1. SOILS: BASIC CONCEPTS AND PRINCIPLES

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LEARNING OBJECTIVES

After studying this chapter, a student should be able to:

- Explain the concept of soil: its components and composition.
- Differentiate between soil, land, and earth; topsoil and subsoil; mineral and organic soil; soil fertility and productivity; and quantity factor and intensity factor.
- Discuss the role of soil in plant growth.
- Define and understand soil science and its various branches.
- List plant nutrients and specify the criteria of their essentiality and the mechanisms by which nutrients reach the surface of plant roots.
- Understand dynamic equilibria in soil with particular emphasis on soil solution and nutrient uptake by plants.

1.1 What is soil?

Like water and air, soil is a basic natural resource. **Soil** is defined as the nonconsolidated upper part of the earth's crust that serves as a natural medium for the growth of land plants (Soil Science Society of America 1987). Therefore, soil is indispensable for crop production. The wise use and preservation of the soil resources of a country can transform a poor society into a prosperous one (Miller and Donahue 1992).

For an agriculturist, soil is a habitat for plants. However, there are different concepts and viewpoints regarding soil in various scientific disciplines. For instance, what a soil scientist considers *soil*, a mining engineer or geologist may call *fragmented rocks* or debris covering the rocks and

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minerals; a civil engineer may call it *earth* or the foundation material for constructing roads and buildings; and an economist may call it *land*.

Soil is a variable mixture of three major components: solids, liquids, and gases. Mineral soils contain about half solids and half pore space (water and air) (Fig. 1.1). Of the total soil volume, approximately 50% is solid, about

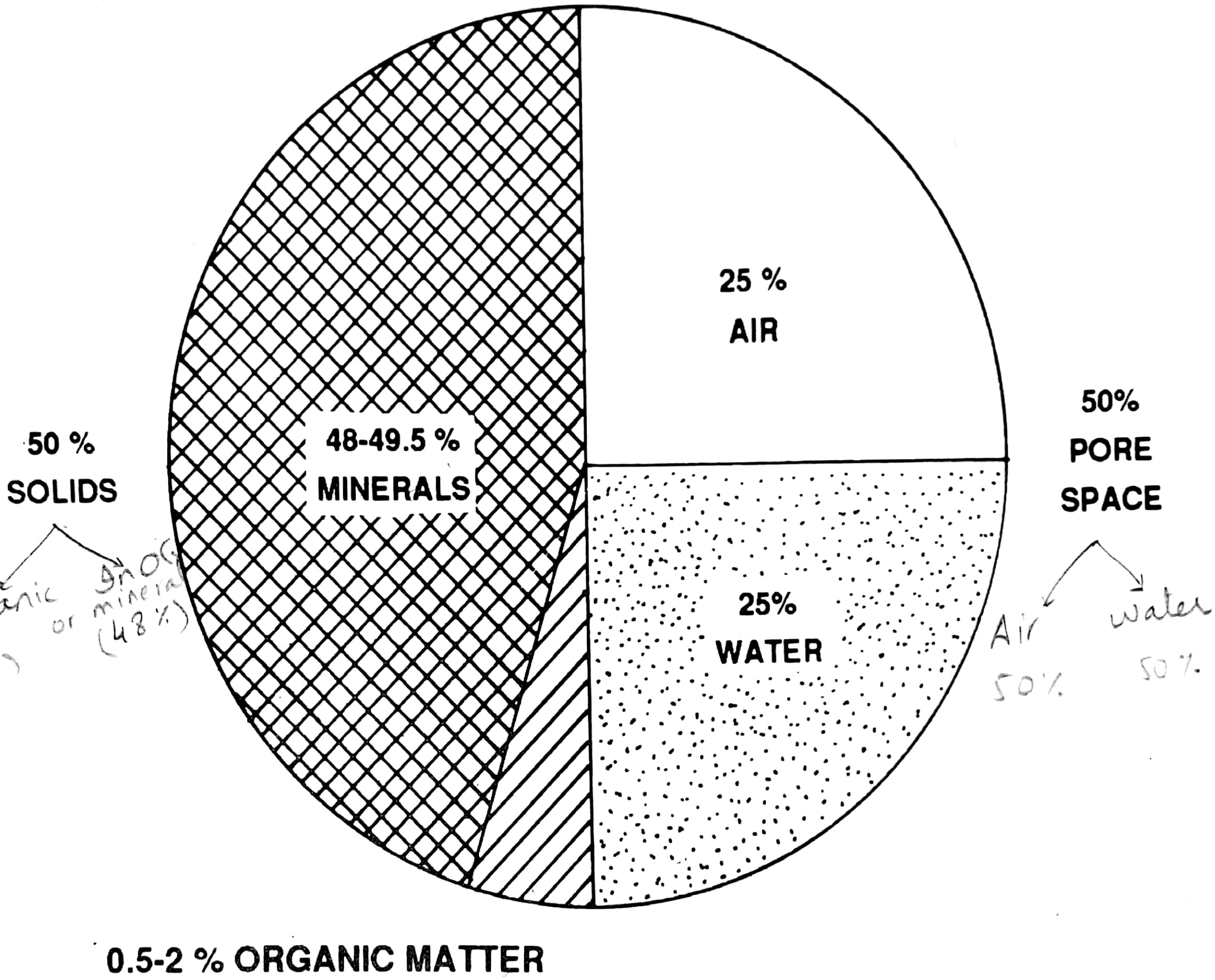

Figure 1.1 Volumetric components of a mineral soil with good physical structure (Adapted from Brady 1990:11).

48% mineral matter, and about 2% organic matter. At field capacity moisture level, the pore space is occupied roughly half by water and half by air. However, the proportions of water and air are subject to rapid and great fluctuation. Subsoils generally contain less organic matter and less total pore space, but generally have a higher moisture content than topsoils. The three major soil components occur in a thoroughly mixed condition in soils.

Solid phase. The solid phase is the major reservoir of most plant nutrients. It provides physical support for the plants and a means of holding added nutrients in the root zone. The solid phase is made up of two components: **mineral** (inorganic) and **organic**. The mineral component consists of primary and secondary minerals, amorphous substances, and fragments of parent rocks. The organic component includes soil fauna (animals) and flora (plants), plant roots, plant residues, and humus. Except for organic soils (Histosols), not present in Pakistan, the mineral component predominates in soils. The organic soil component is the major source of soil N and also contains other nutrients, mainly S and P. Thus this component is very important for soil fertility. Soil organic matter is also important for soil structure and greatly affects the water, air, and temperature economy of the soil (discussed in detail in Chapter 8).

Liquid phase. The liquid phase, the soil solution, is mainly responsible for nutrient transport in the soil and is the immediate source of most nutrients and water absorbed by plant roots. Nutrients in the solid and liquid phases of the soil exist in a dynamic equilibrium. These relationships and their effects on nutrient availability to plants are considered in the latter part of this chapter as well in Chapters 6, 9, 10, 11, and 12.

Gaseous phase. Soil gases occupy the soil pores along with water. They are the same gases contained in the atmosphere above the soil surface, but their concentrations in soil may be different. For example, carbon dioxide levels in soils are normally higher than in air due to root respiration and decomposition of soil organic matter. The gaseous phase also provides oxygen for respiration of plant roots and soil organisms.

1.1.1 Soil, land, and earth

In contrast to the definition of soil, **land** is generally defined as the physical environment consisting of relief, soil, hydrology, climate, and vegetation insofar as they determine land use. In addition to the nature of the soil and its productivity potential, the value of a tract of land is determined by its location, size, and distance from amenities like roads, cities, and markets, as well as the nature of its potential use (discussed in detail in Chapter 15).

The term **earth** is used by engineers as a general name for unconsolidated land masses that can be dug, moved, or formed by equipment.

1.1.2 Mineral and organic soils

Mineral (inorganic) soils are low in organic matter and consist predominantly of mineral matter. Mineral soils usually contain <20% organic carbon (or <12–18% if saturated with water). In contrast, **organic soils** are characterized by very high content of organic carbon; >20% (or >12–18% if saturated with water) (Soil Science Society of America 1987). Organic soils have high water-holding and cation exchange capacities, but their bulk density is much lower than that of mineral soils (may be as low as 0.1 g/cm^3). In the U.S. Soil Taxonomy System (Soil Survey Staff 1975), organic soils are classified as **Histosols** and are also known as **peat** and **muck** soils. Since such soils are formed under humid climates and stagnated water conditions, Histosols (organic soils) do not exist in Pakistan because of the arid to semiarid climate in this country. The formation of Histosols is common in wet, cold areas such as Canada, Finland, and Alaska (USA), and in wet areas having stagnant marshes and swamps, such as Ireland. The extent of Histosols is only 0.9% of all soils of the world; they have the minimum total area of all 11 soil orders of the U.S. Soil Taxonomy system (Miller and Donahue 1992).

Because of the absence of organic soils in Pakistan, the discussion in various chapters of this book relates to mineral soils only.

1.1.3 Topsoil and subsoil

Topsoil refers to the surface-soil layer or plough layer, or the furrow slice. In general, the term 'soil' refers to topsoil. This is the major zone of root development, and contributes a large share of the nutrients and water used by plant roots. During cultivation, the topsoil layer is ploughed and manipulated. Its physical as well as chemical properties can be modified by agronomic practices like cultivation, addition of organic manures, fertilizers, amendments (e.g. gypsum) and herbicides, etc. Therefore, the fertility and even its productivity can be manipulated for crop production.

Subsoil is comprised of the soil layers immediately below the topsoil layer or furrow slice. Crop production is also influenced by subsoil, although to a lesser extent. In addition to root development, plants also obtain nutrients and moisture from this soil layer. Unlike topsoil, the subsoil is subject to little human manipulation, except by deep tillage and drainage. However, land use decisions are greatly influenced by the nature of the subsoil.

1.1.4 Soil as a medium for plant growth

Soil provides mechanical support to plants, space for root growth and development, and an environment for root respiration. Soil is also a medium for interaction with other organisms, both beneficial and harmful. It also serves as a source of nutrients and water for plant growth. The essential plant nutrients taken up by roots from the soil are used with sugars (photosynthesis) to make other organic compounds in the plant or are needed for certain growth processes of the plant. Plants require light, air, water, mineral nutrients, and favourable temperature for their growth (Fig. 1.2). With the exception of light, soils can supply all these factors. Like a factory, plants utilize their raw materials and transform them, by utilizing light energy from the sun, into sugars and later to other materials constituting about 95% of plant dry matter, such as starch, fats, proteins, and cellulose. It is in the green leaves, that *food manufacture* takes place by the process called **photosynthesis** as follows:

$$\underset{\text{Carbon dioxide}}{6CO_2} + \underset{\text{Water}}{6H_2O} \xrightarrow[\text{Chlorophyll}]{\text{Sunlight}} \underset{\text{Sugar}}{C_6H_{12}O_6} + \underset{\text{Oxygen}}{6O_2}$$

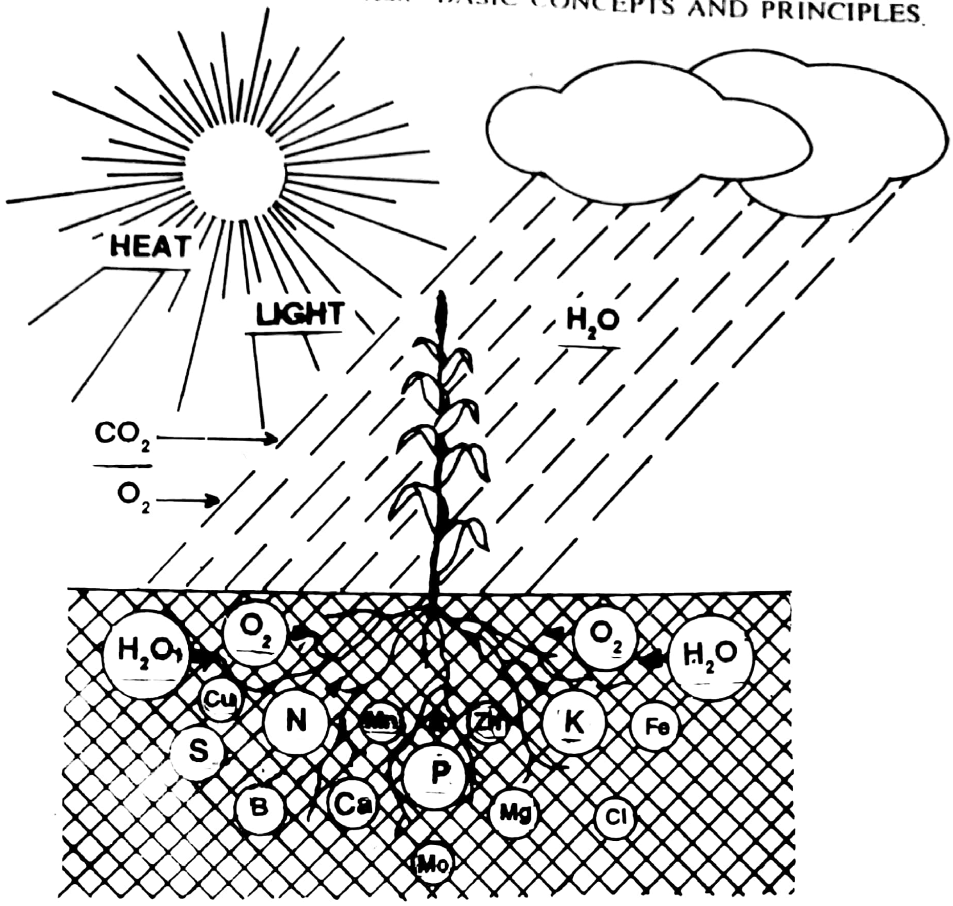

Figure 1.2 For their growth, plants obtain nutrients from the soil, light energy from the sun, carbon dioxide from the air, and hydrogen from water (After Schroeder 1984:117).

In photosynthesis, chlorophyll (the green pigment in plant leaves) traps light energy from the sun and transforms it to chemical energy by utilizing carbon dioxide from the air and hydrogen from water.

1.2 Definition of soil science

Soil science is a scientific discipline concerning the study of soil as a natural resource from the point of view of plant growth. One of the fathers of modern soil science, Friedrich Albert Fallou, stated the importance of soil science in 1862 as follows:

> "There is nothing in the whole of nature which is more important than or deserves as much attention as the soil. Truly, it is the soil which makes the world a friendly environment for mankind. It is the soil which nourishes and provides for the whole of nature; the

whole of creation depends on the soil which is the ultimate foundation of our existence (Schroeder 1984:3)."

Soil science is an applied scientific discipline of comprehensive nature because of its relationships with so many other sciences, as is shown in Figure 1.3. All the sciences depicted in this figure contribute to the develop-

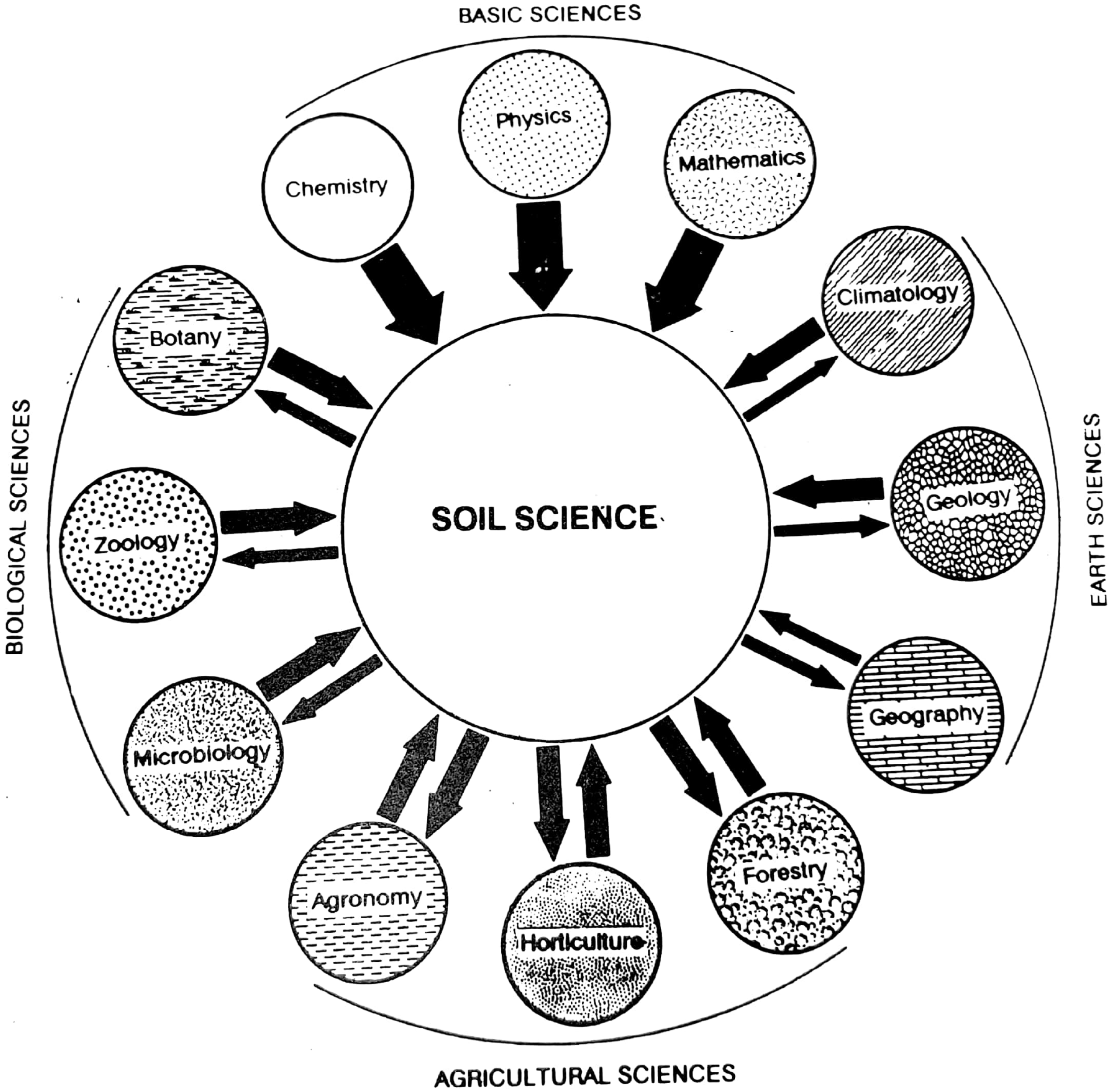

Figure 1.3 Soil science in relation to other scientific disciplines (adapted from FitzPatrick 1983:xviii).

ment of soil science. Whereas the basic sciences (chemistry, physics, and mathematics) make a unilateral contribution, the other disciplines have reciprocal relationships, the greatest being between soil science and the other applied agricultural sciences (agronomy, horticulture, and forestry).

1.2.1 Branches of soil science

Soil is a complex and variable medium, and its study and management is not simple. Consequently, the discipline of soil science is very comprehensive. Soil science comprises a number of areas including genesis, taxonomy, classification, survey and mapping, physics, chemistry, mineralogy, biology, fertility, salinity, erosion and conservation. This textbook contains chapters on all these aspects incorporating local information and experience. To make things understandable and manageable, soil science is systematically divided into a number of branches. Various branches of soil science, as defined in the *Glossary of Soil Science Terms* (Soil Science Society of America 1987), are briefly discussed here.

A. **Soil genesis and classification (pedology).** Soil **genesis** deals with weathering of rocks and minerals and factors and processes of soil formation. Soil **classification** is the systematic arrangement of soils into groups or categories on the basis of their characteristics.

B. **Soil survey.** Deals with systematic examination of soils in the field and laboratory, their description, classification, mapping, and interpretation according to their suitability for different management systems.

C. **Soil chemistry.** Deals with the chemical constitution, chemical properties, and chemical processes taking place in the soil.

D. **Soil fertility.** Concerns the ability of a soil to supply the essential plant nutrients for plant growth.

E. **Soil physics.** Deals with the mechanical behaviour of soil mass, i.e. the physical properties of soils, with emphasis on the state and transport of matter (especially water) and energy in the soil.

F. **Soil salinity.** Deals with the excess soluble salts present in the soil, their reclamation, and soil management for saline agriculture.

G. **Soil mineralogy.** Deals with the primary and secondary soil minerals and their contribution to the chemistry, physics, fertility, and biology of soils and their relationship to soil genesis.

H. **Soil biology.** Concerns soil-inhabiting organisms and their functions and activities.

I. **Soil conservation.** Deals with protection of the soil from physical loss by erosion (by wind and water) or chemical deterioration. Thus, soil conservation is concerned with a combination of all management and land-use methods that safeguard the soil against deterioration by natural or human-induced factors.