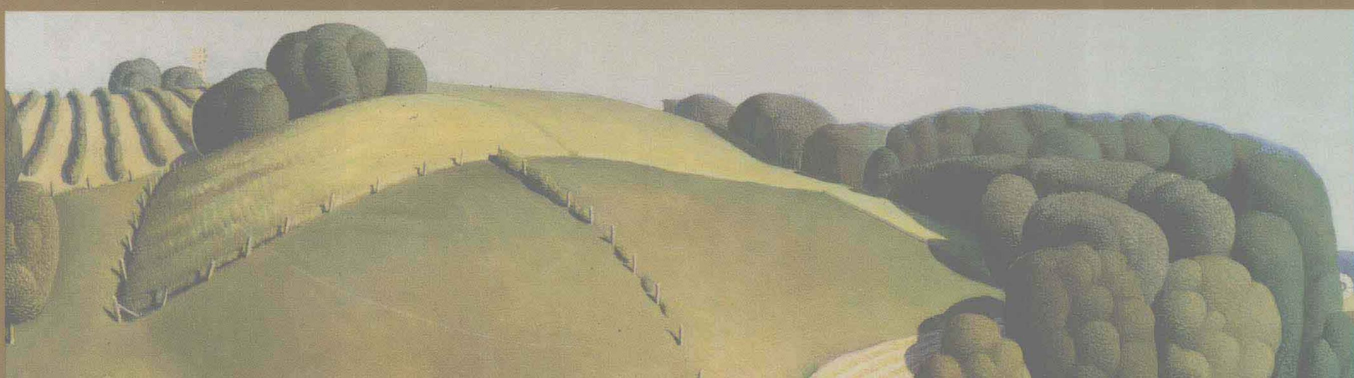
THE NATURE AND PROPERTIES OF SOILS

ELEVENTH EDITION



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The Nature and Properties of Soils

Eleventh Edition

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Preface

A fundamental knowledge of soil science is a prerequisite to meeting the many natural-resource challenges that will face humanity in the 21st century. This new edition of the classic book on soil science emphasizes the soil as a natural resource and highlights the many interactions between the soil and other components of the ecosystem. Throughout the text, soil properties and processes are illustrated with examples from forest, range, agricultural, wetland, and constructed ecosystems. Our priority is to explain the fundamental principles of soil science that have applications relevant to students in many fields of study. We recognize that for some students this book will be their only formal exposure to soil science, while for other students this book represents the initial step in a comprehensive soil science education.

We have therefore sought the advice of professors and students to help us make this book an exciting introduction to the fascinating world of soil science. We also intend for this book to be a "keeper," one that will serve natural-resource and agricultural students as a reliable reference as they pursue their professional activities in the years to come. Therefore, while much is new in substance and style in this edition, we have been careful to maintain the level of rigor and thoroughness that has made previous editions so valuable.

The study of soils can be both fascinating and intellectually satisfying. The soil is an ideal system in which to observe practical applications for basic principles of biology, chemistry, and physics. In turn, these principles can be used to minimize the degradation and destruction of one of our most important natural resources.

We gratefully acknowledge the able research and editorial assistance of Karen Lowell and Joyce Torio. The book has greatly benefited from comments and suggestions contributed by many colleagues, especially those in universities around the country who responded to our questionnaire on the 10th edition. For their advice and counsel we would like to give special thanks to Hari Eswaran, Sharon Waltman, and Diane Shields (USDA/NRCS), George Ley (Tanzania Ministry of Agriculture), Bruce James, Martin Rabenhorst, Paul Shipley, and Richard Weismiller (University of Maryland).

Last, but not least, we must express our special thanks to our wives, Martha and Trish, for their constant encouragement and for their permitting us to utilize almost every free moment during the past 18 months to concentrate on the revision of this textbook.

N. C. B. and R. R. W.

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THE SOILS AROUND US

If we take time to learn the language of the land,
the soil will speak to us.
—R. WEIL AND W. KROONTJE, LISTENING TO THE LAND

The Earth, our unique home in the vastness of the universe, is in crisis. Depletion of the ozone layer in the upper atmosphere is threatening us with an overload of ultraviolet radiation. Tropical rain forests, and the incredible array of plant and animal species they contain, are disappearing at an unprecedented rate. Groundwater supplies are being contaminated in many areas and depleted in others. In parts of the world, the capacity of soils to produce food is being degraded, even as the number of people needing food is increasing. It will be a great challenge for the current generation to bring the global environment back into balance (Figure 1.1).

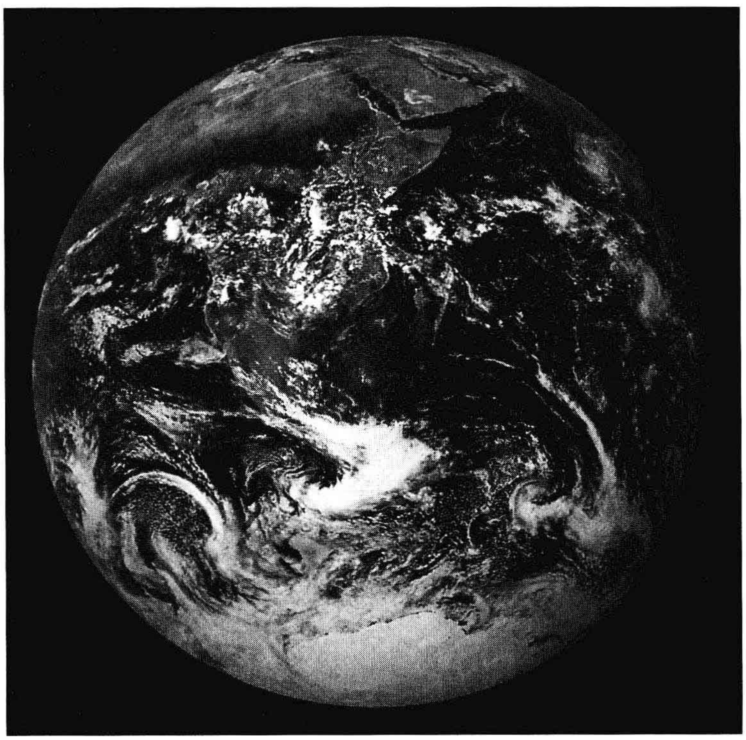

FIGURE 1.1 Our planet is unique in that it is covered with life-sustaining water and soil. Great care will be required in preserving the quality of both if our species is to continue to thrive. (Photo courtesy of NASA)

Soils are crucial to life on earth. From ozone depletion to rain forest destruction to water pollution, the global ecosystem is impacted in far-reaching ways by the processes carried out in the soil. To a great degree, soil quality determines the nature of plant ecosystems and the capacity of land to support animal life and society. As human societies become increasingly urbanized, fewer people have intimate contact with the soil, and individuals tend to lose sight of the many ways in which they depend upon soils for their prosperity and survival. The degree to which we are dependent on soils is likely to increase, not decrease, in the future. Of course, soils will continue to supply us with nearly all of our food and much of our fiber. On a hot day, would you rather wear a cotton shirt or one made of polyester? In addition, biomass grown on soils is likely to become an increasingly important source of energy and industrial feedstocks, as the world's finite supplies of petroleum are depleted over the coming century. The early signs of this trend can be seen in the soybean oil–based inks, the cornstarch plastics, and the wood alcohol fuels that are becoming increasingly important on the market (Figure 1.2).

The art of soil management is as old as civilization. As we move into the 21st century, new understandings and new technologies will be needed to protect the environment and at the same time produce food and biomass to support society. The study of soil science has never been more important to farmers, engineers, natural resource managers, and ecologists alike.

1.1 FUNCTIONS OF SOILS IN OUR ECOSYSTEM

In any ecosystem, whether your backyard, a farm, a forest, or a regional watershed, soils have five key roles to play (Figure 1.3). First, soil supports the growth of higher plants, mainly by providing a medium for plant roots and supplying nutrient elements that are essential to the entire plant. Properties of the soil often determine the nature of the veg-

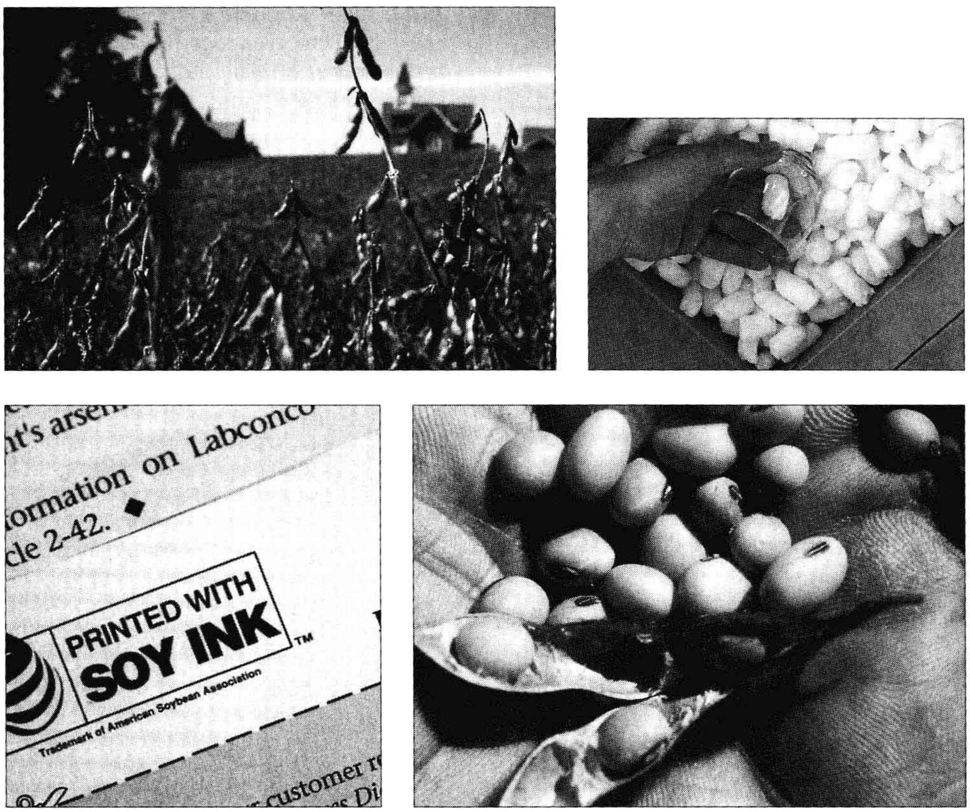

FIGURE 1.2 In the future, we will be increasingly dependent on soils to grow renewable resources that can substitute for dwindling supplies of crude oil. Plastics and inks, for example, can be manufactured from soybean seed oil instead of from petroleum. Soybean oil is edible and far less toxic to the environment. Plastics, such as packaging foam "peanuts," made from cornstarch are readily biodegradable. (Photos courtesy of R. Weil)

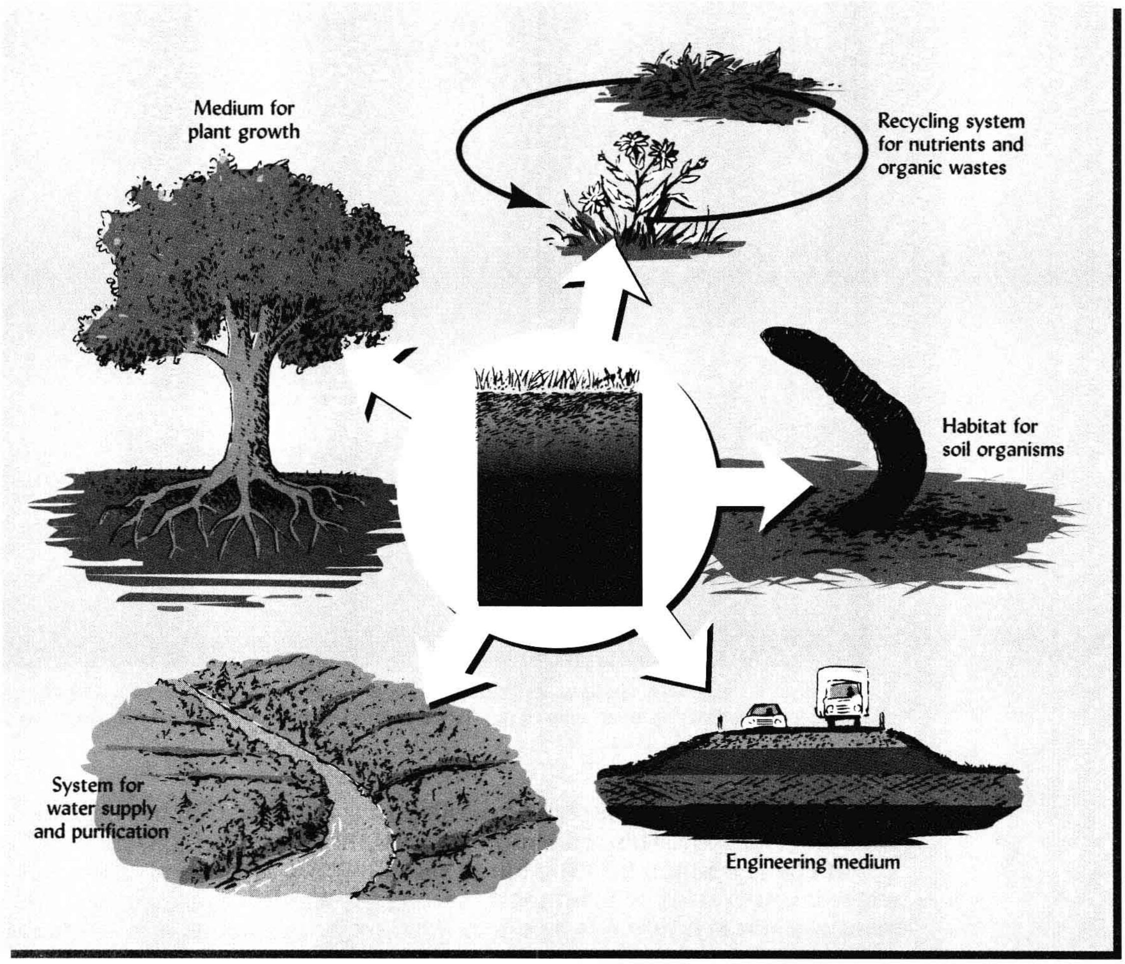

FIGURE 1.3 The many functions of soil can be grouped into five crucial ecological roles.

etation present and, indirectly, the number and types of animals (including people) that the vegetation can support. Second, soil properties are the principal factor controlling the fate of water in the hydrologic system. Water loss, utilization, contamination, and purification are all affected by the soil. Third, the soil functions as nature's recycling system. Within the soil, waste products and dead bodies of plants, animals, and people are assimilated, and their basic elements are made available for reuse by the next generation of life. Fourth, soils provide habitats for a myriad of living organisms, from small mammals and reptiles to tiny insects to microscopic cells of unimaginable numbers and diversity. Finally, in human-built ecosystems, soil plays an important role as an engineering medium. Soil is not only an important building material in the form of earth fill and bricks (baked soil material), but provides the foundation for virtually every road, airport, and house we build.

1.2 MEDIUM FOR PLANT GROWTH

Imagine a growing tree or a corn plant. The aboveground portion of this plant may be most familiar, but the portion of the plant growing below the soil surface, its root system, may be nearly as large as the portion we see above ground. What things do these plants obtain from the soils in which their roots proliferate? It is clear that the soil mass provides physical support, anchoring the root system so that the plant does not fall over. Occasionally, as in Figure 1.4, plants will fall over during windy conditions if shallow soils or restrictive soil layers make them top-heavy.

Plant roots depend on the process of respiration to obtain energy. Since root respiration, like our own respiration, produces carbon dioxide (CO_2) and uses oxygen (O_2), an

FIGURE 1.4 This wet, shallow soil failed to allow sufficiently deep roots to develop to prevent this tree from blowing over when snow-laden branches made it top-heavy during a winter storm. (Photo courtesy of R. Weil)

important function of the soil is "ventilation"—allowing CO_2 to escape and fresh O_2 to enter the root zone. This ventilation is accomplished via the network of soil pore spaces.

An equally important function of the soil pores is to absorb rainwater and hold it where it can be used by plant roots. As long as plant leaves are exposed to sunlight, the plant requires a continuous stream of water to use in cooling, nutrient transport, turgor maintenance, and photosynthesis. Since plants use water continuously, but it usually rains only occasionally, the water-holding capacity of soils is essential for plant survival. A deep soil may store enough water to allow plants to survive long periods without rain (see Figure 1.5).

FIGURE 1.5 The mango tree in this central Africa field is in full leaf and beginning to flower, even though no rain had fallen for the five months prior to when this photograph was taken. The trees are still using water stored from the previous rainy season in this deep clayey soil. It is the local belief that abundant flowering on the mango tree presages a good rainy season to come. Note that the more shallow-rooted grasses growing in thinner soils on the hillside are in a light-colored, dried-up, dormant condition. (Photo courtesy of R. Weil)

As well as moderating moisture changes in the root environment, the soil also moderates temperature fluctuations. Perhaps you can recall digging in garden soil on a summer afternoon and feeling how hot the soil was at the surface and how much cooler just a few centimeters below. The insulating properties of soil protect the deeper portion of the root system from the extremes of hot and cold that often occur at the soil surface. For example, it is not unusual for the temperature at the surface of bare soil to exceed 35 or 40°C in midafternoon, a condition that would be lethal to most plant roots. Just a few centimeters deeper, however, the temperature may be 10°C cooler, allowing roots to function normally.

There are many potential sources of **phytotoxic substances** in soils. These toxins may result from human activity, or they may be produced by plant roots, by microorganisms, or by natural chemical reactions. Many soil managers consider a function of a good soil to be protection of plants from toxic concentrations of such substances by ventilating gases, by decomposing or adsorbing organic toxins, or by suppressing toxin-producing organisms. At the same time, it is true that some microorganisms in soil produce organic, growth-stimulating compounds. These substances, when taken up by plants in small amounts, may improve plant vigor.

Soils supply plants with inorganic, mineral nutrients in the form of dissolved ions. These mineral nutrients include such metallic elements as potassium, calcium, iron, and copper, as well as such nonmetallic elements as nitrogen, sulfur, phosphorus, and boron (Table 1.1). The plant takes these elements out of the soil solution and incorporates most of them into the thousands of different organic compounds that constitute plant tissue. A fundamental role of soil in supporting plant growth is to provide a continuing supply of dissolved mineral nutrients in amounts and relative proportions appropriate for plant growth. While plants may use minute quantities of organic compounds from soils, uptake of these substances is certainly not necessary for normal growth. The organic metabolites, enzymes, and structural compounds making up a plant's dry matter consist mainly of carbon, hydrogen, and oxygen which the plant obtains by photosynthesis from air and water, not from the soil.

It is true that plants can be grown in nutrient solutions without soil (**hydroponics**), but then the plant-support functions of soils must be engineered into the system and maintained at a high cost of time, effort, and management. Although hydroponic production can be feasible on a small scale for a few high-value plants, the production of the world's food and fiber and the maintenance of natural ecosystems will always depend on the use of millions of square kilometers of productive soils.

1.3 REGULATOR OF WATER SUPPLIES

There is much concern about the quality and quantity of the water in our rivers, lakes, and underground aquifers. Governments and citizens everywhere are working to stem

TABLE 1.1 Elements Essential for Plant Growth and Their Sources[a]

Used in relatively large amounts (>0.1% of dry plant tissue)		*Used in relatively small amounts (<0.1% of dry plant tissue)*
Mostly from air and water	*Macronutrients (from soil solids)*	*Micronutrients (from soil solids)*
Carbon (C)	Nitrogen (N)	Iron (Fe)
Hydrogen (H)	Phosphorus (P)	Manganese (Mn)
Oxygen (O)	Potassium (K)	Boron (B)
	Calcium (Ca)	Molybdenum (Mo)
	Magnesium (Mg)	Copper (Cu)
	Sulfur (S)	Zinc (Zn)
		Nickel (Ni)
		Chlorine (Cl)
		Cobalt (Co)

[a]Many other elements are taken up from soils by plants, but are not essential for plant growth. Some of these elements (such as sodium, silicon, iodine, fluorine, barium, and strontium) do enhance the growth of certain plants, but do not appear to be as universally required for normal growth as are the 18 listed in this table.