1
Importance of Soil Physics

1.1 SOIL: THE MOST BASIC RESOURCE

Soil is the upper most layer of earth crust, and it supports all terrestrial life. It is the interface between the lithosphere and the atmosphere, and strongly interacts with biosphere and the hydrosphere. It is a major component of all terrestrial ecosystems, and is the most basic of all natural resources. Most living things on earth are directly or indirectly derived from soil. However, soil resources of the world are finite, essentially nonrenewable, unequally distributed in different ecoregions, and fragile to drastic perturbations. Despite inherent resilience, soil is prone to degradation or decline in its quality due to misuse and mismanagement with agricultural uses, contamination with industrial uses, and pollution with disposal of urban wastes. Sustainable use of soil resources, therefore, requires a thorough understanding of properties and processes that govern soil quality to satisfactorily perform its functions of value to humans. It is the understanding of basic theory, leading to description of properties and processes and their spatial and temporal variations, and the knowledge of the impact of natural and anthropogenic perturbations that lead to identification and development of sustainable management systems. Soil science is, therefore, important to management of natural resources and human well-being.

1.2 SOIL SCIENCE AND ECOLOGY

Ecology is the study of plants and animals in their natural environment (*oikes* is a Greek world meaning home). It involves the study of organisms and their interaction with the environment, including transformation and flux of energy and matter. Soil is a habitat for a vast number of diverse organisms, some of which are yet to be identified. Soil is indeed a living entity comprising of diverse flora and fauna. The uppermost layer of the earth ceases to be a living entity or soil, when it is devoid of its biota.

An ecosystem is a biophysical and socioeconomic environment defined by the interaction among climate, vegetation, biota, and soil (Fig. 1.1). Thus, soil is an integral and an important component of

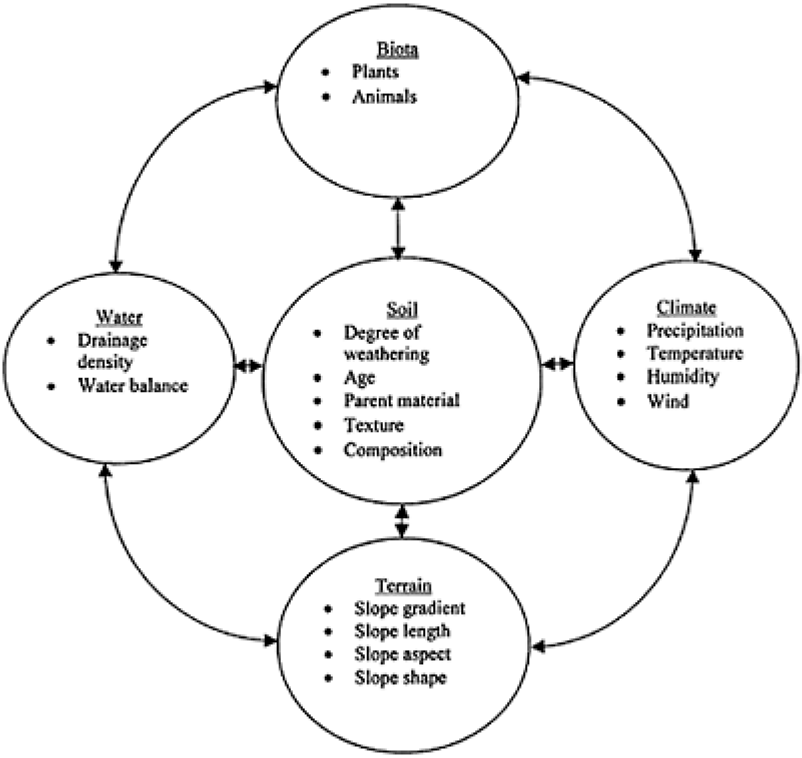

FIGURE 1.1 Soil is an integral component of an ecosystem, also made up of biota, climate, terrain, and water.

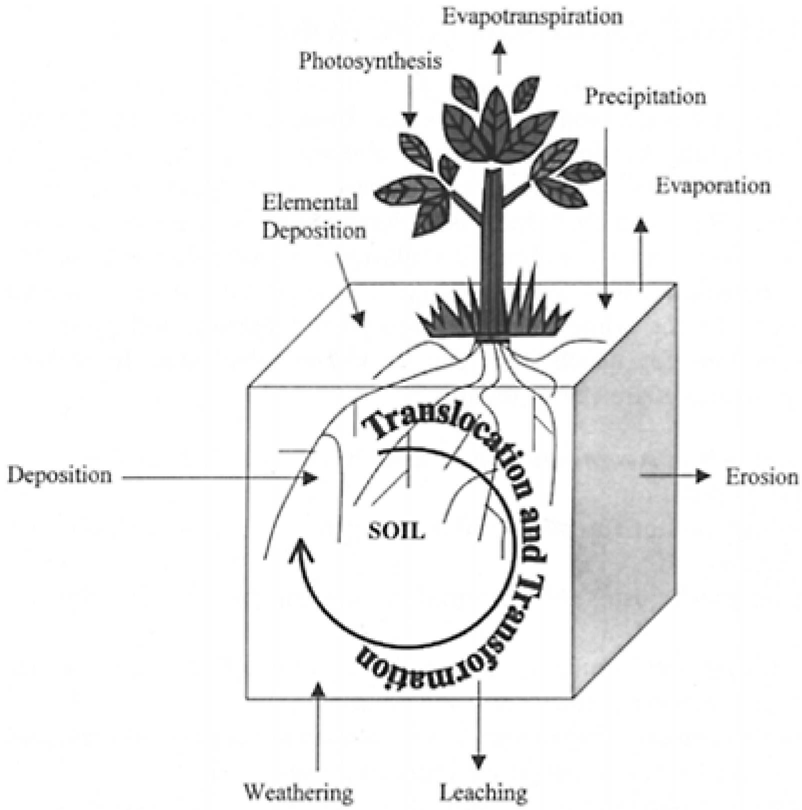

FIGURE 1.2 A pedosphere represents a dynamic interaction of soil with the environment.

any ecosystem. In the context of an ecosystem, soil is referred to as the *pedosphere*. The pedosphere is an open soil system (Buol, 1994). It involves transfer of matter and energy between soil and the atmosphere, hydrosphere, biosphere, and lithosphere (Fig. 1.2). The lithosphere adds to the soil through weathering and new soil formation and receives from the soil through leaching. It receives alluvium and colluvium from soils upslope and transfers sediments to soil downslope. In addition, there are transformations and translocations of mater and energy within the soil. An ecosystem can be natural (e.g., forest, prairie) which retains much of its original structure and functioning, or managed (e.g., agricultural, urban) which has been altered to meet human needs. The productivity of managed and functioning of all (natural and managed) ecosystems depends to a large extent on soil quality and its dynamic nature.

1.3 SOIL QUALITY AND SOIL FUNCTIONS

Soil quality refers to the soil's capacity to perform its functions. In other words, it refers to soil's ability to produce biomass, filter water, cycle elements, store plant nutrients, moderate climate, etc. For an agrarian population, the primary soil function has been the production of food, fodder, timber, fiber, and fuel. Increased demands on soil resources have arisen due to increases in human population, industrialization of the economy, rising standards of living, and growing expectations of people all over the world. In the context of the twenty-first century, soil performs numerous functions for which there are no viable substitutes. Important among these functions are the following:

1. Sustaining biomass production to meet basic necessities of a growing human population
2. Providing habitat for biota and a vast gene pool or a seedbank for biodiversity
3. Creating mechanisms for elemental cycling and biomass transformation
4. Moderating environment, especially quality of air and water resources, waste treatment and remediation
5. Supporting engineering design as foundation for civil structures, and as a source of raw material for industrial uses
6. Preserving archeological, geological, and astronomical records
7. Maintaining aesthetical values of the landscape and ecosystem, and preserving cultural heritage

Soil quality refers to its capacity to perform these functions, and to soils capability for specific functions that it can perform efficiently and on a sustainable or long-term basis (Lal, 1993; 1997; Doran et al., 1994; Doran and Jones, 1996; Gregorich and Carter, 1997; Karlen et al., 1997; Doran et al., 1999). Soil's agronomic capability refers to its specific capacity to grow crops and pasture. In most cases, however, soil cannot perform all functions simultaneously. For example, soil can either be used for crop cultivation or urban use.

Soil degradation refers to decline in soil quality such that it cannot perform one or several of its principal functions. Soil degradation is caused by natural or anthropogenic factors. Natural factors, with some exceptions such as volcanic eruptions and landslides, are usually less drastic than anthropogenic perturbations. Thus, severe degradation is typically caused by anthropogenic perturbations. Soil degradation leads to decline in soil quality causing reduction in its biomass productivity, environmental moderation capacity, ability to support engineering structures, capacity to perform aesthetic and cultural functions, and ability to function as a storehouse of gene pool and archeological/historical records. Thus, a degraded soil cannot perform specific functions of interest/utility to humans.

1.4 SOIL SCIENCE AND AGROECOSYSTEMS

Agroecology is the study of interaction between agronomy (i.e., study of plants and soils) and ecology. It is defined as the study and application of ecological principles to managing agroecosystems. Therefore, an agroecosystem is a site of agricultural/agronomic production, such as a farm. In this context, therefore, agriculture is merely an anthropogenic manipulation of the carbon cycle (biomass or energy) through uptake, fixation, emission, and transfer of carbon and energy. Soil quality plays an important role in anthropogenic manipulation of the carbon cycle. More specifically, soil physical quality, which is directly related to soil physical properties and processes, affects agronomic productivity through strong influences on plant growth.

1.5 SOIL PHYSICS

Soil physics is the study of soil physical properties and processes, including measurement and prediction under natural and managed ecosystems. The science of soil physics deals with the forms, interrelations, and changes in soil components and multiple phases. The typical components are: mineral matter, organic matter, liquid, and air. Three phases are solid, solution and gas, and more than one liquid phase may exist in the case of nonaqueous contamination. Physical edaphology is a science dealing with application of soil physics to agricultural land use. The study of the physical phenomena of soil in relation to atmospheric conditions, plant growth, soil properties and anthropogenic activities is called physical edaphology. Study of soil in relation to plant growth is called *edaphology,* whereas study of soil's physical properties and processes in relation to plant growth is called *physical edaphology*. Thus, physical edaphology is a branch of soil physics dealing with plant growth.

Soil physics is a young and emerging branch of pedology, with significant developments occurring during the middle of twentieth century. It draws heavily on the basic principles of physics, physical chemistry, hydrology, engineering and micrometeorology (Fig. 1.3). Soil physics applies these principles to address practical problems of agriculture,

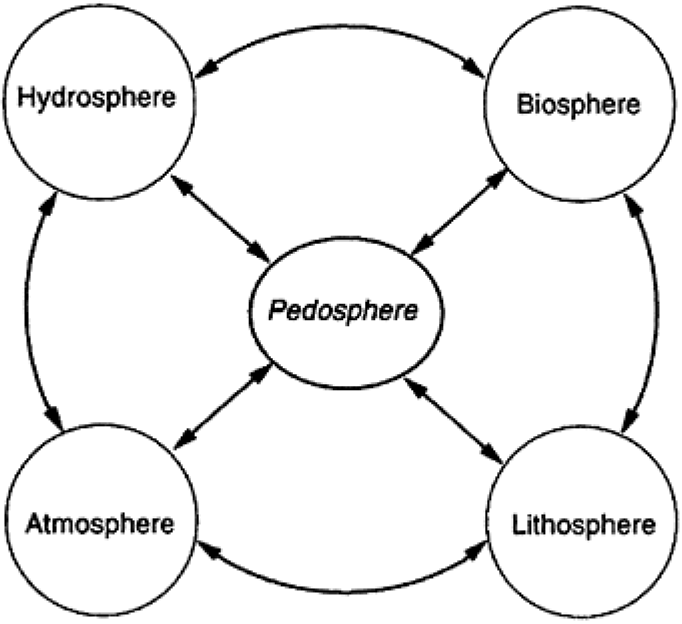

FIGURE 1.3

ecology, and engineering. Its interaction with emerging disciplines of geography (geographic information system or GIS), data collection (remote sensing), and analytical techniques (fuzzy logic, fractal analysis, neural network, etc.) has proven beneficial in addressing practical problems in agriculture, ecology, and environments. Indeed, soil physics plays a pivotal role in the human endeavor to sustain agricultural productivity while maintaining environment quality.

1.6 SOIL PHYSICS AND AGRICULTURAL SUSTAINABILITY

Agricultural sustainability implies non-negative trends in productivity while preserving the resource base and maintaining environmental quality. The role of physical edaphology in sustaining agricultural production while preserving the environment cannot be overemphasized. While the economic and environmental risks of soil degradation and desertification are widely recognized (UNEP, 1992; Oldeman, 1994; Pimental et al., 1995; Lal, 1994; 1995; 1998; 2001; Lal et al., 1995; 1998), the underlying processes and mechanisms are hardly understood (Lal, 1997). It is in this connection that the application of soil physics or physical edaphology has an important role

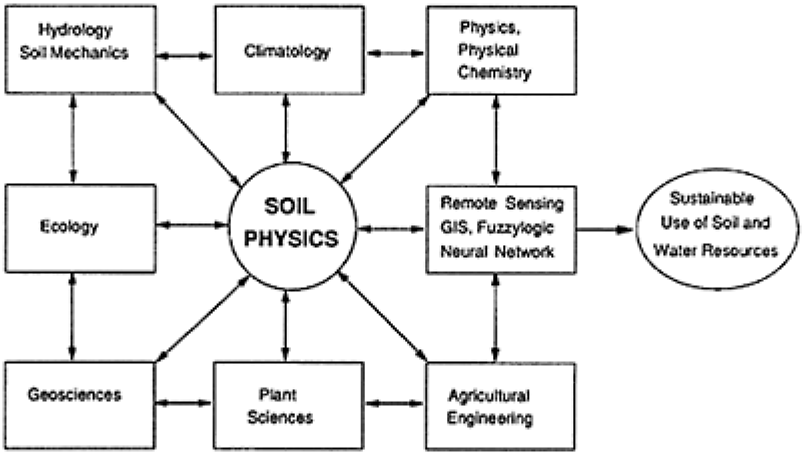

FIGURE 1.4 Interaction of soil physics with basic and applied sciences.

to play in: (i) preserving the resource base, (ii) improving resource use efficiency, (iii) minimizing risks of erosion and soil degradation, and restoring and reclaiming degraded soils and ecosystems, and (iv) enhancing production by alleviation of soil/weather constraints through development and identification of judicious management options (Fig. 1.4). Notable applications of soil physics include control of soil erosion; alleviation of soil compaction; management of soil salinity; moderation of soil, air, and water through drainage and irrigation; and alteration of soil temperature through tillage and residue management. It is a misconception and a myth that agricultural productivity can be sustained by addition of fertilizer and/or water per se. Expensive inputs can be easily wasted if soil physical properties are suboptimal or below the critical level. High soil physical quality (Lal, 1999a; Doran et al., 1999) plays an important role in enhancing soil chemical and biological qualities. Applications of soil physics can play a crucial role in sustainable management of natural resources (Fig. 1.5). Fertilizer, amendments, and pesticides can be leached out, washed away, volatilized, miss the target, and pollute the environment under adverse soil physical conditions. Efficient use of water and nutrient resources depends on an optimum level of soil physical properties and processes. Soil fertility, in its broad sense, depends on a favorable interaction between soil components and phases that optimize soil physical quality. Soil physical properties important to agricultural sustainability are texture, structure, water retention and transmission, heat capacity and thermal conductivity, soil strength, etc.

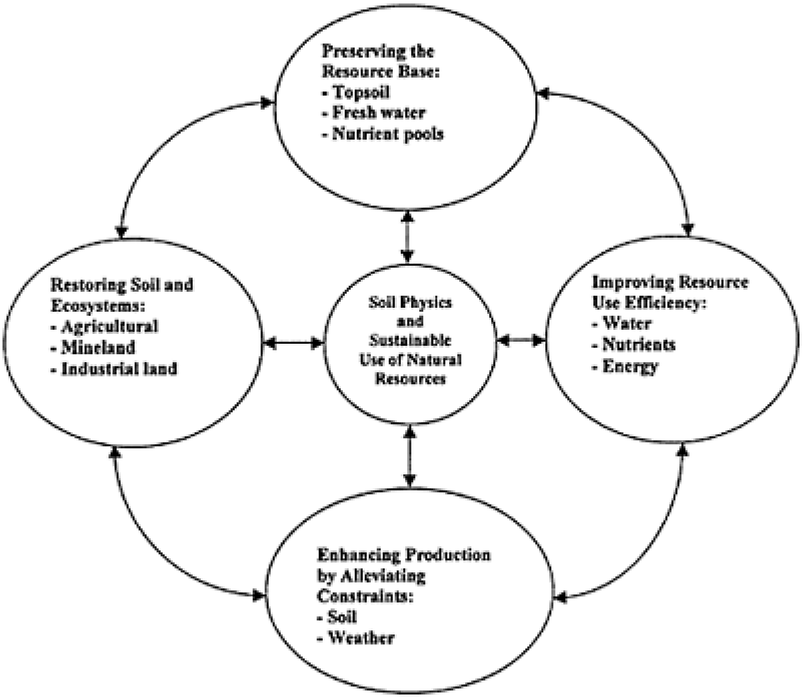

FIGURE 1.5 Applications of soil physics are crucial to sustainable use of natural resources for agricultural and other land uses.

These properties affect plant growth and vigor directly and indirectly. Important soil physical properties and processes for specific agronomic, engineering, and environmental functions are outlined in Table 1.1. Soil structure, water retention and transmission properties, and aeration play crucial roles in soil quality.

Soil physical properties are more important now than ever before in sustaining agricultural productivity because of the shrinking global per capita arable land area (Brown, 1991; Engelman and LeRoy, 1995). It was 0.50 ha in 1950, 0.20 ha in 2000, and may be only 0.14 ha in 2050 and 0.10 ha in 2100 (Lal, 2000). Therefore, preserving and restoring world soil resources is crucial to meeting demands of the present population without jeopardizing needs of future generations.

TABLE 1.1 Soil Physical Properties and Processes That Affect Agricultural, Engineering, and Environmental Soil Functions

Process	Properties	Soil functions
Biomass productivity (agricultural functions)		
1. Compaction	Bulk density, porosity, particle size distribution, soil structure	Root growth, water and nutrient uptake by plants
2. Erosion	Structural stability, erodibility, particle size, infiltration and hydraulic conductivity, transportability, rillability	Root growth, water and nutrient uptake, aeration
3. Water movement	Hydraulic conductivity, pore size distribution, tortuosity	Water availability to plants, chemical transport
4. Aeration	Porosity, pore size distribution, soil structure, concentration gradient, diffusion coefficient	Root growth and development, soil and plant respiration
5. Heat transfer	Thermal conductivity, soil moisture content	Root growth, water and nutrient uptake, microbial activity
Engineering functions		
1. Sedimentation	Particle size distribution, dispersibility	Filtration, water quality
2. Subsidence	Soil strength, soil water content, porosity	Bearing capacity, trafficability
3. Water movement	Hydraulic conductivity, porosity	Seepage, waste disposal, drainage
4. Compaction	Soil strength, compactability, texture	Foundation strength
Environmental functions		
1. Absorption/adsorption	Particle size distribution, surface area, charge density	Filtration, water quality regulation, waste disposal
2. Diffusion/aeration	Total and aeration porosity, tortuosity, concentration gradient	Gaseous emission from soil to the atmosphere

1.7 SOIL PHYSICS AND ENVIRONMENT QUALITY

In the context of environment quality, soil is a geomembrane that buffers and filters pollutants out of the environment (Yaalon and Arnold, 2000). It is also a vast reactor that transforms, deactivates, denatures, or detoxifies chemicals. Soil physical properties and processes play an important role in these processes. The environmental purification functions of soil are especially important to managing and moderating the quality of air and water resources (Fig. 1.6). Soil physical properties and processes influence the greenhouse effect through their control on emission of radiatively-active gases (e.g., CO_2, CH_4, N_2O, and NO_x) (Lal et al., 1995; Lal, 1999b; Bouwman, 1990). A considerable part of the 80 ppmv increase in atmospheric CO_2 concentration since the industrial revolution (IPCC, 1995; 2001) has come from C contained in world soils. Soil physical properties and processes determine the rate and magnitude of these gaseous

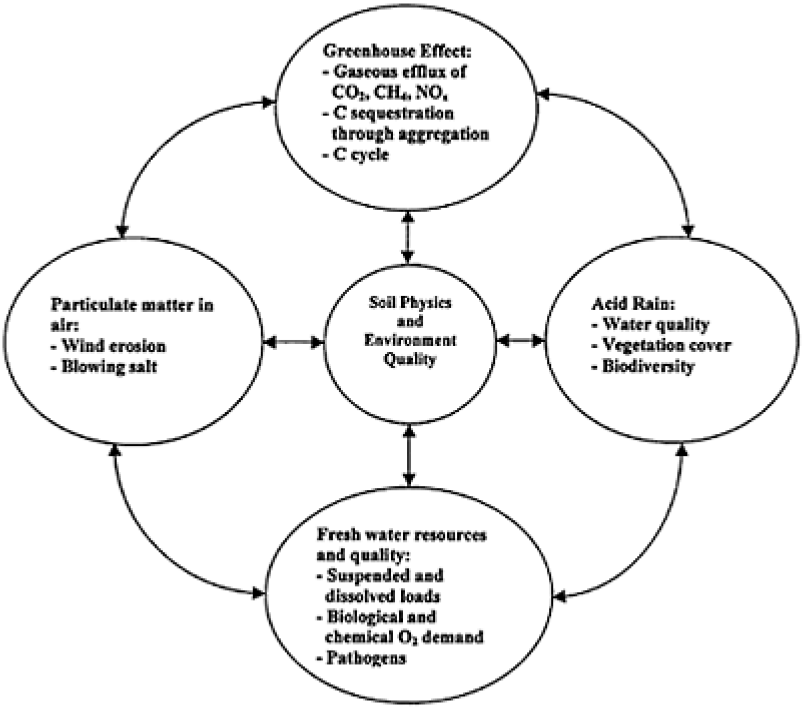

FIGURE 1.6 Applications of soil physics to environment quality.

emissions. Formation and stabilization of soil structure (i.e., development of secondary particles through formation of organomineral complexes), is a prominent consequence of C sequestration in soil. Air quality is also influenced by soil particles and chemicals (salt) airborne by wind currents. Management of soil structure, control of soil erosion, and restoration of depleted soils are important strategies of mitigating the global climate change caused by atmospheric enrichment of CO_2 (Lal, 2001).

Fresh water, although renewable, is also a finite quantity and a scarce resource especially in arid and semiarid regions. Soil, a major reservoir of fresh water, influences the quality of surface and ground waters (Engelman and LeRoy, 1993; Lal and Stewart, 1994). The pedospheric processes (e.g., leaching, erosion, transport of dissolved and suspended loads in water) interact with the biosphere and the atmosphere to influence properties of the hydrosphere. Soil physical properties important to the hydrosphere, in terms of the quality and quantity of fresh water resources, are water retention and transmission properties of the soil, surface area and charge properties, and composition of inorganic and organic constituents.

1.8 SOIL PHYSICS AND THE GRADUATE CURRICULA

Understanding of the soil physical properties and processes is necessary to developing and implementing strategies for sustainable management of soil and water resources for achieving world food security, controlling soil erosion, abating the nonpoint source pollution/contamination of natural waters, developing a strong foundation for stable engineering structures, and mitigating the climate change through sequestration of carbon in soil, biota, and wetlands. Further, understanding soil–climate– vegetation–human interaction is essential to development, utilization, management, and enhancement of natural resources. Therefore, studying soil physics is essential to all curricula in soil science, agronomy/crop-horticultural sciences, plant biology, agricultural engineering, climatology, hydrology, and environmental sciences. This book is specifically aimed to meet the curricula needs of students and researchers interested in these disciplines.

PROBLEMS

1. Why is soil a nonrenewable resource?

2. List soil functions of importance to pre- and postindustrial civilization.

3. Describe soil degradation and its impact.

4. Explain the difference between the terms “property” and “process,” and givespecific examples in support of your argument.

5. Describe soil quality and factors affecting it.

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