1 Concepts of Soil

Soils are natural unconsolidated materials on the surface of the earth and are composed of solid, liquid, and gas. They have organic as well as inorganic matter, which are intimately mixed together by natural processes. By this mixing and transforming, they are aggregated into a porous body. The pores accommodate air and water. Thus, there are four major components of soil—mineral matter, organic matter, water, and air. The soil has evolved through pedogenic processes as a dynamic and a three-dimensional body. Soils have attained the capacity of supporting various ecosystems on the earth. They provide plants with anchorage, nutrients, water, air, and warmth and protect them from toxins. Soils have crucial ecological functions: It is a transformer of energy, it is a recycler of materials, it is a purifier of water, and above all, it functions as an ecosystem component.

1.1 Different People Have Different Concepts of Soil

Everybody is familiar with soils, and everybody has his own ideas about soil. These ideas differ from people to people because they think of soils in different ways, or they use soils for different purposes. To a farmer, soil and land have the same meanings. He understands soil where crops can be grown. To him, only the root zone of the crop plants is important. A potter uses mud for pottery; to him, there is no difference between mud or clay and soil. Professionals also differ in their concepts of soil. For example, a geologist views soil as the biologically modified upper part of the regolith, a term to mean unconsolidated materials on the earth's surface over bedrock and formed by weathering of rocks and minerals. To a geographer, soil is the discontinuous thin envelope of loose material on the surface of the earth. An engineer considers soil as any kind of loose, unconsolidated earth material on which foundations of roads, buildings, and other structures are constructed. He does not distinguish between soil and other loose materials on land such as sediment.

All these views partly reflect the nature of soils, but none gives a complete idea about soil as it occurs and functions in nature. To a soil scientist, soil is a three-dimensional body which has characteristics that distinguish it from other natural materials. The soil is an unconsolidated material on the earth's surface that has evolved through complex pedogenic processes by the natural amalgamation of mineral and organic matter; that has achieved distinct morphological, physical, chemical, and biological characteristics; and that has attained the capacity of supporting vegetation and other life forms. It is, in fact, an ecosystem itself and, at the same time, a part of the greater terrestrial ecosystems.

1.2 There Are Many Different Definitions of Soil

Different scientists have defined soil in different ways. Some of these definitions are given below to show the evolution of the modern concepts of soil.

> Soils are applied solely to those superficial or nearly superficial horizons of rocks, that have been more or less modified naturally by the interaction of water, air and various kinds of organisms, either living or dead; this being reflected in a certain manner in the composition, structure and color of such formations. Where these conditions are absent, there are no natural soils, but artificial mixtures of rock.
>
> Dokuchaev (1879)

> Soil is the uppermost weathered layer of the earth's crust; it consists of rocks that have been reduced to small fragments and have been more or less changed chemically together with the remains of plants and animals that live on it and in it.
>
> Ramann (1905)

> Soil is, more or less, loose, friable material in which, by means of their roots, plants may or do find foothold, nourishment as well as all other conditions of growth.
>
> Hilgard (1914)

> The soil is a natural body of mineral and organic constituents, differentiated into horizons, of variable depth, which differs from the material below in morphology, physical makeup, chemical properties and composition, and biological characteristics.
>
> Joffe (1949)

> Soil is a collection of natural bodies occupying a portion of the earth surface that supports plant growth and that has properties

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due to the integrated effect of climate and vegetation acting upon parent material, as conditioned by relief, over a period of time.
Kellogg (1960)

Soil is a natural body comprised of solids (minerals and organic matter), liquid, and gases that occurs on the land surface, occupies space, and is characterized by one or both of the following: horizons, or layers, that are distinguishable from the initial material as a result of additions, losses, transfers, and transformations of energy and matter or the ability to support rooted plants in a natural environment.
USDA, NRCS (2003)

1.3 All Loose Materials on the Surface of the Earth Are Not Soils

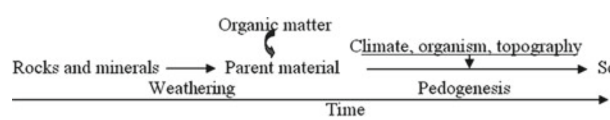
There are many loose materials resembling soils on the surface of the earth; they are not soils, although they may have limited capacity of supporting plant growth. For example, desert sands are not soils; normally, they lack organic matter, available water, and capacity to support plants. Sands are discrete particles; they are not aggregated like soil. Sandy beaches and dunes are not soils; they may have some organic matter, but they do not show profile development. Similar is the case with sediments on riverbeds. They are actually parent materials. Under favorable conditions and over time, these parent materials will develop into soils. Thus, parent materials below the solum (the depth to which pedogenesis has occurred; Sect. 3.1) and above the solid bedrock are not soils. Unconsolidated mineral or organic material thinner than 10 cm overlying bedrock, unconsolidated material covered by more than 60 cm of water throughout the year, and organic material thinner than 40 cm overlying water are not soils. Some soils may have water covering its surface to a depth of 60 cm or less either at low tide in coastal areas or during the driest part of the year in areas inland. Subaqueous soils (soil materials, mud/sediments, found underwater; Sect. 13.7.4) occur immediately below a water depth of <2.5 m (USDA, NRCS 2003).

1.4 Soil Is Not Land Itself; It Is a Part of Land

Often land is used synonymously with soil, but the two are not the same. Land is the non-water part of the earth's surface, while soil occupies only a thin upper part of some land. There is no soil on some other lands. Some land has rocky surfaces; some are covered by desert sands and some by glaciers and ice over the solid rocks. On some land, there are deposits of fresh sediments that have not been altered enough to be called soil. Soil has a lower limit (usually above the parent material—the material from which soil has developed), while land has none. Whatever deep we dig the land, it remains the same land. At a depth of the land, there is no soil. Land does not bear significant vegetation unless it has soil on it. The part of the land that can be seen at a glance is called landscape. The part of the landscape that has similar slope, vegetation, or cropping potential is known as a land. The same land may contain different soils at different positions. Both land and soil are natural resources, but soil is not normally owned as a property. A land can be owned as a property. Land may have a variety of uses depending on soil and other characteristics.

1.5 Soil Is a Natural Body

The soil is a natural entity. It has evolved over a long time in a place through natural processes under natural conditions from natural materials. The materials from which the soils are formed are called parent materials (Sect. 3.6). Parent materials may be organic and inorganic, although most soils (more than 99% of world soils) develop from inorganic or mineral parent materials. They are disintegrated and decomposition products of rocks and minerals (Chap. 2). Some soils develop from organic parent materials which are residues of past vegetation, usually accumulated under wet conditions. The natural processes involved in disintegration and decomposition of rocks and minerals are collectively known as weathering (Sect. 2.14). At a point of disintegration and decomposition during evolution of soil on a bare surface, organisms including plants, animals, and microbes take hold and add organic matter to the parent materials. Climate and organisms act upon it at a topography and transform it into soil after a long period of time (Jenny 1941, 1980). The processes involved in this transformation are collectively called pedogenesis (factors of soil formation and pedogenic processes are discussed in detail in Chap. 3).



So, the soil is a natural body. Brady and Weil (2002) says, "Soil is a natural body in the same sense as that a mountain, a lake or a valley is."

1.6 Soil Is a Three-Dimensional Body

"A soil" is a natural unit that has a definite range of physical, chemical, and biological properties. But there are variations in soil properties at all directions of a landscape. After some distance in the lateral direction, we find a different soil having different properties. Soil has a lower limit too. The upper part of the regolith (unconsolidated and loose materials above bedrock; Sect. 3.1) is soil. So, a soil has three dimensions,

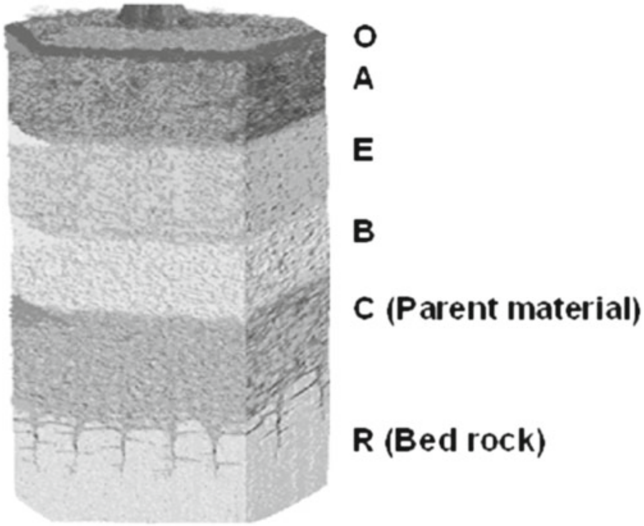


Fig. 1.1 A pedon; exposed sides of the pedon represent soil profile

two laterals and one vertical, that is, length, width, and depth. A soil has a volume too. The smallest volume of a soil having similar characteristics throughout the lateral dimensions is called a pedon (Soil Survey Staff 1975, 1999). Simonson (1978) defined pedon as the smallest effective unit of soil. A pedon is actually an arbitrary unit chosen for examination of soil in field and sampling for study. A pedon may have an area of 1–10 m^2, and it is usually hexagonal in shape (Fig. 1.1). It extends in depth into the parent material from which the soil has developed. A group of similar pedons that occur together in a landscape is called a polypedon. A polypedon represents a soil individual. Different soils in a landscape have polypedons of different pedon characteristics.

The pedon characteristics are exhibited by the exposed sides of the pedon. An exposed side of the pedon actually represents the soil profile (Sect. 3.1) which is defined as the vertical section of soil from surface down to the parent material. The horizontal layers in a soil profile roughly parallel to one another and formed by pedogenic processes are known as horizons. Horizons are, however, different from layers. A soil layer is any stratum which is not formed by pedogenic processes. A layer is generally formed by geological processes or by human activity. There are five master horizons denoted by O, A, E, B, and C. Below the C horizon, there is usually the bedrock in soils formed from residual parent materials and unaltered sediments in transported parent materials.

1.7 Soil Is a Dynamic Body

Soils continually change at different rates and along different pathways. They continually evolve and are never static for more than short periods of time (Schaetzl and Anderson 2005). Daniels and Hammer (1992) stated that soils were four-dimensional systems. Time is the fourth dimension because soils change with time. These changes are physical, chemical, and biological; most changes are biogeophysical and biogeochemical in nature. There is always exchange of gases (oxygen, carbon dioxide, water vapor) between the soil and the atmosphere, infiltration and percolation of water, leaching of materials in suspension and solution, and aggregation of particles. Soil minerals are continuously weathered releasing soluble substances into the soil solution. Plants absorb soluble cations and anions and alter the composition of soil solution. Soil organisms act relentlessly in changing the soil environment. There are always decomposition of organic matter and release of carbon dioxide, mineralization of nitrogen, phosphorus, sulfur, and bases, formation of humus and organo-metal complexes, fixation of nitrogen, etc. Despite these changes, the state of the soil always tends to remain at equilibrium with the environment it is exposed to. Thus, there are always complex interactions between the soil and the environment.

1.8 Soil Is a Transformer of Energy

Soil acts as a receptor and transmitter of solar radiant energy (Fig. 1.2). This energy is utilized in photosynthesis, evaporation, transpiration, heating of soil particles, water and gases, chemical reactions, physiological functions of soil organisms, etc. Energy is emitted from the soil by exothermic chemical reactions, organic matter decomposition and soil respiration, etc. Soil transmits energy through particle contacts, movement of water and gases, etc. Energy is absorbed and released in soil by wetting and drying, heating and cooling, and weathering.

Thus, energy is transformed in soil through physical, chemical, and biological processes. Energy is always at a state of flux within the soil.

1.9 Soil Is a Recycler of Materials

Almost all materials in soil, inherent to it or added to it, undergo diverse transformations. These transformations may be physical, chemical, biochemical, biological, or all. The most remarkable transformation that occurs in soil is the decomposition of organic matter. All organic substances added naturally or as manures and wastes are altered and decomposed by soil flora and fauna. The bulk is lost as CO_2 to the atmosphere; a part is retained as humus mixed with mineral soil particles, and the bases are released to the available soil nutrient pool. They are absorbed by growing plants.

We dispose a large quantity of domestic wastes daily to our home yard or gardens. If that had not decomposed within a short time, how noxious our life would have been. Thus, soil is a great recycler of materials. Soil has also a huge storage of

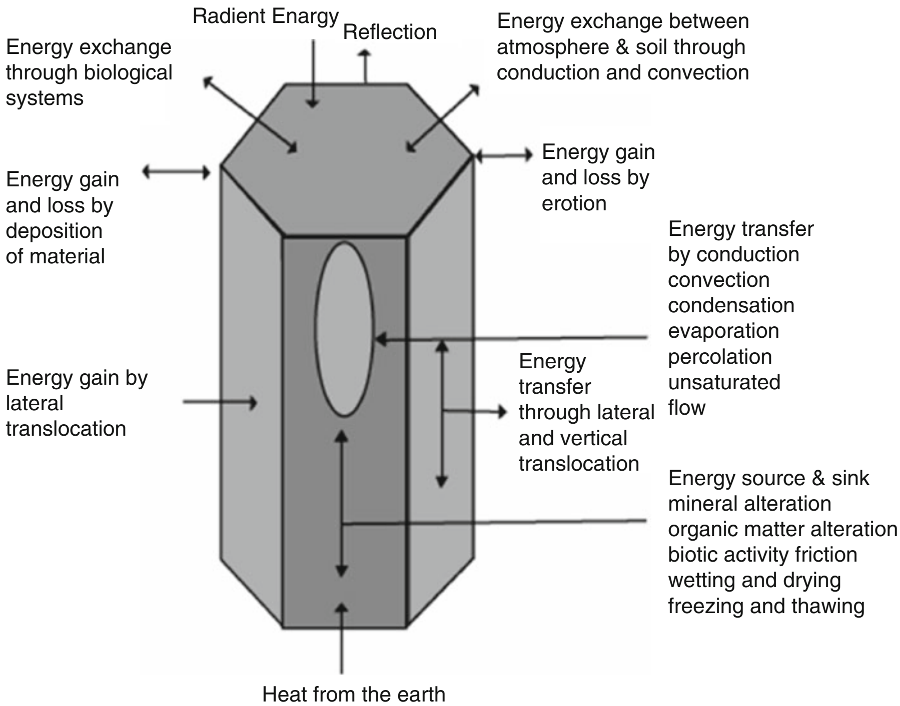


Fig. 1.2 Transformation of energy in soil (After Buol et al. 1997)

organic matter. Organic matter is continually being added and decomposed keeping the storage in a balance. Soil may be a significant C-sink if managed properly. Therefore, soil acts as an environmental buffer. Inorganic substances are also transformed by chemical or biological processes and are rendered soluble/insoluble, mobile/immobile, and active/inactive.

1.10 Soil Is a Purifier of Water

When water, rain or wastewater, falls on soil, some is evaporated and transpired, some runs off, and the most part infiltrates. Soil stores some water, but a considerable amount passes through the soil profile into the groundwater. During temporary storage and transmittance of this water in soil, suspended and dissolved organic matter is decomposed, the sediments are deposited in soil matrix, the contaminants are removed by reaction with soil constituents or exchanged in the colloidal phase, and the purified water enters into the groundwater or flows as stream water. In a healthy soil ecosystem, soil organisms reduce the impacts of pollution by buffering, detoxifying, and decomposing potential pollutants. Most surface water travels a long way over or through the soil before it reaches lakes and rivers. During the travel, sediments are deposited, and contaminants are removed by soil. Quality of water in the watershed largely depends on the quality of soil around. So, soil is a natural filter.

1.11 Soil Is an Ecosystem

An ecosystem is a unit of organisms interacting among themselves at a space and with their abiotic environmental components in a way that flow of materials and energy within the system tends to remain in a dynamic equilibrium. Ecosystems may be broadly classified as terrestrial ecosystems and aquatic ecosystems. Further divisions as forest ecosystem, grassland ecosystem, marine ecosystem, lake ecosystem, pond ecosystem, etc., may also be done. The soil is a component of all terrestrial ecosystems. However, the soil is itself an ecosystem in that it harbors a large number of organisms which interact among them and with the physical and chemical soil environment (Fig. 1.3).

Among the biotic components of the soil are the producers such as green plants, algae, and autotrophic bacteria; the consumers including soil animals, for example, detritus feeders and predators; the decomposers such as fungi and heterotrophic bacteria; and the transformers such as nitrifiers, denitrifiers, and sulfur bacteria. Their populations and functions depend on physical and chemical environment prevailing in the soil. A particular soil acts as a large number of habitats for a diverse group of organisms which have their own niches that overlap with others. The organisms have both competitive and cooperative relationships among themselves for functional and structural habits.

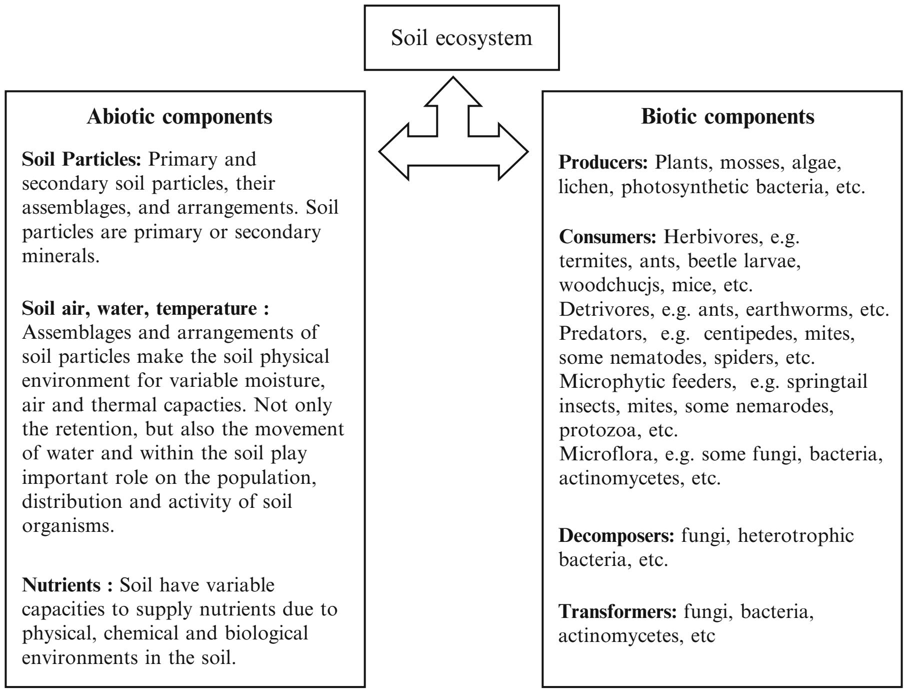


Fig. 1.3 Components of soil ecosystem

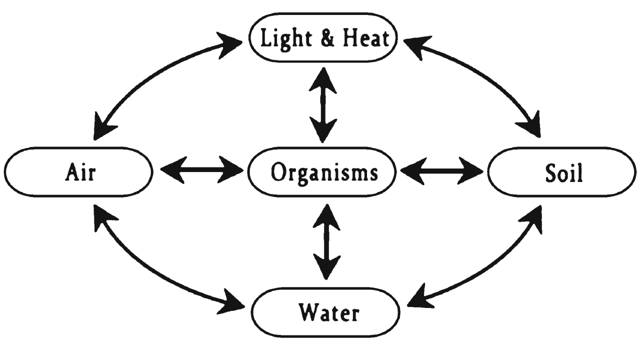


Fig. 1.4 Environmental components that surround organisms

1.12 Soil Is a Component of the Environment

Lodha (1996) defines environment as materials and conditions "that surround an individual or a community at any point in its life cycle." These include physical and cultural surroundings. Actually, environment consists of the complex of physical, chemical, and biotic factors that act upon an organism or an ecological community and ultimately determine its form and survival. An organism or a biotic community interacts with its environment. These interactions between individuals, between populations, and between organisms and their environment form ecological systems, or ecosystems.

Environment includes climate (light, temperature, air, humidity, precipitation, and wind), lithosphere (rocks and soils), hydrosphere (lakes, streams, groundwater, and ocean), and biosphere (organisms—flora and fauna) (Fig. 1.4). These environmental components interact to reach equilibrium and form the ecosystems. A permanent change in any of these conditions, such as a change in temperature or intensity of light, is a change in the environment. Change in the environment may be natural, as experienced through the evolution of atmosphere and life, or may be caused by development activities of human. Human-induced environmental changes are abrupt and tax on the health and survival of human itself.

Exchange of materials and energy takes place between the soil and its environment. For example, climatic elements, such as precipitation and temperature, have the most pronounced effect on the formation and properties of soils. For example, Oxisols (highly leached soils with accumulation of quartz, Fe and Al oxides) and Ultisols (strongly leached soils with accumulation of clay in subsoil) are associated with humid tropical climate and Spodosols (soils with accumulation of humus and oxides of Al and Fe in subsoil) with humid temperate climate (Chap. 3 for formation and Chap. 4 for characteristics of these soils). Climate affects weathering and determines to a large extent the contents of clay, weatherable minerals, soluble salts, organic matter, and nutrients in soil.

On the other hand, soil acts both as a great source and sink of CO_2. Further, wetland soils cause emissions of CH_4, H_2S, and NH_3 gases to the atmosphere. Soil properties affect the distribution of natural plants and growth and yield of crop plants.

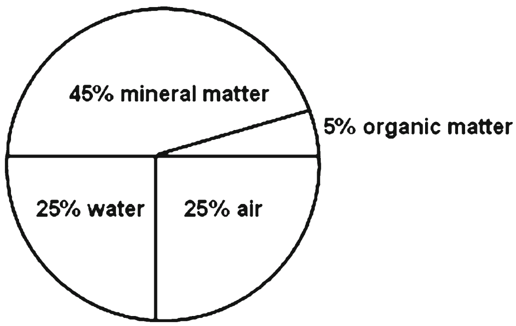


Fig. 1.5 Average volume composition of a loam-textured surface soil

Soil affects qualities of surface and groundwaters. Better managed watershed areas yield good quality water. Soils may become contaminated with heavy metals. These contaminants may pollute water bodies and affect human health.

1.13 Major Components of Soils Vary in Volume Proportions

On an average, an ideal loam-textured surface mineral soil contains 45% mineral matter, 5% organic matter, 25% water, and 25% air by volume (Fig. 1.5). However, the volume composition highly varies with soil types. For example, organic matter in soils of warm tropical areas, Ultisols, Oxisols, and other soils, is very low (<2%) due to rapid decomposition rates. Histosols (organic soils) and holistic horizons in other soils may contain very high (>80%) organic matter. Mollisols (grassland soils) have intermediate organic matter content (Chap. 4). Air and water contents in soils are more variable. Some soils are wet at all times such as hydric soils (soils saturated with water and conducive to the development of hydrophytic vegetation; Chap. 13), requiring artificial drainage if they are to be used for agriculture except wetland rice. Some soils such as Aridisols (soils of the dry regions) are continuously dry, because of inadequate rainfall or excessive drainage, and will grow few plants without irrigation. Most agricultural soils have adequate water to meet vegetation requirement during a considerable part of the year, although plants often suffer during periods of drought.

1.14 Soil Is a Medium of Plant Growth

Soil is one of the factors of plant growth. Terrestrial plants have the following demands on soil: anchorage, water, air, nutrients, and protection from toxins. Plants need adequate air, water, and nutrients in their root zone for optimum growth and yield. For example, plants require some hundred to some thousand grams of water to produce 1 g dry matter (Foth 1990). The capacity of soils to provide air, water, and nutrients depends on their physical, chemical, and biological properties. We find that plants suffer from poor air, water, and nutrient supply in some soils. There are soil management practices to overcome such soil problems. Soil air, water, and nutrients and their management are discussed in detail in Chaps. 5, 6, and 10, respectively.

Plant species differ in their soil requirements because of their evolution in different environments and due to differences in their genetic makeup. The demands of a particular plant even differ at different growth stages. We find *Lantana camara* in acid soils and *Casuarina equisetifolia* on saline soils. Soils suitable for rice may not be so for potato. In other words, all soils are not suitable for all plants. So, selection of crop plants according to the characteristics of the soil along with necessary amendments lies behind the success of crop production.

The capacity of soils to supply nutrients in available forms in adequate amounts and proper balance, and absence of any toxicity is known as soil fertility. On the other hand, the capacity of soil to produce optimum yield under optimum management is known as soil productivity.

Study Questions

1. Define soil. Distinguish between soils and non-soils.
2. Discuss soil as a natural body that undergoes continual changes.
3. What is an ecosystem? Explain that soil is itself an ecosystem besides being part of all terrestrial ecosystems.
4. Why does volume composition of soil differ widely? When does a soil contain much air or much water?
5. How does soil recycle organic matter and purify water?

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