SOIL: A RENEWABLE RESOURCE

Growing the food and fiber needed to support human life is a complex enterprise that requires knowledge from many different fields and cooperation from many different groups of people. In this section, we'll survey some of the principles of soil science and look at some of the inputs necessary for continued agricultural production.

Of all the earth's crustal resources, the one we take most for granted is soil. We are terrestrial animals and depend on soil for life, yet most of us think of it only in negative terms. English is unique in using "soil" as an interchangeable word for earth and excrement. "Dirty" has a moral connotation of corruption and impurity. Perhaps these uses of the word enhance our tendency to abuse soil without scruples; after all, it's only dirt.

The truth is that **soil** is a marvelous substance, a living resource of astonishing beauty, complexity, and frailty. It is a complex mixture of weathered mineral materials from rocks, partially decomposed organic molecules, and a host of living organisms. It can be considered an ecosystem by itself. Soil is an essential component of the biosphere, and it can be used sustainably, or even enhanced, under careful management.

There are at least 15,000 different soil series or types in the United States and many thousands more worldwide. They vary because of the influences of parent material, time, topography, climate, and organisms on soil formation. There are young soils that, because they have not weathered much, are rich in soluble nutrients. There are old soils, like the red soils of the tropics, from which rainwater has washed away most of the soluble minerals and organic matter, leaving behind clay and rust-colored oxides.

To understand the potential for feeding the world on a sustainable basis we need to know how soil is formed, how it is being lost, and what can be done to protect and rebuild good agricultural soil. With careful husbandry, soil can be replenished and renewed indefinitely. Many farming techniques deplete soil nutrients, however, and expose the soil to the erosive forces of wind and moving water. As a result, in many places we are essentially mining this resource and using it much faster than it is being replaced.

Building good soil is a slow process. Under the best circumstances, good topsoil accumulates at a rate of about 10 tons per hectare (2.5 acres) per year—enough soil to make a layer about 1 mm deep when spread over a hectare. Under poor conditions, it can take thousands of years to build that much soil. Perhaps one-third to one-half of the world's current croplands are losing topsoil faster than it is being replaced. In some of the worst spots, erosion carries away about 2.5 cm (1 in.) of topsoil per year. With losses like that, agricultural production has already begun to fall in many areas.

Soil is a complex mixture

Most soil is about half mineral. The rest is plant and animal residue, air, water, and living organisms. The mineral particles are derived either from the underlying bedrock or from materials transported and deposited by glaciers, rivers, ocean currents,

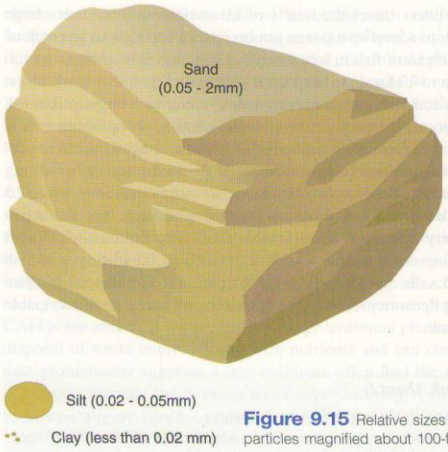


Figure 9.15 Relative sizes of soil particles magnified about 100-fold.

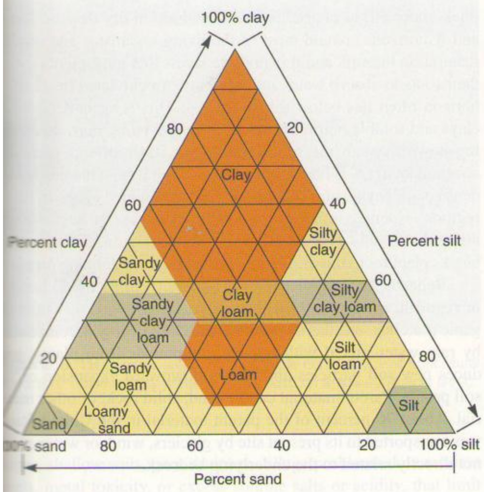
windstorms, or landslides. The weathering processes that break rocks down into soil particles are described in chapter 14.

Particle sizes affect the characteristics of the soil (fig. 9.15). The spaces between sand particles give sandy soil good drainage and usually allow it to be well aerated, but also cause it to dry out quickly when rains are infrequent. Tight packing of small particles in silty or clay soils makes them less permeable to air and water than sandy soils. Tiny capillary spaces between the particles, on the other hand, store water and mineral ions better than more porous soils. Because clay particles have a proportionately large surface area and a high ionic charge, they stick together tenaciously, giving clay its slippery plasticity, cohesiveness, and impermeability. Soils with a high clay content are called "heavy soils," in contrast to easily worked "light soils" that are composed mostly of sand or silt. Varying proportions of these mineral particles occur in each soil type (fig. 9.16). Farmers usually consider sandy loam the best soil type for cultivating crops.

The organic content of soil can range from nearly zero for pure sand, silt, or clay, to nearly 100 percent for peat or muck, which is composed mainly of partly decomposed plant material. Much of the organic material in soil is **humus,** a sticky, brown, insoluble residue from the partially decomposed bodies of dead plants and animals. Humus is the most significant factor in the development of "structure," a description of how the soil particles clump together. Humus coats mineral particles and holds them together in loose crumbs, giving the soil a spongy texture that holds water and nutrients needed by plant roots, and maintains the spaces through which delicate root hairs grow.

Living organisms create unique properties of soil

Without soil organisms, the earth would be covered with sterile mineral particles far different from the rich, living soil ecosystems on which we depend for most of our food. The activity of the myriad organisms living in the soil help create structure, fertility, and tilth (condition suitable for tilling or cultivation) (fig. 9.17).



igure 9.16 Soil texture is determined by the percentages of y, silt, and sand particles in the soil. Soils with the best texture most crops are loams, which have enough larger particles (sand) be loose, yet enough smaller particles (silt and clay) to retain ater and dissolved mineral nutrients.

Soil organisms usually stay close to the surface, but that thin living layer can contain thousands of species and billions of individual organisms per hectare. Algae live on the surface, while bacteria and fungi flourish in the top few centimeters of soil. A single gram of soil (about one-half teaspoon) can contain hundreds of millions of these microscopic cells. Algae and blue-green bacteria capture sunlight and make new organic compounds. Bacteria and fungi decompose organic detritus and recycle nutrients that plants can use for additional growth. The sweet aroma of freshly turned soil is caused by actinomycetes, bacteria that grow in funguslike strands and give us the antibiotics streptomycin and tetracyclines.

Micorrhizal symbiosis is an association between the roots of most plant species and certain fungi. The plant provides organic compounds to the fungus, while water and inorganic nutrients are absorbed from the soil by the fungus and transferred to the plant. As a result, micorrhizal plants often grow better—especially in infertile soil—than those lacking fungal partners. There can be 20 m of fungal strands in a gram of soil.

Roundworms, segmented worms, mites, and tiny insects swarm by the thousands in that same gram of soil from the surface. Some of them are herbivorous, but many of them prey upon one another. Soil roundworms (nematodes) attack plant rootlets and can cause serious crop damage. A carnivorous fungus snares nematodes with tiny loops of living cells that constrict like a noose when a worm blunders into it. Burrowing animals, such as gophers, moles, insect larvae, and worms, tunnel deeper in the soil, mixing and aerating it. Plant roots also penetrate lower soil levels,

igure 9.17 Soil ecosystems include numerous consumer organisms, as depicted here: (1) snail, (2) termite, (3) nematodes and nematode-killing stricting fungus, (4) earthworm, (5) wood roach, (6) centipede, (7) carabid (ground) beetle, (8) slug, (9) soil fungus, (10) wireworm (click beetle a), (11) soil protozoan, (12) sow bug, (13) ant, (14) mite, (15) springtail, (16) pseudoscorpion, and (17) cicada nymph.

drawing up soluble minerals and secreting acids that decompose mineral particles. Fallen plant litter adds new organic material to the soil, returning nutrients to be recycled.

Soils are layered

Most soils are stratified into horizontal layers called **soil horizons** that reveal much about the history and usefulness of the soil. The thickness, color, texture, and composition of each horizon are used to classify the soil. Together these horizons make up a **soil profile** (fig. 9.18).

The soil surface is often covered with a layer of leaf litter, crop residues, or other fresh or partially decomposed organic material. This organic layer is known as the O horizon. Below this layer is the A horizon or **topsoil,** composed of mineral particles mixed with organic material. The A horizon can range from several meters thick under virgin prairie to almost nothing in dry deserts. The O and A horizons contain most of the living organisms and organic material in the soil, and it is in these layers that most plants spread their roots to absorb water and nutrients. An eluviated (leached) E horizon often lies below the A horizon. This layer is depleted of clays and soluble nutrients, which are removed by rainwater seeping down through the soil. These clays and nutrients generally accumulate in the B horizon, or **subsoil.** The B horizon may have a dense or clayey texture because of the accumulated clays. In desert regions, a dense, impermeable "hardpan" layer of accumulated minerals or salts may develop on the B horizon. This hardpan blocks plant root growth and prevents water from draining properly.

Beneath the subsoil is parent material, called the C horizon or **regolith,** made of weathered rock fragments with very little organic material. Weathering in the C horizon, largely accomplished by rain water mixed with organic compounds from plants, produces new soil particles and allows downward expansion of the soil profile. Parent material can be sand, solid rock, or other material. About 70 percent of the parent material in the United States was transported to its present site by glaciers, wind, or water and is not directly related to the underlying bedrock.

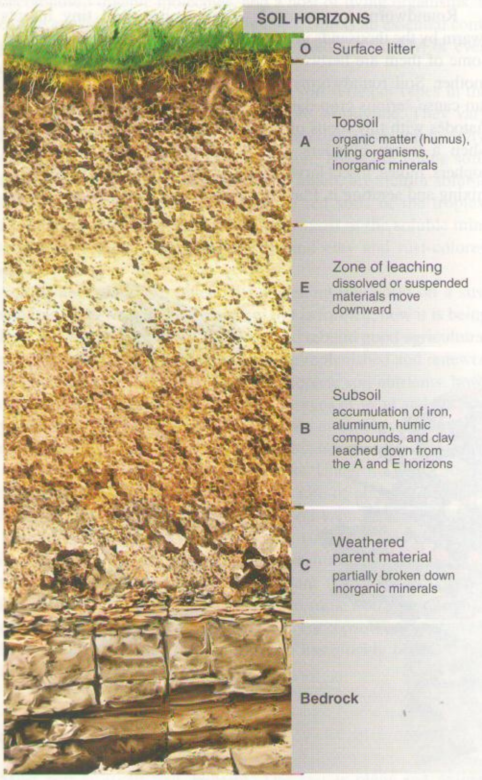


Figure 9.18 Soil profile showing possible soil horizons. The actual number, composition, and thickness of these layers varies in different soil types.

Soils are classified according to their structure and composition

In the United States, soils are classified into 12 *soil orders.* The richest farming soils, with thick, organic-rich A horizons are *mollisols* (formed under grasslands) and *alfisols* (formed under deciduous forests). Both of these develop where rainfall and temperatures are moderate. *Spodosols* also develop in temperate climates, but usually under pine forests, where acidic needle litter causes a characteristic whitish, ashy-looking E horizon. In hot and rainy environments, *oxisols* and *ultisols* develop. These soils are severely depleted of nutrients and tend to be reddish because iron-rich minerals make up much of the remaining soil material. *Aridosols* form in arid environments, have little organic material, and often contain accumulated salt or hardpan layers. Some soil types are defined mainly by parent material: *andisols* develop from volcanic material, and *vertisols* develop from clay-rich material such as lake beds or shale bedrock. *Histosols* are formed of waterlogged, incompletely decayed plant material. Other soils are largely defined by degree of development; *entisols* and *inceptisols* have little or no horizon development. This may be because these soils are on recently exposed parent material (such as glacial debris) or because they are in an environment where soil development is extremely slow because of slight rainfall or organic activity. A relatively new soil order is *gelisols,* soils in permafrost areas. These soils occur only at high latitudes or high altitudes.

WAYS WE USE AND ABUSE SOIL

Only about 12.5 percent of the earth's land area (16.6 million km^2 out of a total of 132.4 million km^2) is currently in agricultural production. Perhaps four times as much land could potentially be converted to cropland, but much of this land serves as a refuge for cultural or biological diversity or suffers from constraints, such as steep