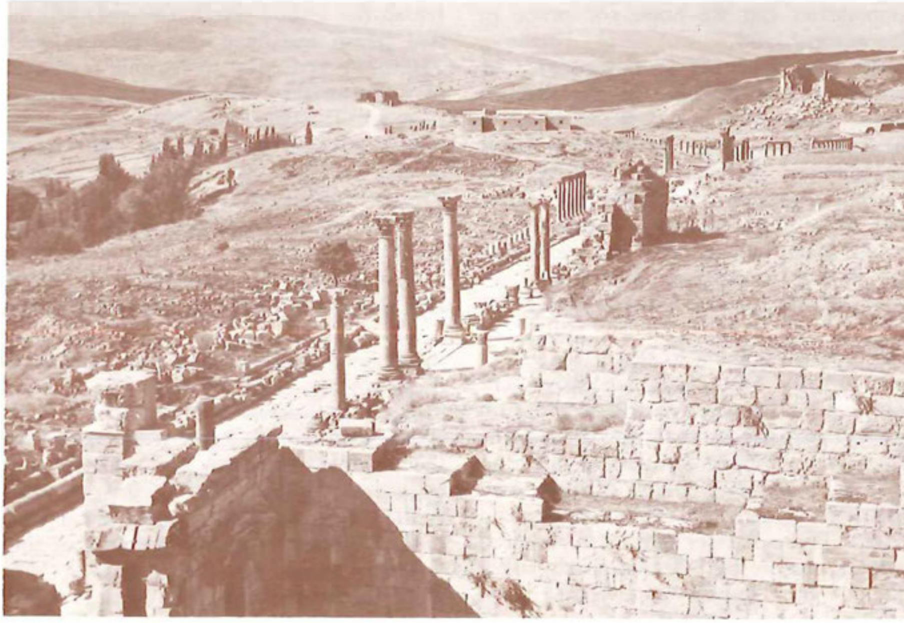

FIGURE 4.—Ruins of one of the Hundred Dead Cities of Syria. From 3 to 6 feet of soil has been washed off most of the hillsides. This city will remain dead because the land around it can no longer support a city.

replaced piecemeal many times through the centuries.

The Hundred Dead Cities

Still farther to the north in Syria, we came upon a region where erosion had done its worst in an area of more than a million acres of rolling limestone country between Hama, Alleppo, and Antioch. French archaeologists, Father Mattern, and others found in this man-made desert more than 100 dead cities.

Butler of Princeton rediscovered this region a generation ago. These were not cities as we know them, but villages and market towns. The ruins of these towns were not buried. They were left as stark skeletons in beautifully cut stone, standing high on bare rock (fig. 4). Here, erosion had done its worst. If the soils had remained, even though the cities were destroyed and the populations dispersed, the area might be repeopled again and the cities rebuilt. But now that the soils are gone, all is gone.

We are told that in A. D. 610–612 a Persian army invaded this thriving region. Less than a generation later, in 633–638, the nomads out of the Arabian Desert completed the destruction of the villages and dispersal of the population. Thus, all the measures for conserving soil and water that had been built up through centuries were allowed to fall into disuse and ruin. Then erosion was unleashed to do its deadly work in making this area a man-made desert.

Looking for the Forests of Lebanon

About 4,500 years ago, we are told by archaeologists, a Semitic tribe swept in out of the desert and occupied the eastern shore of the Mediterranean and established the harbor towns of Tyre and Sidon. On the site of another such ancient harbor town is Beirut, which today is the capital of Lebanon. You can see it from a high point on the Lebanon Mountains overlooking the Mediterranean Sea.

These early Semites were Phoenicians. They found their land a mountainous country with a very narrow coastal plain and little flat land on which to carry out the traditional irrigated agriculture as it had grown up in Mesopotamia and Egypt. We may believe that as the Phoenician people increased, they were confronted with three choices: (1) Migration and colonization, which we know they did; (2) manufacturing and commerce, which we know they did; and (3) cultivation of slopes, about which we have hitherto heard little.

Here was a land covered with forests and watered by the rains of heaven, a land that held entirely new problems for tillers of soil who were accustomed to the flat alluvial valleys of Mesopotamia and the Nile. As forests were cleared either for domestic use or for commerce, slopes were cultivated. Soils of the slopes eroded then under heavy winter rains as they would now. Here under rain farming, they encountered severe soil erosion and the problem of establishing a permanent agriculture on sloping lands.

We find, as we read the record on the land in this fascinating region, tragedy after tragedy deeply engraved on the sloping land. To control erosion walls were constructed across the slopes. Ruins of these walls can be seen here and there today. These measures failed, and erosion caused the soil to shift down slope. As the fine-textured soil was washed away, leaving loose rocks at the surface, tillers of the soil piled the rocks together to make cultivation about them easier. In these cases the battle with soil erosion was definitely a losing one.

Elsewhere we found that the battle with soil erosion had been won by the construction and maintenance of a remarkable series of rock-walled terraces extending from the bases to the crests of

Figure 5.—Rock-walled bench terraces in Lebanon that have been in use for thousands of years. The construction of terraces of this type would cost from $2,000 to $5,000 per acre if labor was figured at 40 cents per hour. Such expensive methods of protecting land are practical only where people have no other land on which to raise their food.

slopes like fantastic staircases (fig. 5). At Beit Eddine in the mountains of Lebanon east of Beirut, we found the slopes terraced even up to grades of 76 percent.

The mountains of ancient Phoenicia were once covered by the famous forests, the cedars of Lebanon. An inscription on the temple of Karnak, as translated by Breasted, announces the arrival in Egypt before 2900 B. C. of 40 ships ladden with timber out of Lebanon.

You will recall that it was King Solomon, nearly 3,000 years ago, who made an agreement with Hiram, King of Tyre, to furnish him cypress and cedars out of these forests for the construction of the temple at Jerusalem. Solomon supplied 80,000 lumberjacks to work in the forest and 70,000 to skid the logs to the sea. It must have been a heavy forest to require such a force. What has become of this famous forest that once covered nearly 2,000 square miles?

Today, only 4 small groves of this famous Lebanon cedar forest are left, the most important of which is the Tripoli grove of trees in the cup of a valley. An examination of the grove revealed some 400 trees of which 43 are old veterans or wolf trees. As we read the story written in tree rings, it appears that about 300 years ago the grove had nearly disappeared with no less than 43 scattered veteran trees standing.

These trees with wide-spreading branches had grown up in an open stand. About that time a little church was built in their midst that made the grove sacred. A stone wall was built about the grove to keep out the goats that grazed over the mountains. Seeds from the veteran trees fell to the ground, germinated, and grew up into a fine close-growing stand of tall

FIGURE 6.—Cedars still grow in Lebanon when given a chance. This is part of one of the four small groves that still exist. It is in the grounds of a monastery and is protected from goat grazing by the stone fence.

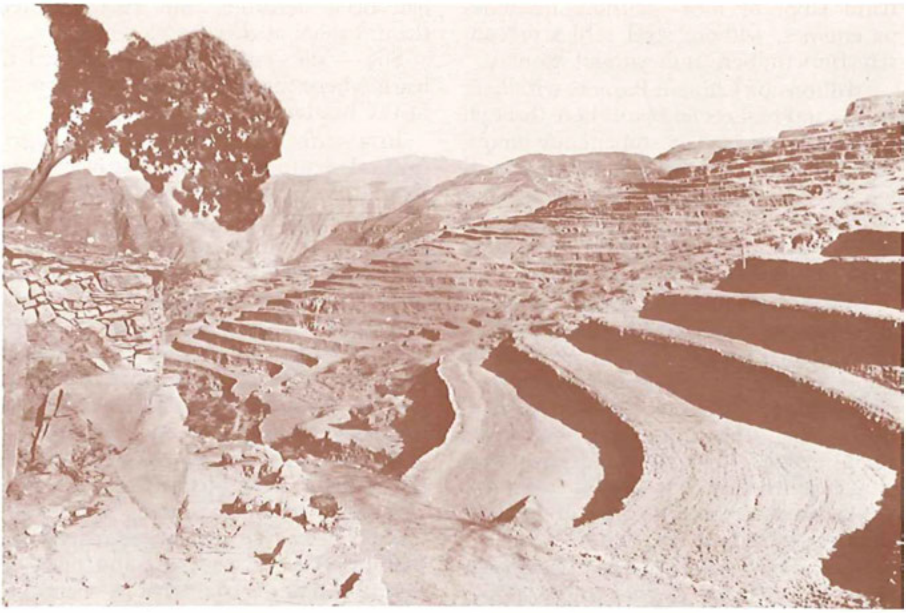

FIGURE 7.—These bench terraces in Shansi Province illustrate the extent to which some Chinese farmers have gone to conserve the remaining soil on their hillsides.

straight trees that show how the cedars of Lebanon will make good construction timber when grown in forest conditions (fig. 6).

Such natural restocking also shows that this famous forest has not disappeared because of adverse change of climate, but that under the present climate it would extend itself if it were safeguarded against the rapacious goats that graze down every accessible living plant on these mountains.

China's Sorrow

Before moving on to Cyprus and North Africa, let's look at China. Civilization here probably arose somewhat later than that in the Near East and was influenced by it. Mixed agriculture, irrigation, the oxdrawn plow, and terracing of slopes are notable similarities in the two regions (fig. 7).

It was in China, where I was engaged in an international project for famine prevention in 1922–27, that the full and fateful significance of soil erosion was first burned into my consciousness.

During an agricultural exploration into the regions of North China, seriously affected by the famine of 1920–21, I examined the site where the Yellow River, in 1852, broke from its enormous system of inner and outer dikes. As we traveled across the flat plains of Honan, we saw a great flat-topped hill looming up before us. We traveled on over the elevated plain for 7 miles to another great dike that stretched across the landscape from horizon to horizon. We mounted this dike and there before us lay the Yellow River, the Hwang Ho, a great width of brown water flowing quietly that spring morning into a tawny haze in the east.

Here in a channel fully 40 to 50 feet above the plain of the great delta lay the river known for thousands of years as "China's Sorrow." This gigantic river had been lifted up off the plain over the entire 400-mile course across its delta and had been held in this channel by hand labor of men—without machines or engines, without steel cables or construction timber, and without stone.

Millions of Chinese farmers with bare hands and baskets had built here through thousands of years a stupendous monument to human cooperation and the will to survive. Since the days of Ta-Yu, nearly 4,000 years ago, the battle of floods with this tremendous river have been lost and won time and again.

But why should this battle with the river have to be endless? Any relaxation of vigilance let the river break over its dikes, calling for herculean and cooperative work to put the river back again in its channel. Then suddenly it dawned upon me that the river was brown with silt, heavily laden with soil that was washed out of the highlands of the vast drainage system of the Yellow River.

As its flood waters reached the gentler slope of the delta (1 foot to the mile), the current slowed down and began to drop its load of silt. Deposits of silt in turn lessened the capacity of the channel to carry floodwaters and called on the farmers threatened with angry floods to build up the dikes yet higher and higher, year after year.

There was no end to this demand of the river if it were to be confined between its dikes. Final control of the river so heavily laden with silt was hopeless; yet millions of farmers toiled on.

In 1852, the yellow-brown waters of the Hwang Ho broke out of its elevated channel to seek another way to the sea. It had emptied into the Yellow Sea, where it had usurped the old outlet of the Shai River.

This time the river broke over its dikes near Kaifeng, Honan, and wandered to the northeast over farm lands, destroying villages and smothering the life out of millions of humans, and discharged into the Gulf of Chihli, 400 miles north of its former outlet. In its rage it had refused to be lifted any higher off its plain. Hundreds of thousands of farmers had been defeated. Silt had defeated them, valiant as they were.

Silt — silt — silt! We determined to learn where this silt came from, even up to the headwaters.

In a series of carefully planned agricultural explorations we discovered the source of the silt that brought ruin to millions of farmers in the plains. In the Province of Shansi we found how the line of cultivation was pushed up slopes, following the clearing away of forests. Soils, formerly protected by a forest mantle, were thus exposed to summer rains, and soil erosion began a headlong process of destroying land and filling streams with soil waste and detritus.

Without a basis of comparison, we might easily have misread the record as written there on the land. But temple forests, preserved and protected by the Buddhist priests, gave me and my Chinese associates a remarkable chance to measure and compare rates of erosion within these forests and on similar slopes and soils that had been cleared and cultivated.

In brief, my Chinese scientific associates[1] and I carried out a series of soil-erosion experiments during rainy seasons of 3 years. In these experiments we measured the rate of runoff and erosion by means of runoff plots within temple forests, out on farm fields under cultivation, and on fields abandoned because of erosion. For the first time in soil-erosion studies, we got experimental data for such comparisons. Here too, we found how the Yellow River had become China's Sorrow, for we found that runoff and erosion from cultivated land were many times as great as from temple forests.

It was clear that if the farmers of the delta plain were ever to be safeguarded from the mounting perils of the silt-laden Yellow River, the source of the silt must be stopped by erosion control.

Farther west in the midst of the famous and vast loessial deposits of North

[1] T. I. Li, C. T. Ren, C. O. Lee, and others. See Proceedings of the Pan-Pacific Science Congress, Tokyo. 1926.

FIGURE 8.—These huge gullies indicate the severity of soil erosion in the deep, and once fertile, loessial soils of northern China. Millions of acres have been cut up like this and are now almost worthless.

China, we found in the Province of Shansi that an irrigation system first established in 246 B. C. had been put out of use by silt. Here again silt was the villain.

We sought out the origin of the silt that had brought an end to an irrigation project that had fed the sons of Han during the Golden Age of China. This origin was found in areas where soil erosion had eaten out gullies 600 feet deep (fig. 8). It was while contemplating such scenes that I resolved to challenge the conclusions of the great German geologist, Baron Von Richthofen, and of Ellsworth Huntington that the decadence of North China was due to desiccation or pulsations of the climate.

Temple forests gave the clue. They demonstrated beyond a doubt that the present climate would support a generous growth of vegetation capable of preventing erosion on such a scale. Human occupation of the land had set in motion processes of soil wastage that were in themselves sufficient to account for the decadence and decline of this part of China, without adverse change of climate.

It was in the presence of such tragic scenes on a gigantic scale that I resolved to run down the nature of soil erosion and to devote my lifetime to study of ways to conserve the lands on which mankind depends.

Soil Waste in Ancient Cyprus

Let's now go back and follow the westward course of civilization from the Holy Lands through North Africa and on into Europe. In Cyprus we found the land use problems of the Mediterranean epitomized in a comparatively small area.

In the plain of Mesaoria is a telling record in and about a Byzantine church. The church on the outskirts of the village of Asha in eastern Cyprus is surrounded by a graveyard and its wall. The alluvial plain now stands 8 feet above the level of the churchyard as we measured it. On entering the church we stepped down 3 feet from the yard level to the floor of the church. Inside we noted that low pointed arches were blocked off, and new arches had been cut for doors and windows.

The aged vestryman told us that about 30 years ago a flood from the plain had filled the church with water and left 2 feet of silt on the floor. Rather than clean it out, a new stone floor had been laid over the silt deposit. Thus, 8 plus 3 plus 2 equals 13 feet, the height of the present alluvial plain above the original church floor. From these measurements we concluded that the plain had filled in, not less than 13 feet, with erosional debris washed off the drainage slopes.

Across North Africa

Along the northern coast of Africa into Tunisia and Algeria we read the record of the granary of Rome during the empire—by surveying a cross section from the Mediterranean to the Sahara Desert, from 40 inches of rainfall to 4 inches, from Carthage on the coast to Biskra at the edge of mysterious Sahara.

In Tunisia we found that it rains in the desert of North Africa in wintertime now as it did in the time of Caesar—in 44 B. C. Caesar complained of how a great rainstorm with wind had blown over the tents of his army encampment and flooded the camp. It rained hard enough to produce flash floods in the wadies. At one place muddy water swept across the highway in such volume that we decided to wait for the flash flow to go down before proceeding.

We stood on the site of ancient Carthage, the principal city of North Africa in Phoenician and Roman times—the city that produced Hannibal and became a dangerous rival of Rome. In 146 B. C., at the end of the Third Punic War, Scipio destroyed Carthage, but out of the doomed city he saved 28 volumes of a work on agriculture written by a Carthaginian by the name of Mago.

Mago was recognized by the Greeks and Romans as the foremost authority on agriculture in the Mediterranean area. These works of Mago on agricultural subjects were translated by such Roman writers as Columella, Varro, and Cato. The translations tell us that the traditions of conserving soil and water discovered on the slopes of ancient Phoenicia had been brought there by colonists. We suspect these measures furnished the basis of the great agricultural production that was so important to the Romans during the Empire.

Over a large part of the ancient granary of Rome we found the soil washed off to bedrock and the hills seriously gullied as a result of overgrazing. Most valley floors are still cultivated but are eroding in great gullies fed by accelerated storm runoff from barren slopes. This is in an area that supported many great cities in Roman times.

We found at Djemila the ghosts of Cuicul, a city that once was great and populous and rich but later was covered completely, except for about 3 feet of a single column, by erosion debris washed off the slopes of surrounding hills. For 20 years French archaeologists had been excavating this remarkable Roman City and had unearthed great temples, two great forums, splendid Christian churches, and great warehouses for wheat and olive oil. All this had been buried by erosional debris washed from the eroding slopes above the city. The surrounding slopes, once covered with olive groves, are now cut up with active gullies.

The modern village houses only a few inhabitants. The flat lands are still farmed to grain but the slopes are bare and eroding and wasting away. What is the reason for this astounding decline and ruin?

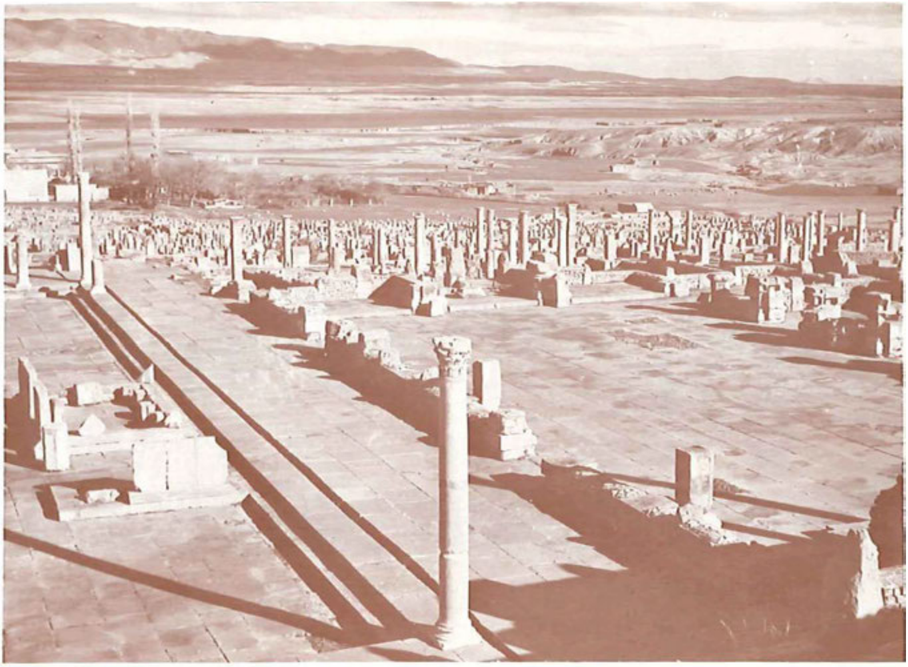

FIGURE 9.—The ruins of Timgad—an ancient Roman city built during the first century A. D. The few huts seen in the center background now house about 300 inhabitants, which is all the eroded land will support. Note that the eroded hills in the background are almost as desolate as the ruins of the city.

Timgad, Lost Capital of a Lost Agriculture

Farther to the south we stopped to study the ruins of another great Roman city of North Africa, Thamugadi, now called Timgad (fig. 9). This city was founded by Trajan in the first century A. D. It was laid out in symmetrical pattern and adorned with magnificent buildings, with a forum embellished by statuary and carved porticoes, a public library, a theater to seat some 2,500 persons, 17 great Roman baths, and marble flush toilets for the public.

After the invasion of the nomads in the seventh century had completed the destruction of the city and dispersal of its population, this great center of Roman culture and power was lost to knowledge for 1,200 years. It was buried by the dust of wind erosion from surrounding farm lands until only a portion of Hadrian's arch and 3 columns remained like tombstones above the undulating mounds to indicate that once a great city was there.

The French Government has been excavating this great center for 30 years. Remarkable examples of building, of art, and of ways of living during Roman times in North Africa have been disclosed, all supported by the agriculture of the Granary of Rome.

But today this great center of power and culture of the Roman Empire is desolation. It is represented by a modern village of only a few hundred inhabitants who live in squalid structures, the walls of which are for the most part built of stone quarried from the ruins of the ancient city. Water erosion has cut a gully down into the land and exposed an ancient aqueduct that supplied water to the city of Timgad from a great spring some 3 miles away.

FIGURE 10.—Ruins of the amphitheater at the former city of Thysdrus, in Tunisia, which would seat 60,000 people. Today, only a few thousand people inhabit this area. The small flock of sheep in the foreground are a fair indication of the land's ability to support life.

Within and surrounding Timgad, we studied remarkable ruins of great olive presses where today there is not a single olive tree within the circle of the horizon.

On the plain of Tunisia we came upon in El Jem the ruins of a great amphitheater, second only in size to that of Rome. (fig. 10). It was built to seat some 60,000 people, but it would be difficult to find 5,000 persons today within this district. The ancient city now lies buried around the amphitheater and a sordid modern village is built on the buried city.

What was the cause of the decadence of North Africa and the decline of its population? Some students have suggested that the climate changed and became drier, forcing people to abandon their remarkable cities and works. But Gsell, the renowned geologist who studied this problem for 40 years, challenged the conclusion that the climate has changed in any important way since Roman times.

So Director Hodet of the Archaeological Excavations at Timgad decided as an experiment to plant olive trees on an unexcavated part of the city where there would be no possibility of subirrigation. He planted young olive trees in the manner prescribed in Roman literature, watering them in the following two long dry summer seasons. These olive trees are thriving, indicating that where soils are still in place, olive trees will grow today probably very much as they did in Roman times.

On the plains about Sfax, ruins of olive presses were found by early travelers, but no olive trees. Forty years ago an experiment to plant olive trees there was decided upon. Now more than 150,000 acres are planted to olive trees; their products support thriving industries in the modern city of Sfax. These plantings indicate that the climate of today has not become significantly drier since Roman times.

Other students of this baffling problem have suggested that pulsations of climate with intervening dry periods, sufficient to blot out the civilization of North Africa, have taken place. Such undoubtedly could have been the case. But at Sousse we found telling evidence on this point in an olive grove that has survived since Roman times. These olive trees were at least 1,500 years old, we were informed.

I was interested in the way these trees were planted—in basins bordered by banks of earth with ways of leading in unabsorbed storm runoff from higher ground. We passed along this area at a time of heavy rains which showed just how this method had worked since the trees were first planted. If there have been pulsations of climate since Roman times, this grove should show that the drier periods were not sufficiently severe to kill the olive trees. We conclude that it does not seem probable that either a progressive change of climate or pulsations of climate account for the decadence of North Africa. We must seek other causes.

On hillsides between Constantine and Timgad, we found on the land a record that indicates what has happened to soils of the granary of ancient Rome. We found some hills that, according to the botanists, were covered with savannah vegetation of scattered trees and grass. Vegetation had conserved a layer of soil on these hills for unknown ages.

With the coming of a grazing culture, brought in by invading nomads of Arabia, erosion was unleashed by overgrazing of the hills. We can see here on the landscape how the soil mantle was washed off the upper slopes to bedrock. Accelerated runoff from the bared rock cut gullies into the upper edge of the soil mantle, working it downhill as if a great rug were being pulled off the hills.

The accumulation of torrential flows during winter storms is cutting great gullies through the alluvial plains just as it does in New Mexico, Arizona, and Utah of our own country. The effect of this is to lower the water table, bringing about the effects of desiccation without reduction in rainfall.

In this manner has the country been seriously damaged, and its capacity to support a population much reduced. Unleashed and uncontrolled soil erosion is sufficient to undermine a civilization, as we found in North China and as seems to be true in North Africa as well.

The Dry Lands of North Africa

We traveled across North Africa southward toward the Sahara Desert into zones of less and less rainfall. Beyond the cultivated area in Roman times was a zone devoted to stockraising on a large scale. Thousands of cisterns were built in Roman or pre-Roman times to catch storm runoff from the land to store it for outlying villages and for watering herds of livestock during the dry summer seasons.

Many of these cisterns were being cleaned out and repaired by the French Government before World War II, to be used for the same purpose as they were in ancient times. One of the modern cisterns was four times as large as any Roman cistern, with a capacity of 100,000 cubic feet. This cistern was filled in 2 years and now furnishes water for the seminomads who inhabit this part of North Africa.

Still farther toward the desert, about 70 miles south of Tebessa, we found a remarkable example of ancient measures for the conservation of water. At some time in the Roman or possibly pre-Roman period, peoples of this region built check dams to divert storm water around slopes into canals to spread it upon a remarkable series of bench terraces.

This area of unusual interest raises a number of questions we are not yet able to answer. If these terraces were cultivated to crops in times past, they are the best evidence we have that climate has become drier since they were first built. But if they were built for spreading water to increase forage production for grazing herds, as the French are using them today, they are not evidence of an adverse change of climate. This evidence alone could leave us in doubt, but other evidence indicates that water spreading was most used here for crops.

It would be interesting to know the date and the reason for building these terraces. They may indicate that with

Roman occupation of North Africa the native tribes were driven beyond the border of the Roman Empire and were forced to devise these refined measures for conservation and use of water in a dry area. Or they may indicate that North Africa was so densely populated that it was necessary to use these refinements in the conservation of water to support the population on the margins of a crowded region.

While the land of North Africa has been seriously damaged, as one can see written on landscape after landscape, the country is still capable of far greater than its present production. In Roman times a high degree of conservation of soils and waters was reached with an intensive culture of orchards and vineyards on the slopes and intensive grain growing in the valleys.

All this depended on efficient conservation and use of the rainfall. We find numerous references to such practices in the literature of the time. But, as nomads swept in out of the desert, their extensive and exploitive grazing culture replaced these highly refined measures of land use and let them fall into disuse and ruin. Erosion was unleashed on its destructive course, and the capacity of the land to support people was seriously reduced.

The veteran student of North Africa, Professor Gautier, answered my query as to whether climate of North Africa had changed since Roman times, in the following way: "We have no evidence to indicate that the climate has changed in an important degree since Roman times, but the people have changed."

We conclude that the decline of North Africa is due to a change in a people and more especially to a change in culture and methods of use of land that replaced a highly developed and intensive agriculture and that allowed erosion to waste away the land and to change the regime of waters.

A Word About Land Use in Italy

The westward course of civilization has left its marks in Italy. We found at Paestum, south of Naples, one of the best preserved Greek temples, located on the coastal plain near the sea. Here, there was no overwash of erosional material or accumulation of dust from wind erosion and no gully erosion in the plain. We walked on the same level as the Greeks who built the temple 2,600 years ago.

But population pressure in Italy, under its smiling climate and blue skies, has pushed the cultivation line up the slopes and caused the building of villages on picturesque ridge points. In Italy there are 826 persons per square mile of cultivated land, while in the United States there are only 208.

This method of comparing population density gives us the advantage because of our vast grazing lands that support great herds of livestock. But if we had the same density of population per square mile of cultivated land in the United States as has Italy, we should have 520 million people. This gives us some idea of the relative densities and pressures of population upon the land and accounts for the intensive use not only of the plains but of the steep slopes.

We do not have space to tell the details of how the Pontine Marshes, that for 2,000 years defied the reclamation efforts of former rulers of Italy, were successfully reclaimed recently. This former pestilential area has been drained and rid of malaria and is now divided into farms equipped with reinforced concrete houses of attractive design, where families are established free from perils of malaria and safe in the security of their land.

Torrent Control in the French Alps

In southeastern France we found the same condition of intensive use of land on valley floors and on steep, terraced slopes. In the French Alps, population pressure on land of the plains has pushed the cultivation line up the slopes into mountains and has denuded grassy meadows by overgrazing.

This excessive use of the mountainous

FIGURE 11.—A terraced citrus orchard in southern France. It is believed that terraces of this type were first built in France by the Phoenicians about 2,500 years ago. Modern French farmers are still maintaining and farming such hillsides, however, because of the scarcity of good land.

areas in the French Alps unleashed torrential floods that for more than a century ravaged productive Alpine valleys. Erosional debris was swept down by recurring torrential floods to bury fields, orchards, and villages; to cut lines of communication; and to kill inhabitants of the valleys.

So serious became this menace to the welfare of the region that the French Government, after much study and legislation, undertook in 1882 a constructive program of torrent control. Since that time hundreds of millions of francs have been spent for works of torrent control that are remarkably successful.

Intensive Land Use in France

We found slopes in southern France cultivated on gradients up to 100 percent with terrace walls as high as the benches were wide. Some of these terraced fields had been under cultivation for more than a thousand years—likely much longer, for the Phoenicians are believed to be responsible for terracing in this part of France (fig. 11).

When the soils of these terraces become fatigued, as the French say, they are turned over to a depth of more than 3 feet once in 15 to 30 years as the need may be. Thereafter, a cover crop is planted on the newly exposed soil material for two or more years, followed by plantings of orchard trees or vines or vegetables.

In eastern France we found in various stages adjustments of farming to slopes. In places, terraces were built with rock walls on the contour to reduce slope gradients; elsewhere, rock walls were built on the contour to form level benches. At other places, farmers dug up the soil of the bottom furrow of their fields that were laid out in contour strip crops, loaded the soil into carts, hauled it to the upper edges of the fields, and dumped it along the upper contour furrows to compensate for downslope move-

FIGURE 12.—These French farmers are digging up the soil along the lower furrow of their field and loading it into a cart. It will be hauled uphill and spread along the upper edge. They do this job each winter to help compensate for the downhill movement of soil by erosion.

ment of soil under the action of plowing and the wash of rain (fig. 12). This was done each year. Where the slope was too steep to haul the soil uphill, they loaded the soil of the bottom furrow in baskets and carried it on their backs to the upper edges of the field. In this way these farmers of France take care of their soil from generation to generation.

In southwestern France, in the region of Les Landes, we studied, probably, the greatest achievement of mankind in the reclamation of sand dunes. It is recorded that the Vandals in A. D. 407 swept through France and destroyed the settlements of the people who in times past had tapped pine trees of the Les Landes region and supplied resin to Rome. Vandal hordes razed the villages, dispersed the population, and set fire to the forests, destroying the cover of a vast sandy area. Prevailing winds from the west began the movement of sand. In time, moving sand dunes covered an area of more than 400,000 acres that in turn created 2¼ million acres of marshland.

Sand dunes in their eastward march covered farms and villages and dammed streams, causing marshes to form behind them. Malaria followed and practically depopulated the once well-peopled and productive region. These conditions caused not only disease and death, but impoverishment of the people as well.

In 1778 Villers was appointed by the French Government to create a military port at Arcachon. He reported that it was first necessary to conquer the movement of the sand dunes, and presented the principle of "dune fixation." About 20 years later Napoleon appointed his famous engineer, Bremontier, to control these dunes.

Space will not permit my telling the fascinating details of this remarkable story—of how the dunes were conquered by establishing a littoral dune and reforesting the sand behind, and how marshy lands were drained by Chambrelent after a long period of experimentation and persuasion of public officials. Now this entire region is one vast forest supporting thriving timber and resin industries and numerous health resorts.

Fortunately for comparison, one dune on private land was for some reason left uncontrolled. This dune is 2 miles long, ½ mile wide, and 300 feet high (fig. 13). It is now moving landward, covering the forest at the rate of about 65 feet a year. As I stood on this dune and saw in all directions an undulating evergreen forest to the horizon, I began to appreciate the magnitude of the achievement of converting the giant sand-dune and marshland into profitable forests and health resorts.

How the Dutch Farm the Ocean Floor

In Holland we found another of mankind's great achievements—the reclamation of the ocean floor for farming.

Holland is a land of about 8¼ million acres, divided into two almost equal parts—above and below high-tide level. It is inhabited by 8 million industrious people. Its land included the great delta of the North Sea built up with the products of erosion sculptured out of the lands of Germany and Switzerland and northeastern France, brought down by the Rhine and Meuse Rivers. Now 45 percent of the area lies below high-tide level and one-fourth lies below mean sea level. The Dutch from time immemorial have been carrying on an unending battle with the sea. They have become expert in filching land from the grasp of the angry waters of the North Sea.

If the United States were as densely populated per square mile of cultivated land as Holland, the population of the United States would be 1¼ billion. The density of population of Holland has called for an increase of its land area.

FIGURE 13.—One of the uncontrolled sand dunes in the Les Landes forest of southwestern France. French engineers have, in the past, brought about 400,000 acres of such dunes under control, and the area is again producing timber.

FIGURE 14.—A Dutch farm in the Wieringermeer Polder of the Netherlands. Only 7 years before this picture was taken this land was covered by the North Sea.

Rather than to seek additional land by conquest of its neighbors it has turned to the conquest of the sea.

The Zuider-Zee project, two centuries in the planning, is Holland's masterpiece in a 2,000-year battle with the North Sea. This project adds more than 550,000 acres of new land to Holland's territory, converting the old salt Zuider-Zee into a sweet-water lake renamed the Yssel Meer.

The Dutch have built great dikes to dam off the sea and have pumped the water out of the basins with great pumping plants. They have diked off the sea and dewatered the land, leached it of its salt, and converted it into productive farm land. We stood on fertile farm land that was the floor of the sea only 7 years earlier, but now is divided into farms equipped with fine houses and great barns (fig. 14). At a cost of about $200 an acre, this land was reclaimed from the sea and divided into farms.

The Dutch by this means have created a new agricultural paradise into which only select farmers may enter. Out of 30 applications for each farm, one applicant is selected on the basis of character, the past record of his family, and his freedom from debt. The successful applicant is put on probation for a period of 6 years. If he farms the land in accordance with the best interests of the land and of the country, he will be permitted to continue for another period. If he fails to do so, he must get off and give another farmer applicant a chance.

A Glance at England

In the mild climate of England, we find that tillers of soil have had little difficulty with soil erosion. This is true because rains come as mists, slopes are gentle, and fields are usually farmed to close-growing crops. England is well suited to grassland farming and to the growing of small grains. Clean-tilled crops have never been in general use. We found fields in England that have been cultivated for more than a thousand years where the yields of wheat have been raised to averages of 40 to 60 bushels per acre. The maximum yield thus far is 96 bushels to the acre. The principal problems before the farmers of England are rotations, seed selection, and farm implements.

World War II made new demands on the lands of England. Before blockading action by the enemy, the British Isles depended on imports for two-thirds of their total food supply. One-third of their population was fed from their own lands, requiring about 12 million acres of cultivated land for this purpose. Fully 50 percent more land was plowed to grow food crops. Pastureland and grassland on slopes were cultivated. Soil erosion may become a problem more serious than ever before in British agriculture, because of the extraordinary demands for the growing of food.

The New World

And now we cross the Atlantic to the new land which was isolated from the peoples of the Old World until civilization had advanced through fully 6,000 years.

The peoples found here, presumably descendants of tribes coming from Asia in the distant past, had been handicapped in the development of agriculture by lack of large animals suitable for domestication and by ignorance of the wheel and the use of iron. They had, however, learned to conserve soil and water in a notable way, especially in the terrace agriculture of Peru and Central America and in the Hopi country of southwestern United States. Some have held that this knowledge was brought across the South Pacific by way of islands, on many of which such practices are still found. In any case, lacking iron or even bronze tools, these peoples for the most part still depended largely on hunting, fishing, and gathering—along with shifting cultivation—for their livelihood. Thus, the soil resources seem to have been for the most part almost unimpaired.

To the peoples of the Old World, the Americas were a land of promise and a release from the oppressions, economic and political, brought on by congested populations and failures of people to find adjustments to their long-used land.

North America, as the first colonists entered it, was a vast area of good land, more bountiful in raw materials than ever was vouchsafed any people. Its soils were fat with accumulated fertility of the ages; its mountains were full of minerals and forests; its clear rivers were teeming with fish. All these were abundant—soil productivity, raw materials, and power for a remarkable civilization.

Here was the last frontier; for there are no more new continents to discover, to explore, and to exploit. If we are to discover a way of establishing an enduring civilization we must do it here; this is our last stand. We have not yet fully discovered this way; we are searching for the way and the light. Here is a challenge of the ages to old and young alike. Here is a chance to solve this age-old problem of establishing an enduring civilization—of finding an adjustment of a people to its land resources.

Our land is like a great farm with fields suited to the growing of cotton, corn, and other crops and with land for pastures, woods, and general farming. In the West, our country has vast grazing lands well suited to the raising of herds of sheep and cattle and fertile alluvial valleys in the arid regions, overawed by high mountains that condense the waters out of moisture-laden winds to irrigate garden lands. Such is the American farm, capable of feeding at least 350 million people when the land is intensively cultivated under full conservation and fully occupied with a complex division of labor that will give us a higher general standard of living than we enjoy today.

The Record of Our Own Land

But now let us read the record of our own land in a short period of 300 years.

In the past 150 years, our occupation of this fabulous land has coincided with the coming of the age of science and power-driven machines.

Along the Atlantic coast in the Piedmont we find charming landscapes of fields with red soils and glowing grain fields. But in their midst we find an insidious enemy devouring the land—stealing it away, ere we are aware, by sheet erosion, rain by rain, washing it down into the streams and out to the sea. Sheet erosion, marked by shallow but numberless rills in our fields, is blotted out by each plowing.

We forget what is happening to the good earth until we measure these soil and water losses. More than 300 million acres out of our 400-odd million acres of farm fields are now eroding faster than soil is being formed. That means destruction of the land if erosion is not controlled.

We are not guessing. Erosion experiment stations located throughout the country have given us accurate answers. Let us compare rates of erosion under different conditions of land coverage and use. Measurements through 5 years at the Statesville, N. C., erosion experiment station show that, on an 8-percent slope, land in fallow without cropping lost *each year* an average of 29 percent of rainfall in immediate runoff and 64 tons of soil per acre in wash-off of soil.

This means that in 18 years, 7 inches of soil (the average depth of topsoil) would be washed away. Under continuous cropping to cotton, as was once the general practice in this region, the land lost each year an average of 10 percent of rainfall and 22 tons of soil per acre per year.

At this rate it would take 44 years to erode away 7 inches of soil. Rotations reduced, but did not stop, erosion for the land lost 9 percent of the rain and enough soil so that it would take 109 years to erode away 7 inches of soil. That is a very short time in the life of our Nation. But where the land was kept in grass, it lost less than 1 percent of rain and so little soil that it would take 96,000 years to wash away 7 inches of soil. This rate is certainly no faster than soil is formed.

Under the natural cover of woods, burned over annually, as has unfortunately been the custom in southern woods, each year the land lost 3½ percent of rain and 0.06 ton of soil per acre so that it would take 1,800 years to erode away 7 inches of soil. But where fire was kept out of the woods and forest litter accumulated on the forest floor, the land lost less than one-third of 1 percent of the rainfall. And, according to the calculations, it would require more than 500,000 years to wash away 7 inches of soil. Such a rate of erosion is indeed far below the rate of soil formation.

Here in a nutshell, so to speak, we have the underlying hazard of civilization. By clearing and cultivating sloping lands—for most of our lands are more or less sloping—we expose soils to accelerated erosion by water or by wind and sometimes by both water and wind.

In doing this we enter upon a regime of self-destructive agriculture. The direful results of this suicidal agriculture have in the past been escaped by migration to new land or, where this was not feasible, by terracing slopes with rock walls as was done in ancient Phoenicia, Peru, and China.

Escape to new land is no longer a way out. We are brought face to face today with the necessity of finding out how to establish permanent agriculture on our farms under cultivation before they are damaged beyond reclamation, and before the food supply of a growing population becomes deficient.

In an underpopulated land such as ours, farmed extensively rather than intensively, there will be considerable slack before privations on a national scale overtake us. But privations of individual farm families, resulting from wastage of soil by erosion, are indicators of what will come to the Nation. As our population increases, farm production will go down from depletion of soil resources unless measures of soil conservation are put into effect throughout the land.

We must be in possession of a certain amount of abundance to be provident: a starving farmer will eat his seed grain; you will do it and I will do it, even though we know it will be fatal to next year's crop. Now is the time, while we still have much good land capable of restoration to full or greater productivity, to carry through a full program of soil and water conservation. Such is necessary for building here a civilization that will not fall as have others whose ruins we have studied in this bulletin.

A solution to the problem of farming sloping lands must be found if we are to establish an enduring agriculture in the United States. We have only about 100 million acres of flat alluvial land where the erosion hazard is negligible, out of 460 million acres of land suitable for crops. Most of our production comes from sloping lands where the hazard of soil erosion is ever present. This calls urgently for the discovery, adaptation, and application of measures for conserving our soils.

In the results of the Statesville erosion experiment station we saw how a forest with its ground litter was effective in keeping down the rate of soil erosion well within rates of soil formation. Out of untold ages of unending reactions between forces of erosion that wear down the land and forces of plant growth that build up the land through vegetation, the layer of forest litter has proved to be the most effective natural agent in reducing surface wash of soil to a minimum. Here is clearly our objective for a permanent agriculture, namely, to safeguard the physical body of the soil resource and to keep down erosion wastage under cultivation as nearly as possible to this geologic norm of erosion under natural vegetation.

A few years ago I came upon a hill farmer in an obscure part of the mountains of Georgia. He was trying to apply on his cornfield the function of forest litter as he saw it under the nearby forest on the same slope and same type of soil.

It was for me a great experience to talk with J. Mack Gowder of Hall County, Ga., about the fields he had cultivated for 20 years in a way that has caught the

FIGURE 15.—A formerly productive field in Virginia that has been cut to pieces by gully erosion. About 50 million acres of good farm land in the United States have been ruined for further practical cultivation by similar types of erosion.

imagination of thoughtful agriculturists of the Nation. We talked about the simple device of forest ground litter and how effective it is in preventing soil erosion even on steep slopes, and how he thought that if litter at the ground surface would work in the forest it ought also to work on his cultivated fields along the same slope.

Mr. Gowder told me how, as a young man when he bought this steep wooded land more than 20 years ago, he hoped to avoid the soil erosion that was ruining farms on smoother and better land of the country. He planned to do this by stirring his land with deep plowing but without turning the soil.

In this way, he could leave his crop litter at the surface to do the same kind of work that the forest litter does. Gowder chose a bull-tongue plow, only 4 inches wide, to do the trick. He told me that his neighbors laughed at him for such foolish ways of plowing. As a concession to customs of the region, he put in channel terraces with a slight grade as a precaution against storm runoff from unusual rains. But, thus far, they have not been needed.

Now Gowder is cultivating topsoil on slopes up to 17 percent whereas his ridiculing neighbors have only subsoil to farm. They have lost all their topsoil by erosion.

Leaving crop litter, which is sometimes called stubble mulch or crop residue, at the ground surface in farming operations is one of the most significant contributions to American agriculture. Certain adaptations of the method need to be made to meet the problems of different farming regions, but the new principle is the contribution of importance.

FIGURE 16.—This airplane view shows parts of six different farms near Temple, Tex., where the farmers have banded together to combat erosion as a community problem.

Danger Signs in America

Sheet erosion develops into gullies if allowed to continue unchecked for a few years. Such gullies become numberless gutters, leading off storm waters and flash floods that gouge out miniature gorges and ruin the land for further cultivation (fig. 15). Material washed out of such gullies is swept down into river valleys to shoal streams, filling reservoirs, and destroying water storage for hydroelectric power and for irrigation.

One of the most important findings of this survey of the use of land through 7,000 years is that tillers of soil have encountered their greatest problem throughout the ages in trying to establish a permanent agriculture on sloping lands. We have read the record, as written on the land, of failures from place to place but of few instances of success. This same problem is with us in our new land of America, where millions of acres have been destroyed for further cultivation and abandoned.

The Way to an Enduring Agriculture

Our solution for safeguarding our soils on slopes where soil erosion by water is the hazard is (1) to increase the rainwater-intake capacity of the soil by retaining crop litter at the surface, soil improvement, crop rotations, and strip cropping on the contour and (2) to lead away unabsorbed storm waters in channels of broad-base terraces into outlet channels and into natural drainage channels. We have applied these measures during recent years over millions of acres as you may see from an airplane when you fly over the country.

Near Temple, Tex., in the drainage of North Elm Creek, 174 farmers of bordering farms formed a soil conservation association on a drainage basis, ignoring property and county lines in the same way as runoff water ignores such arbitrary lines (fig. 16). Terrace-outlet channels were laid out to carry water harmlessly through one farm and another to natural drainage channels. One terrace-outlet system may serve in this way as many as 5 farms. By this approach to conservation, it is possible to treat the land in accordance with its adaptabilities and to control storm waters according to hydraulic principles. This is indeed physiographic engineering that builds a lasting basis for a thriving civilization.

This does not mean that we have yet found the final answer to full control of soil erosion. Our present practices may not yet stop erosion but will reduce it more and more as application of measures is more and more complete. These measures and others will need further improvement and adaptation to the problems as use of land becomes more and more intensive.

Wind erosion is a serious and destructive problem but restricted to a smaller area of the country than water erosion. Wind erosion attacks level as well as sloping cultivated land in semiarid parts of the country. Wind erosion sorts the soil more thoroughly than water erosion, lifting fine and fertile particles of soil aloft and leaving behind coarser and heavier particles that become sandy hummocks, then sand dunes. Such was the case in the so-called Dust Bowl of the Great Plains.

Control of wind erosion is based first upon a suiting of the land's use to its capabilities and conserving all or most all of the rain that falls on it. This calls for contour farming except on flat lands. Appropriate measures include strip shelter belts of crops, tillage practices that leave crop litter or residue at the surface, and rotations suited to moisture supplies in the soil. These, with progressive improvement of soil-management practices, will control wind erosion. It has proved a simpler task, however, to control wind erosion than the less spectacular but more insidious water erosion.

Lessons From the Old World

In this discussion on lessons from the Old and New Worlds in conserving the vital heritage of our people, I have laid special emphasis on saving the physical body of soil resources rather than their fertility. Maintaining fertility falls properly to the farmer himself. Conserving the physical integrity of the soil resource falls to the Nation as well as to the farmer and landowner, in order to save the people's heritage and safeguard the national welfare. If the physical body of the soil resource is saved, we as a people are safeguarded in liberty of action. We can apply fertilizer and plant a choice of crops in accord with market demands and national needs.

If the soil is destroyed, then our liberty of choice and action is gone, condemning this and future generations to needless privations and dangers. So big is this job—of saving our good land from further damage and of reclaiming to some useful purpose vast areas of seriously damaged land—that full cooperation of the individual interest of farmers with technical leadership and assistance of the Government is not only desirable, but necessary, if we are to succeed.

Another conclusion from our survey of the use of land through 7,000 years, where economic conditions have changed for better or for worse more rapidly than climate, is that land after all is not an economic commodity. It is an integral part of the Nation even as its people are and requires protection by the individual owner and by the Nation as well. Nowhere have we found more telling evidence of this than in California where gold in 1849 lured a host of people to the State, but soils of its valleys have maintained its settlement.

An "Eleventh Commandment"

When in Palestine in 1939, I pondered the problems of the use of the land through the ages. I wondered if Moses, when he was inspired to deliver the Ten Commandments to the Israelites in the Desert to establish man's relationship to his Creator and his fellow men—if Moses had foreseen what was to become of the Promised Land after 3,000 years and what was to become of hundreds of millions of acres of once good lands such as I have seen in China, Korea, North Africa, the Near East, and in our own fair land of America—if Moses had foreseen what suicidal agriculture would do to the land of the holy earth—might not have been inspired to deliver another Commandment to establish man's relation to the earth and to complete man's trinity of responsibilities to his Creator, to his fellow men, and to the holy earth.

When invited to broadcast a talk on soil conservation in Jerusalem in June 1939, I gave for the first time what has been called an "Eleventh Commandment," as follows:

Thou shalt inherit the Holy Earth as a faithful steward, conserving its resources and productivity from generation to generation. Thou shalt safeguard thy fields from soil erosion, thy living waters from drying up, thy forests from desolation, and protect thy hills from overgrazing by thy herds, that thy descendants may have abundance forever. If any shall fail in this stewardship of the land thy fruitful fields shall become sterile stony ground and wasting gullies, and thy descendants shall decrease and live in poverty or perish from off the face of the earth.

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