Chapter 2

The Soil: A Natural Resource

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> *"Be it deep or shallow, red or black, sand or clay, the soil is the link between the rock core of the earth and the living things on its surface. It is the foothold for the plants we grow. Therein lies the main reason for our interest in soils."*
>
> **- Roy W. Simonson.**

2.1. Introduction

India can be called a land of paradoxes because of the large variety of soils. A girdle of high mountains, snow fields, glaciers and thick forests in the north, seas washing lengthy coasts in the Peninsula, a variety of geological formations, diversified climate, topography and relief have given rise to varied physiographic features. In the country, temperature varies from arctic cold to equatorial hot; rainfall from barely a few centimetres in the arid parts, to per-humid with world's maximum rainfall of several hundred centimetres per annum in some other parts. These conditions provide for a landscape of high plateaus, stumpy relic hills, shallow open valleys, rolling uplands, fertile plains, swampy low lands and dreary barren deserts. Such varied natural environments have resulted in a great variety of soils in India compared to any other country of similar size in the world. Agriculture was the mainstay of the people of ancient India and thus the agriculturalists then were quite conscious of the nature of the soils and its relation to the production of specific crops of good economic return. It is no wonder that with such a setting for soil formation and its variation, the students, scientists, teachers and alike, in the country, are still conscious of the worthiness of soil as a unique natural resource and take part in soil care programmes because we all realize the eternal truth that the survival of human mankind depends essentially on the sustained good soil health. The chapter introduced the soil as an entility to the students/learners, a natural body housing, a myriad of biodiversity and a savior of humanity.

2.2 The Soil - Definition from the Users' Point of View

Unlike minerals, plants and animals, soils are neither represented by sharply distinct entities, nor are these exactly definable. Soils, might be described as border-like phenomenon of the earth's surface. They belong to the pedosphere, in which lithosphere, atmosphere, hydrosphere and biosphere overlap and interact (**Figure 1**).

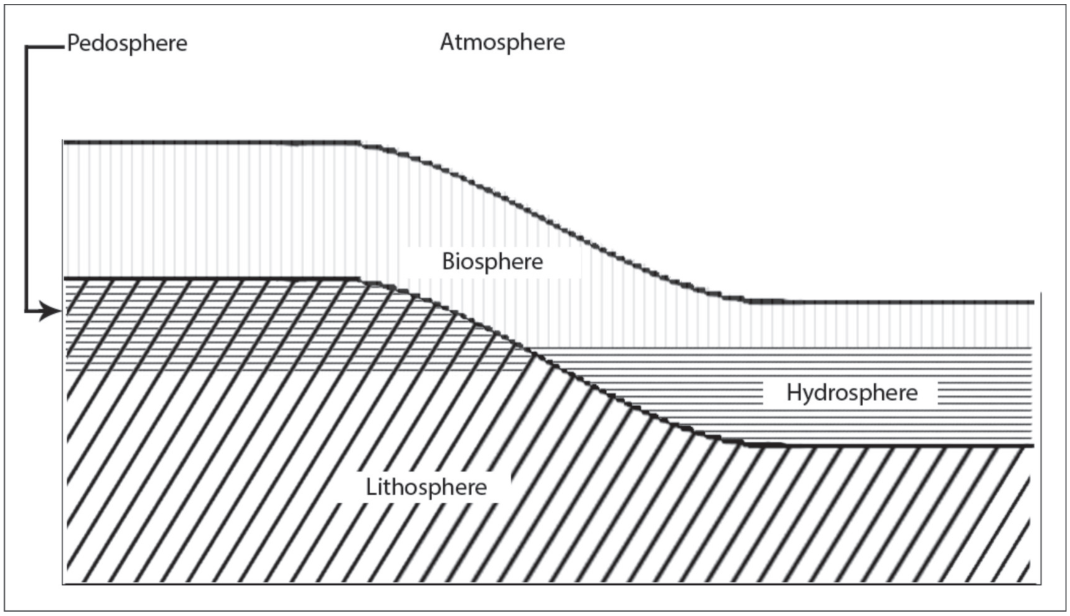


Figure 1. Soil as interface between different spheres of environment

Soil is defined as the i) transformation product of mineral and organic substances on the earth's surface under the influence of environmental factors operating over a very long time showing defined organization and morphology, and ii) growing medium for higher plants and basis of life for higher plants and basis of life for animals and mankind. On a multivariable concept soil is four-dimensional as a space-time system.

Definition of the soil varies according to use for which it is put. According to a Pedologist, soil a) is a natural body, b) both spatial and temporal, c) forms at the surface, d) is a result of complex biogeochemical and physical processes, e) capable of supporting life, and f) can be mapped at an appropriate scale. Engineers define soil as the unconsolidated material above the bedrock. Geologists define soil as the natural medium for the growth of plants on lands. Many a times acronym SOIL is expanded to Soul Of Infinite Life. Soil microbiologists rightly define soil as a *polis* (society or community) that is "governed" by soil organisms where fungi are the "governing" organisms in forest soils whereas other microbes are the "governors" or "soil managers" in other ecosystems. According to the FAO, "Soil is a natural body consisting of layers (soil horizons) that are composed of weathered minerals, organic matter, air and water; it is a natural medium for the growth of plants".

Thus soil can be viewed as the independent dynamic body of nature that acquires properties in accordance with the forces which act upon it.

2.3. Soil as a Natural Body

Soil is a natural body and formed under various ecosystems with the help of various factors. It is the end product of the combined influence of natural processes controlled by climate, topography, organisms, parent material and climate.

2.4. Soil as a Porous System

Soil consists of three different phases as it exists for all matters. These are solid, liquid and gases. An ideal soil has a ratio of 2:1:1 for solid: liquid: gas on volume basis (**Figure**

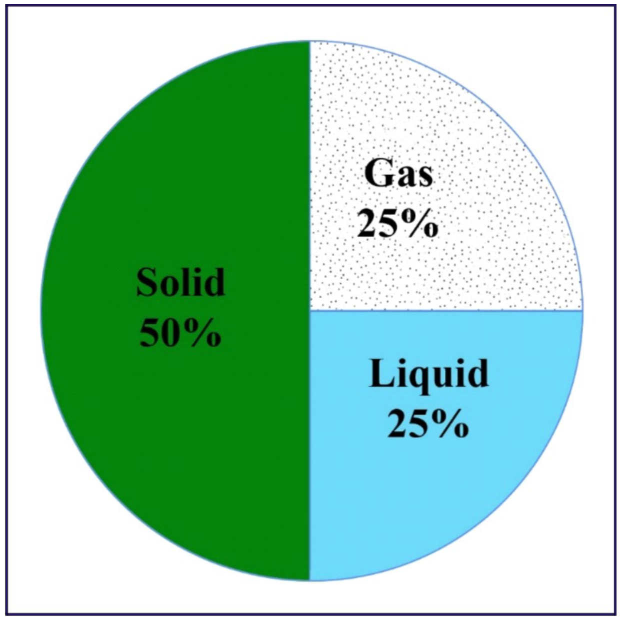


Figure 2. Soil components, showing three phases such as solid liquid and gas

2). Soils contain pores which are of two types namely macro- and micro-pores. Soil as a natural system is porous and permits flow of water within the matrix.

2.5. Soil as a Living Body

Mineral soils hardly contain 1-2% organic matter. Most of the soil materials are inorganic aluminum-silicates. Yet the soil is considered as a living body since it helps survival of numerous micro- and macro-organisms through physical and nutritional support. Many scientists believe that there are more species in existence below the soil surface than above it (**Figure 3**). Some organisms are plant and human pathogens and most of them are innocuous and benign.

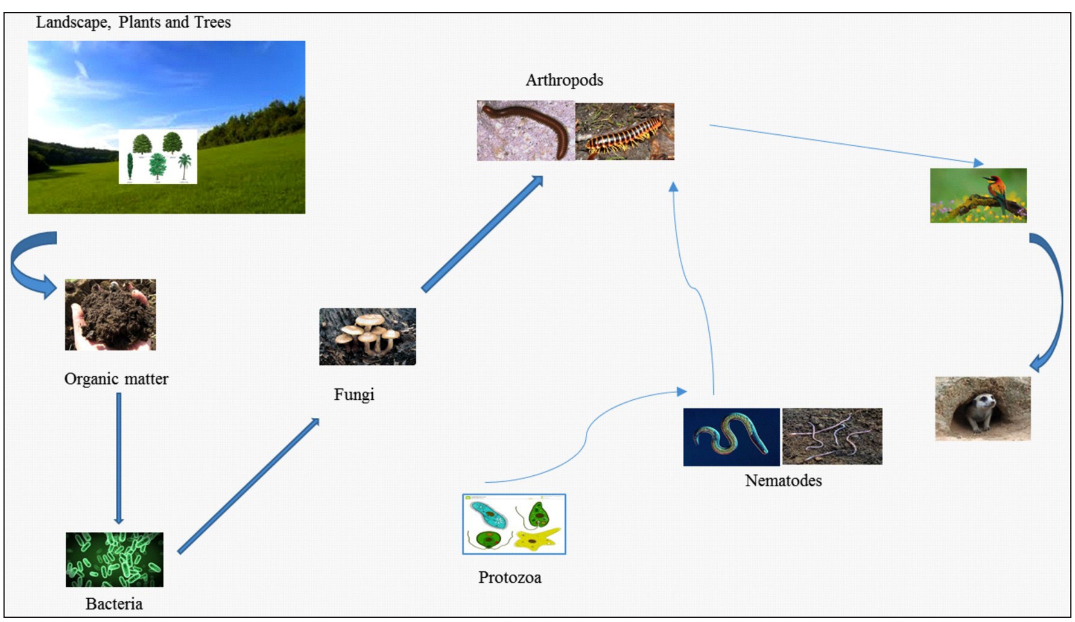


Figure 3. Organisms living in soils to link food web

2.6 The Soil Profile and its Layers (Horizons)

2.6.1. Soil Profile

From the surface, soils look similar; however, the soil as a profile with its distinct characteristics in different layers below shows the signatures of its genesis and importance for plant growth (**Figure 4**). *A soil profile may be defined as a vertical section of the soils that is exposed when a soil is dug down the surface*. In other words, the exposition of a set of horizons from the ground surface to the parent rock, is termed as soil profile. Soil profile is an important tool for nutrient managers, for pedologists (pedology, the study of soil pedons) and edaphologists (edaphology: the study of soil fertility and management) who can interpret various signatures of soil forming factors.

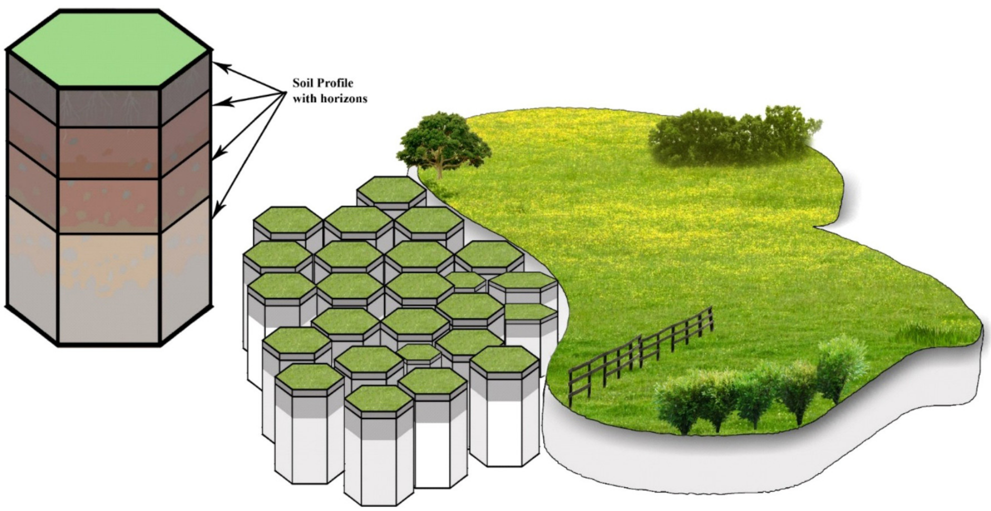


Figure 4. Soil profile and pedons as part of pedosphere

2.6.2. Soil Horizons

A soil horizon is a layer generally parallel to the soil surface (**Figure 5**). Soil horizons differ in terms of various parameters such as colour, structure, texture, boundaries, thickness and other details such as time, iron nodules, and root density. The exact designations of horizons are confirmed in terms of physical, chemical and mineralogical properties with the help of the laboratory data. **Figure 6** shows typical alluvial, black and red soils in India.

Capital letters of O, A, B, C, and F are used to designate specific soil horizons. Each capital letter along with its description of horizon is given below:

- The 'O' horizon refers to organic matter containing soil layer mixed with mineral matter. This horizon is usually common in forest floor. The 'O' horizons may be of two

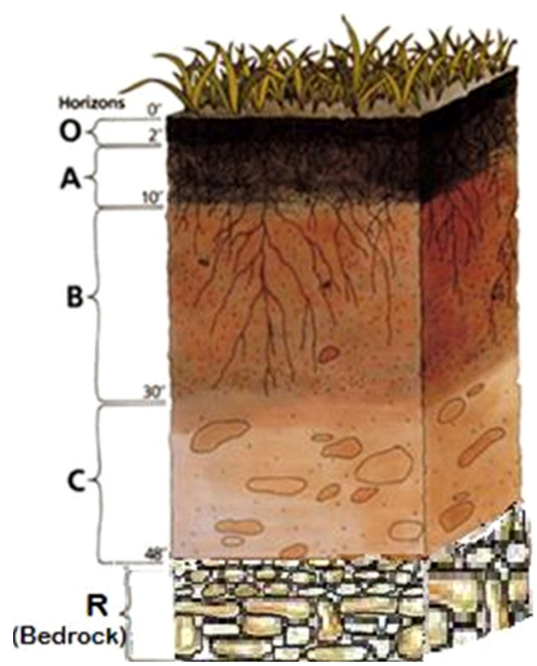
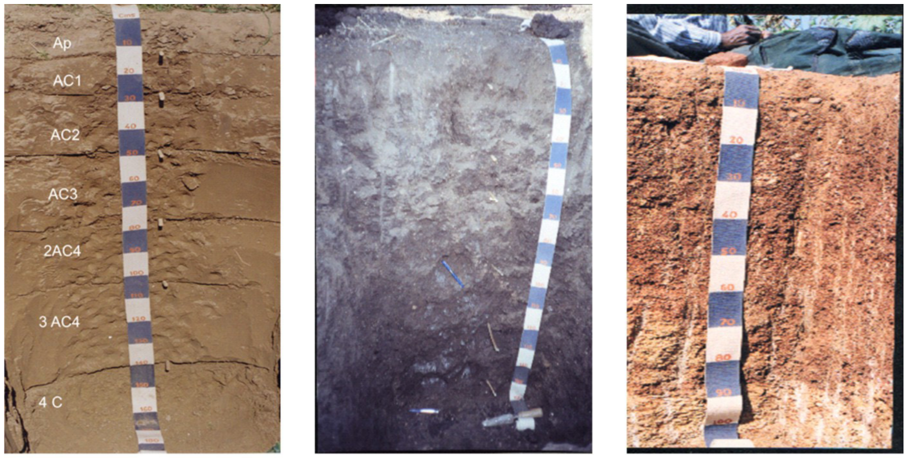


Figure 5. An ideal soil profile showing different horizons



Alluvial soil **Black soil** **Red soil**

Figure 6. Major soil types of India

types - ‘O1’ (decomposed matter of known origin say leaves) and ‘O2’ (well decomposed organic matter).

- The horizon ‘A’ is the topmost surface soil horizon, containing partially decomposed organic matter which rarely exceeds 1% soil organic carbon (SOC) in Indian soils under agriculture. ‘A’ horizon is the layer where maximum biological activities are observed as is evidenced by more microorganisms and roots.
- The ‘E’ horizon was not in the older versions of Text Books of Soil Science. Soil Survey Staff, USA introduced it to denote soil layer which is depleted in terms of clay, iron, and aluminium oxides. This horizon is known as the *eluvial* horizon.
- The ‘B’ horizon is the zone of accumulation. The process of accumulation is called illuviation, and the clays mostly translocated from the ‘E’ horizon (along with Fe, Al oxides) show a clay bulge in the ‘B’ horizon in soils known as Alfisols/ Ultisols. The ‘B’ horizon can be divided into‘B1’, ‘B2’, and ‘B3’ depending on slight variation of structure, texture, and other physical and chemical parameters. For instance, ‘B’ horizon in black soils (Vertisols) with slickensides is denoted as ‘Bss’ (please read Soil survey Staff, Soil taxonomy, 2014 for further information).
- The ‘C’ horizon is the horizon which denotes the parent material. Ideally, it should be the material from which the soil above it is formed. Interestingly, since many soils are translocated by water and/or air, the ‘C’ horizon may not have the parental legacy with the above horizons. In the transition of the ‘B’ and ‘C’ horizons, sometimes a layer may be seen which has the mixed properties of the ‘B’ and ‘C’ horizons and such a layer is designated as the ‘BC’ horizon.
- The ‘R’ horizon below the ‘C’ horizon is the layer of bedrock. Unlike the above layers, it is composed mainly of consolidated masses of hard rock that cannot be dug easily.
- Besides these horizons, there are ‘D’ and ‘L’ layers in literature. The ‘D’ layer refers to a horizon which is not the ‘C’ and ‘B’ either. The ‘L’ refers to limnic materials consisting of peats, diatoms and/or marl layers.

2.7. Topsoil and Subsoil

By and large, the surface horizon varying from 0-15 and 15-25 cm depths and mostly consisting of the ‘A’ horizon in the agricultural lands is referred to as topsoil. The ‘O’ horizon seen in forest soils is not considered since these are rarely used for agriculture.

Top soil harbours most of the microorganisms permitting organic matter decomposition. The roots proliferate in the top soil. Most of the biological activity remains at its peak in the top soil. Since many agricultural crops including cereals and vegetables are shallow rooted, these crops depend on the quality of the top soil in terms of its capacity to supply nutrients and water. This is one of the major reasons of collecting and analyzing the surface soils for soil testing.

The sub-soil, on the contrary, refers to the 'B' horizon in the soil. This horizon is characterized by the accumulated materials from 'A' or 'E' horizons and are often rich in clay that possess more cation exchange capacity (CEC). Since the biological activity gradually decreases down the soil depth, organic matter and nitrogen content usually exhibit a decreasing trend in the subsoil. It may be noted that although shallow-rooted plants depend heavily on the top soil, the perennial crops often survive because of nutrients and moisture retained in the subsoil. Besides, soil is a dynamic entity and in continuum with the top soil properties, which are often controlled by the subsoil and *vice-versa*.

The soil components (solid, liquid and gas) are spatially arranged to form soil body which differentiates into distinct layers known as soil horizon (**Figure 5**).

2.8. Soil - Resultant of Interaction among Pedosphere, Hydrosphere, Biosphere and Atmosphere

As shown in F**igure 1**, soil is in the interface between atmosphere including biosphere, hydrosphere and pedosphere. Soil is the ultimate result of interaction of various factors such as climate (atmosphere, hydrosphere), relief (biosphere), organisms (biosphere), parent material (pedosphere) and time. The combined influence of these factors helps in forming soils showing different properties. Parent materials refer to the material from which the soil is formed. It might include weathered rock materials (residuum). Parent materials are shown in **Table 1**. Inorganic parent materials of soil are minerals contained in consolidated and unconsolidated rocks of earth's surface. The most important minerals are silicates (nesosilicates, inosilicates, phyllosilicates, and tectosilicates). Parent materials formed from inorganic sources consist of various types of rocks (*igneous*: basalt, granite; *sedimentary*: sandstone, limestone, dolomite, shale, and *metamorphic*: gneiss, schist, quartzite, slate, marble).

Table 1. Types and sources of parent materials

Parent material	Sources
Aeolian	Sediments transported and deposited by air; common in sand dunes
Alluvium	Sediments transported and deposited by water (rivers/rivulets/streams)
Colluvium	Sediments transported and deposited by gravity: common in higher elevations and foot hills
Lacustrine	Sediments deposited by lakes
Marine	Sediments deposited by the action of sea and oceans
Organic	Organic materials accumulated as several meters in thickness: common in deep forests
Outwash	Sediments deposited by flowing water: glacier may be the common source
Residuum	Materials deposited due to weathering of hard rock in place
Till	Sediments transported and deposited by glacial till

Igneous and metamorphic rocks comprise over 95% of the earth's crust but cover only about 25% of surface. Sediments cover fewer than 5% of crust but 75% of surface; hence they are more important in soil formation. The rocks and minerals of the earth's surfaces are affected by atmosphere and living organisms; they are broken down by weathering. The products of and the residues from the minerals' weathering take part in neo-formation of secondary minerals, which become part of the soil. Relief or topography indicates slope, its aspect and exact position of landscape in an area. Since slope (and its aspect) governs moisture and vegetation it has a great role to play in soil formation and to decide soil properties such as depth, mineral make-up, particle-size of separates (sand, silt, clay) and organic matter. The altitude of land surface, its inclination and aspect (North, South, East or West) affect the relation between rock surface (and soil surface) and the water table, susceptibility to erosion and lateral movement of water in the soil. It also influences the micro-climate and hence the vegetation as shown in **Figure 6**. The depth of the water table determines whether soil differentiation takes place outside the influence of ground water or flooding or whether ground water has a dominant influence in soil formation. Erosion carries away soil or rock fragments in running water. The steeper the slope and the less permeable the soil, the greater is the erosive effect of rainfall. The input of radiation energy (sunlight) varies with gradient and orientation of slope. This affects temperature and evaporation and, frequently rainfall distribution. Thus the effects of macro-climate and vegetation on soil are always modified. In general, south (S) facing slopes are warmer and drier than north (N) facing while west (W) facing slopes contain more moisture than east (E) facing slopes. Overall, the soil forming processes are more intensive on NW slopes, while other factors remain constant (**Figure 7**).

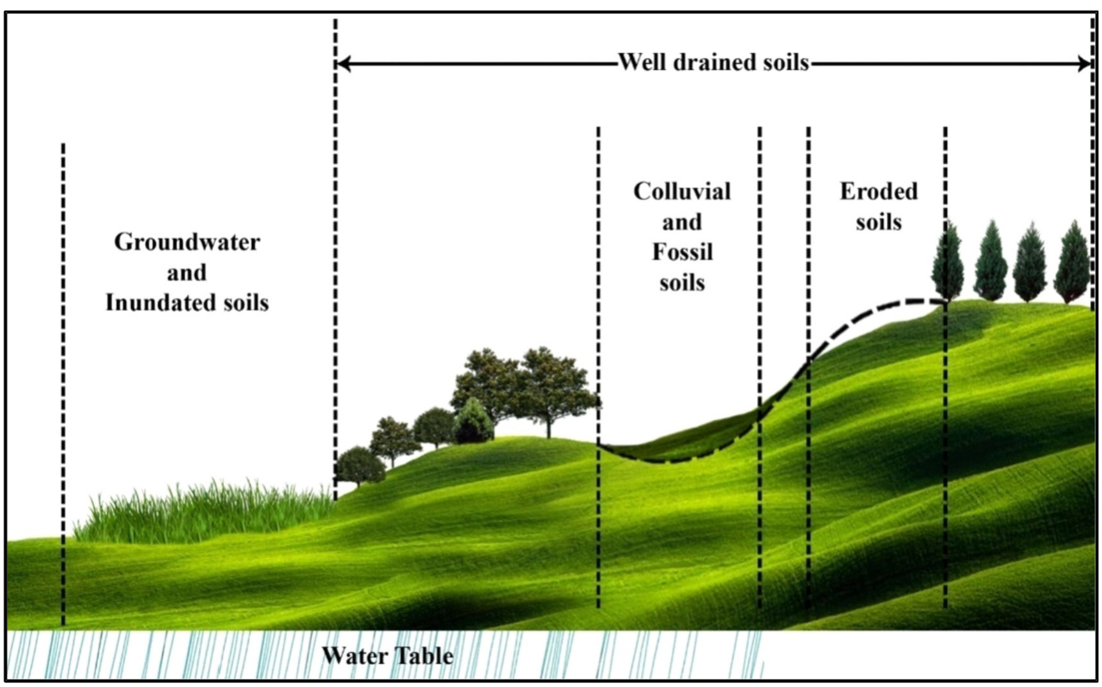


Figure 7. Microclimate, vegetation, and slopes influencing soil formation

Climate, an important component of the atmosphere, controls pedosphere also. It directly influences soil temperature and soil-water relationships and has indirect effects via vegetation. Radiation energy affects rock and soil temperature and thus controls rate of weathering and decomposition. All biological, chemical and physical processes are temperature-dependent. Temperature also has an indirect effect on water loss through evaporation from soil surface and on transpiration. The combined evapo-transpiration increases with rise in temperature and falling vapour saturation of air. Resultantly the temperature greatly affects the water relationships (**Figure 8**). Water is essential for all biological, chemical and physical transformation processes. It controls profile differentiation through i) percolation (rainfall> evaporation), ii) ascent (potential evaporation < rainfall), iii) surface erosion, and iv) water-logging which affect the process of translocation of materials from the top soil to sub-soil.

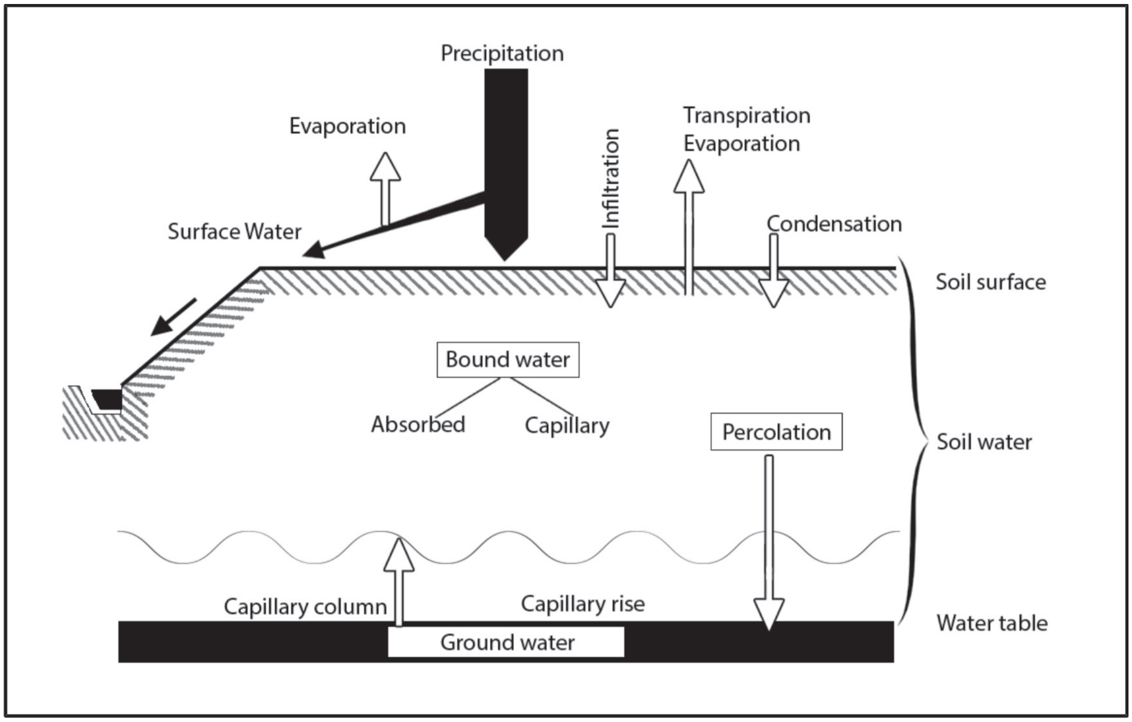


Figure 8. Fate of water after it reaches soil environment

Various factors such as rainfall, temperature and their seasonal variation characterize an area in terms of its bioclimatic systems *viz*. per-humid, humid, sub-humid, semi-arid or arid. The extent to which climate influences soil formation and profile differentiation depends on whether or to what extent water penetrates into the soil. And since it varies, so do the properties of soils in different bioclimatic systems.

The interaction of biosphere in the form of vegetation in soil formation is interesting since it is not an independent factor. It results from the interaction of rock, climate, and soil (**Figure 9**). Type of vegetation is largely determined by climate over very large areas. Thus the main climatic zones correspond with characteristics of the major types of vegetation from Tundra in the north of the globe through conifers, deciduous forests, steppe, *savannah*, semi-desert and desert to the rain forests of the humid tropics. Vegetation, in addition to having modifier effect via climate, also

- provides the parent organic matter of soil from which mineral and/or organic soils (muck, *mull*, *mor*) can form,
- smoothens effects of extremes of temperatures and humidity, affecting the micro-climate or the pedo-climate in the soil to influence soil formation,
- protects the soil-surface against erosion and leaching of nutrients. Plants also bring up nutrients from the lower levels of the soil and return to the surface as litter (conservation in the nutrient cycle), and

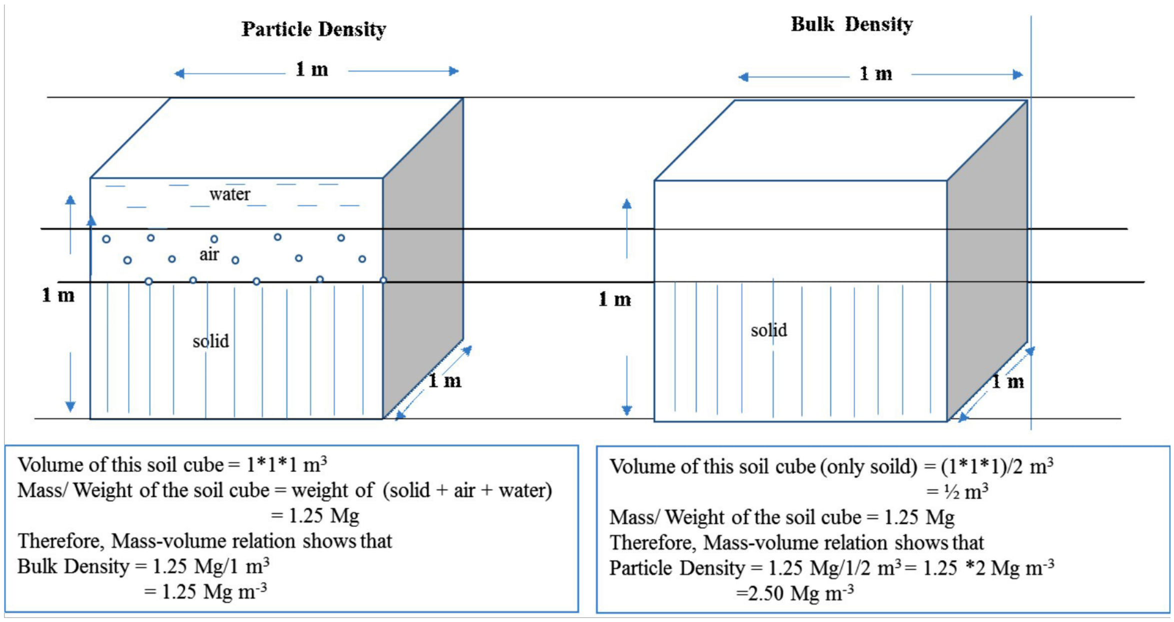


Figure 9. Schematic diagram showing mass-volume relationship in soil to estimate bulk and particle density. Note that particle density is always more than bulk density

- also affects soil fauna which contribute organic matter and affect soil forming processes. Anthropogenic (human interventions) influence on soils consists of directly by cultivation and indirectly by influencing vegetation, climate, relief and parent material. Human interference may either slow down or hasten up soil formation and depending on situation this can lead to soil degradation.

2.9. Soil Composition

Soil is one of the most important natural resources of the earth. It is basically made up of two components *viz* organic and inorganic. Most of the mineral soils are poor in organic components. As a matter of fact in tropical soils of India, the SOC content rarely exceeds 1.5%; logically therefore the entire composition of soil is inorganic on weight basis. On volume basis as discussed earlier soil is composed of three phases *viz* solid, gas and liquid with a general ratio of 2:1:1.

2.9.1. Solid Phase

2.9.1.1. Mineral Components

Soils (except organic soils like peats or mucks) are dominantly inorganic and contain mineral matters. These mineral matters may be grouped into a) crystalline and b) non-crystalline/amorphous components.

2.9.1.2. Crystalline components

These components are defined by inorganic materials in soil which are crystalline towards X-rays, producing characteristic diffraction peaks showing the presence of crystalline minerals. Minerals are naturally-occurring, inorganically formed and show definite, ordered atomic arrangements and chemical composition. Minerals present in clay (<2 μm) fractions are called clay minerals. The minerals vary in size. Some are as large as rock fragments and a few are so small that we need electron microscope to see those particles. Minerals are generally grouped into primary (which are formed at the time of rock formation; example, quartz) and secondary (formed from the primary minerals by weathering process; example, alumino-silicate minerals). By and large, primary minerals are more frequently found in the coarser fragments of soils such as sand (> 50 μm) and silts (50-2 μm) fractions, whereas clays (< 2 μm) are usually dominated by the secondary minerals.

2.9.1.3. Non-crystalline/amorphous components

These are also known as allophanes (*Gk. Allo* = otherwise; foreign) which are amorphus or para-crystalline clay minerals whose structure and composition is still uncertain. They occur frequently in soils formed from volcanic ash. Non-crystalline and amorphous components are also found in soils which are highly weathered especially the red soils from high rainfall areas. These are found as the oxides of iron and aluminium.

2.9.1.4. Soil Organic Matter

It forms 1-5% of the solid part of soil. Although it occupies less but has a large role to play in controlling morphological, physical and chemical properties of soils. Soil organic matter (SOM) is the sole source of native nitrogen in soil, and contains other important nutrients mainly sulphur and phosphorus. The SOM is important for soil structure. It influences water, air and temperature of the soil which indirectly influence various soil-plant processes. It is made up of living organisms of the soil flora and fauna (**Figure 3**), living and dead plant roots, which may be partly decomposed and modified with the newly synthesized organic substances of plant or animal origin. Organic matter may be grouped broadly into two different groups, namely i) original tissues of plants/animals/debris and the partially decomposed product, and ii) humus. The humus includes highly decomposed soil organic matter including dead materials and is the decomposition product of small plant roots, shed aerial parts of higher plants (litter, straw) and organisms of soil flora and fauna. Organic matter is the important source of energy for soil microorganisms.

It should be noted that for a normal soil, the solid: air: water ratio by volume is maintained as 2:1:1. If the relative proportion of one component changes, it affects other components. If the balance is not maintained, the soil behaves abnormally and is often called as the degraded soil. It is therefore, important that the proper ratio of these three components is maintained.

2.9.2. Soil Air

Soil air differs from the atmospheric air. The composition of soil air is controlled by respiration of roots and soil organisms (O_2 requirement and CO_2 production) (**Table 2**). The CO_2 content of air in soil is approximately 10 times that of the atmosphere. If gas exchange is restricted, the CO_2 content in the subsoil can reach values over 10% and O_2 below 10%. It will restrict the root activity. The dynamic nature of soil air not only influences plant growth but also influences flora and fauna which reside in the soil. Soil air is not continuous unlike atmospheric air and is often intercepted by soil pores separated by soil solids. Since the whole pore space in soil must be shared by air and water, air content varies reciprocally with water content. When the soil is saturated with water, its air content is almost nil. Conversely, in extreme cases of dryness soil air might occupy the whole of the pore space in absence of water.

Table 2. Composition of soil and atmospheric air

Components	Composition of air (%)	
	Soil	Atmosphere
O_2	<20.6	20.95
CO_2	>0.2	0.03*
N_2	~79.0	79.0

*Atmospheric CO_2 content has increased due to global warming since then. As in 2015, the CO_2 content in atmosphere is 400 parts per million by volume (ppmV)

The air content at field water capacity (FC) (described under soil water) is called its air capacity which corresponds with that part of the pore space not filled with water (pores >10 μm). Air capacity varies much with pore volume and water content at FC; for example it is 40% for sand, 20% for loam and silt, and 10% by volume for clay in the soil.

2.9.3. Soil Water

It is important that soil meets the water needs of plants and also helps in carrying nutrients in solution. Besides, soil water is an essential factor in all the processes of soil formation including weathering, humus enrichment, mobilization and transport within the soil. The water balance of soil depends on effective rainfall, surface runoff, infiltration, percolation losses by evaporation from soil surface. The water which infiltrates into the soil is partly retained as bound water and partly penetrates down through the soil to recharge the ground water. Ground water can rise by capillary action to replenish the stock of bound water so that plants can use this water when required (**Figure 8**).

Bound water is held in soil against gravity by adsorption at surfaces of solid particles and by capillary forces in small pores. When the soil contains optimum moisture (**Figure 2**) plants can draw water easily since most of the water is held in macro pores and in some pores with intermediate size. When water is in tiny pores (micro pores) it is held tenaciously and hence may not be easily available for absorption by plants. Since it depends on type of soils, rain fall, and irrigation, it indicates that management of water in soils has an important role in growing the crop plants.

It may be noted that the plants get nutrients from soil and water acts as a medium to make these nutrients available for absorption. Soil water contains dissolved plant nutrients which are obtained by plants through exchange phenomenon. Concentration of soluble salts in soil water has a direct role in plant nutrition; nevertheless salt content exceeding the threshold limit renders the soil unproductive. Example is the saline soil.

2.9.4. Mass-Volume Relationship

Soil mass is expressed as 2.24×10^6 kg ha^{-1} for ~ 15 cm soil depth. The mass and volume of the soil is related through the density of soil. The density is of two types

2.9.4.1 Bulk Density

It refers to weight or mass of soil per unit volume. In other words, it is the weight of bulk of the soil which includes all the soil solid components (mineral + organic). Usually bulk density (BD) of the soil ranges from 1.2-1.6 Mg m^{-3}; yet BD more than 1.6 Mg m^{-3} is also not uncommon in Indian soils. It is controlled by type of soil solids as represented by relative proportion of sand, silt and clay and organic matter. Since organic matter is lighter than inorganic particles, higher SOM content will result in the lower BD. Conversely, coarser soils with more sand particles will increase the BD. As indicated earlier (**Figure 2**), the relative proportion of these soil components will determine BD. Higher bulk density will often result in poor drainage making the soils physically degraded and unproductive. Application of organics (manure) will keep the BD at a reasonable level and shall also maintain good soil structure. For all practical purposes BD is a reliable indicator of soil quality and health.

2.9.4.2 Particle Density

It refers to weight or mass of particles present in unit volume occupied by the soil. Exclusion of the volume occupied by water and air spaces always results in higher particle density. For a normal soil maintaining 2:1:1 ratio of solid: water: air the relative volume of particles becomes half of the total volume and therefore, PD becomes double the value of BD in normal cases (**Figure 9**).

2.10. Soil and Environment

Environment in a broader sense includes ecosystems. Soil is at the interface of this larger environment (**Figure 1**). An ecosystem is a dynamic complex of plant, animal and microorganism communities including the nonliving environment and all these components interact among themselves. Since soils support flora and fauna on which humans and animals depend, soil is part of the larger environment. Soil is, in fact, a link between the air, water, rocks and organisms and is responsible for many different functions in the natural world that we call ecosystem services. These soil functions include: air quality and composition, temperature regulation, nutrient elements recycling (including C), water cycling and purification (filtering), natural waste (decomposition) treatment, and recycling and habitat for most living things and their food. We cannot survive without soil and the way it is related to environment. The role of soil in ecosystem is manifold. As a matter of fact soil has a role to play in every sphere of human life as described below.

2.10.1. Habitat for Food and Other Biomass Production

Soils provide environment where seeds grow. They provide nutrients, water and other necessary environment which nurture plants for survival. These plants form together with other plants and organisms to create ecosystems. Soils are part of these ecosystems. These plants provide valuable habitat and form the main sources of food for animals, microorganisms and human beings. Besides, decomposed organic matter from plants and trees form the biomass in soils.

2.10.2. Environmental Interaction

2.10.2.1. Air Quality

Well-covered soil can protect erosion. This can restrict wind erosion to control the purity of atmospheric air which in desert area is always contaminated with impounded air particles causing major health problem. These particles contain various microorganisms which can cause infection and diseases.

2.10.2.2. Temperature Regulation

Soil temperature plays an important role in chemical, bio-chemical and biological interaction in the soil environment. This in turn, influences seed germination, proliferation of microbes making nutrients in form available to plants and microbes and decomposition of organic matter in soil. In soils of cold region, cool temperature can put such reactions at low level causing more organic carbon storage. Tropical soils in India are thus poor in organic carbon as they cannot store more organic matter.

2.10.2.3. Carbon and Nutrient Cycling

Soils contain large amount of both organic and inorganic carbon. While organic form of carbon is boon for farmers, inorganic carbon is mostly a bane (curse) for them. Natural processes are all cyclical and so are the processes through which all nutrients and carbon in soil are cycled. On a global level, the total carbon cycle (**Figure 10**) is more complex and involves carbon stored in fossils, soils, oceans and rocks. Physical, biological and chemical processes in the soils affect the balance in organic carbon compounds and they are released to the atmosphere as CO_2 or are stored in the soil. This same process occurs with nitrogen, phosphorus and all other materials.

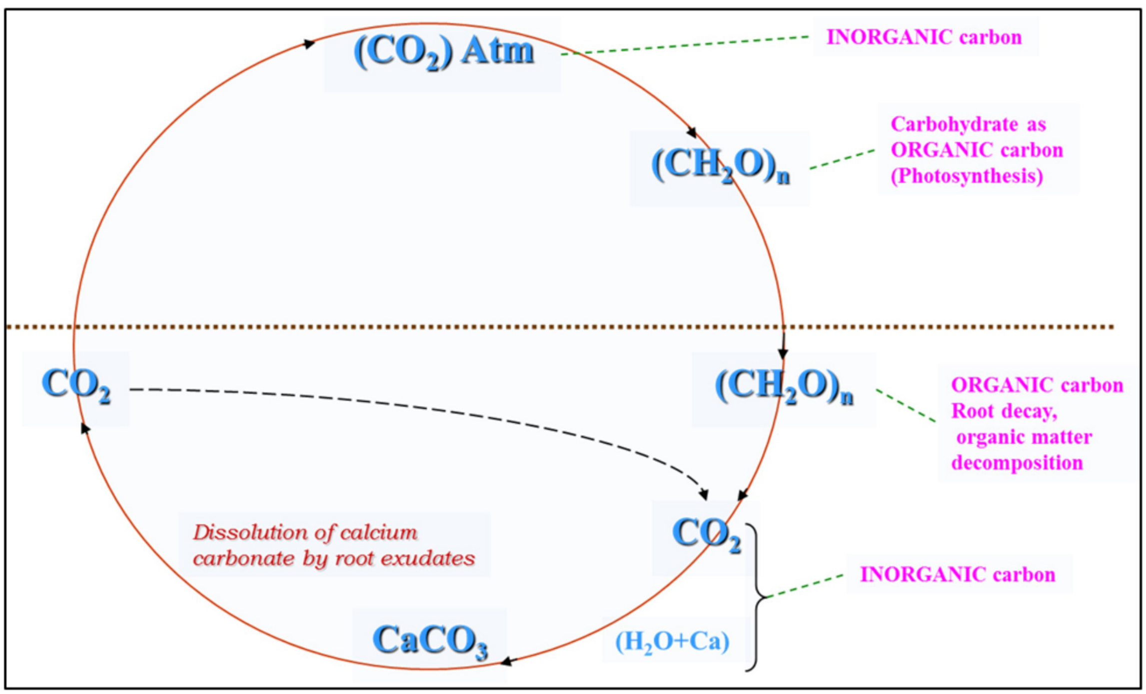


Figure 10. Carbon transfer model and its role in soil

2.10.2.4. Water Filtration

Soil is a great sink; it is a great source indeed. The water we consume and use for other purposes is always filtered by the soil. Not only so, soils absorb water, retain it and make it available for flora and fauna. Without soil and soil particles, water would be running on bare rocks. When it rains, the soil acts as a sponge, soaking water into the ground. This water can be used by plants, microbes and other living things; water also makes the underground aquifers and lakes and flows into streams before eventually making it to the ocean. If rainfall contains harmful materials, the soil acts as a filter; soil makes the water potable which can be used by us. Soil filters water as it reaches from the land surface into the ground water. This occurs through physical, chemical and biological processes. For example, septic systems (for sanitation) rely on these processes to protect ground water quality as well as maintain the quality of the water supplied to us for drinking. If soils are not protected, these can pollute water, and the pollutants might wash away into stream and oceans to affect the overall ecological balance.

2.10.3. Biological Habitat and Gene Pool

It is believed that there are more species in existence below the soil surface than above it. Soil is the habitat of organisms which include microbes and higher animals (**Figure 3**). These are extremely beneficial to soil physical and chemical processes that influence soil fertility and productivity. Soils have vertebrates (mice, mile and prairie dogs). These burrowing animals redistribute soil materials from deeper layers to reach the surface. Organic matter is also physically shred into smaller particles for making decomposition easier. Macroorganisms in soil include earthworms, termites and ants. These animals fill the soil through their burrowing action. Their feces serve as rich sources of soil nutrients. Several species of fungi in soil are important in the decomposition of organic materials to form humus and thus help in the formation of soil aggregates. Other important microbes include actinomycetes, algae, bacteria, nematodes and protozoa. Actinomycetes give soil its characteristic "earthy" aroma when it rains. Soil has a diverse system of biological characteristics often termed as "soil biodiversity". This is beneficial for plant growth, including crop production. With increased diversity, the decomposition of organic matter and release of more nutrients are made possible. **Table 3** shows different soil organisms and their role.

Table 3. Selected soil organisms and their role in soils

Types of organisms	Role
Algae, bacteria	Help in photosynthesis
Actinomycetes, bacteria, fungi	Decomposition of organic matter
Protozoa, nematodes, arthropods	Release plant-available nutrients
Earthworms, arthropods	Shred residues, improve soil structure, make burrows in soils and redistribute the nutrients
Bacteria *(in nodules of legumes)*	Fixation of atmospheric N

Since soil is a shelter for a large number of organisms, it can be considered a genetic reserve or gene pool, ensuring the conditions for the existence of biodiversity of the edaphic environment. Estimates of the number of species of some groups include bacteria (30,000), fungi (15, 00,000), algae (60,000), protozoa (10,000), nematodes (5, 00,000) and earth worms (3,000). One gram of soil may contain 10^9 bacteria, 10^7 actinomycetes, 10^6 fungi, 10^4 algae and 10^5 protozoa. Bacteria are an important part of the soil microflora because of their abundance (up to 10^9 cells per gram of soil), their species diversity (at least 4000 to 7000 genomes per gram soil). Soil as a gene pool was used first by D. Waksman in 1940 (Nobel Laureate in 1952) to isolate antibiotic compound from the actinomycetes. Antibiotic groups extracted from soil are aminoglycosides, glycopeptides, tetracycline, and cephalosporin. Nearly 78% antibacterial agents approved between1983 and 1994 had their origin in soils. These days many genetically modified crops are being developed with the help of microbes from the soil.

2.10.4. Sources of Raw Materials

Soil is a source of several raw materials for industry. It supplies ores for iron, used for steel industry. Aluminium ore as bauxite is excavated from soils. Several minerals like zinc, manganese etc. are mined from the soil. Many pharmaceutical industries depend largely on soil-mined minerals. Materials of daily needs for us like toothpaste, talcum powder, creams and many such items require clay minerals as fillers. The construction of building requires wood, bricks, metals which are also obtained from soils. Located at the interface between lithosphere, atmosphere, and biosphere, the soil becomes one of the most important components of the environment, performing numerous functions in the terrestrial ecosystems as shown in **Figure 11**.

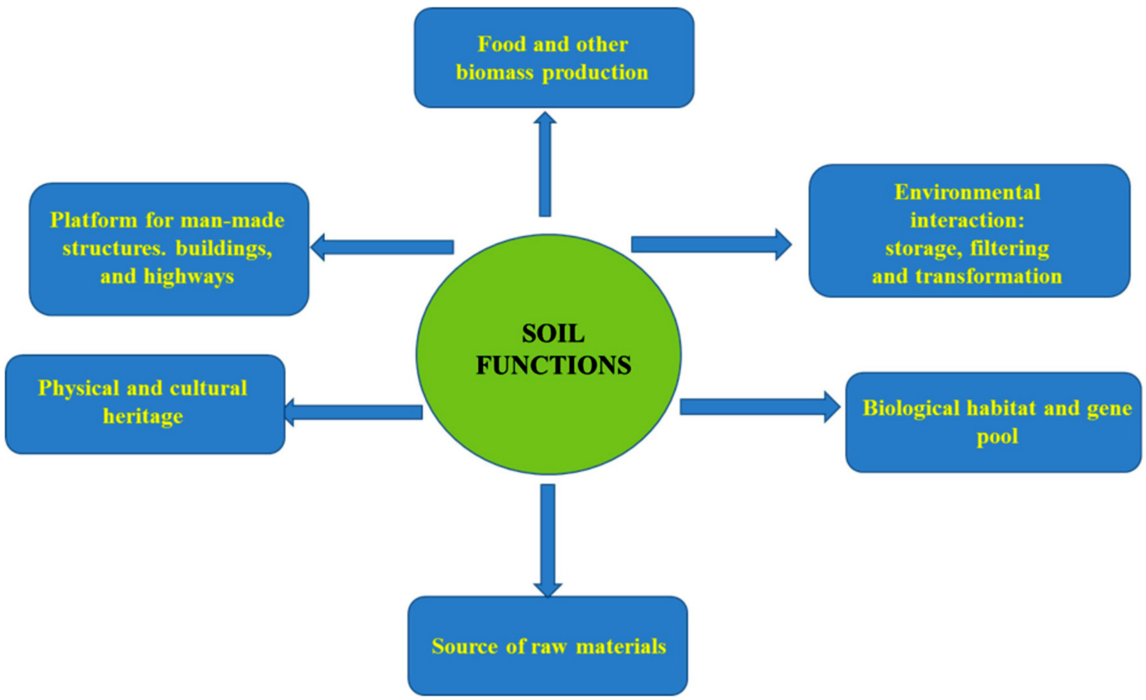


Figure 11. Schematic presentation of soil functions

2.10.5. Physical and Cultural Heritage

Soil acts as a physical and cultural heritage of the natural and cultural history of the human society, because it reflects on the evolution of natural conditions in an agricultural region and some aspects of human evolution. Thus, based on the fossils discovered in the soils, the climate and vegetation characteristics in a certain period of time can be reconstructed. Soil is a good indicator of the environmental quality and evolution since it has the ability to permanently adapt to natural or artificial changes and memorize past events.

Lot of archeological materials such as coal, ash, pottery, tools, bones, and remains of shells can provide important information on paleontological nature about the past including the soil age. The soil has been able to relate the evidence of human civilization. Soil has a tremendous memory to keep the information of the past to trace the events of earlier civilizations. Soil protects all the evidences of the past, which are extremely important to understand the evolution of life on the Earth. In terms of cultural function, the soil is a real geological and archeological heritage to look into the culture of human civilization (**Figure 12**).

Figure 12. Soil has memory and acts as a store house of past events

2.10.6. Platform for Man-made Structures, Buildings and Heritage

Soil acts as a support for houses, industrial buildings, communication ways (road, highways, and airports), sports' fields, and storage of household and industrial wastes. It gives an environment for pipelines installation and underground cables. The soil resulted from the excavation of foundation is also used to cover dumps of wastes from metallurgical complexes or to cover the garbage near cities, as a solution for protection against environmental pollution (**Figure 13**).

Figure 13. Use of soil in building infrastructures: roads, buildings, airports, sports fields and sink for waste materials

2.11. Soil as a Medium for Plant Growth

Soil is the stomach of plants. Early human relied on natural fruits, vegetables, and animals that the soil produced directly or indirectly. Our ancestors understood that soils can be used as the best medium for plant growth since soils can supply adequate moisture and nutrients and can also hold the plants for their growth. We developed ways to cultivate and manage soils which include fertilization, irrigation and plant protection measures. Life thrives in the biosphere, the zone at the interference of the Earth's crust and the atmosphere. Here, the sun provides radiant energy, which green plants capture and transform into sugars and other useful chemicals through the process of photosynthesis (**Figure 14**).

Figure 14. Soil as a medium for plant growth

Moist soils provide nutrients, water, oxygen and physical support to plants (everything that plants need except the energy from the sun and CO_2 from the air). As organisms in the soil decompose dead plants and animals, CO_2 is returned to the air, completing the carbon cycle (**Figure 10**).

2.12. Conclusions

Soil is the most complex element of the environment, it provides a vital link that connects the abiotic (inorganic), biotic (organic) and anthropogenic (human) components. It is an important component of all natural and anthropogenic ecosystems. Because of its process of self-purification and neutralization of organic pollutants, the soil favours the supporting of a certain balance in the environment. The rational use and the soil protection can determine our future. It is compulsory for all of us to see that this precious natural resource is saved so that our future generations have the opportunity to secure their needs such as food, fodder and fuel. This way we can respect and protect the right to survival for our children and grandchildren.

Study Questions

Q 1. Define soil from plant growth medium point of view.

Q 2. How does an engineer define soil?

Q 3. Are soils porous? Explain in brief.

Q 4. Soil contains 1-5% organic matter and mostly inorganics. Do you think soil should be considered a living object? Explain.

Q 5. How do you define top soil? How is it different from the subsoil?

Q 6. What is a soil profile? What are soil horizons? Describe different types of soil horizons with a diagram.

Q 7. What are bulk (BD) and particle densities (PD) of soils? Calculate BD and PD assuming a soil cube as 1 m (soil solid, water; and a ratio of 2:1:1) with its weight as 1.4 Mg. Draw a sketch to explain your calculation.

Q 8. What are the major components of soil? What happens if these components do not maintain the normal ratio of 2:1:1?

Q 9. Enumerate different soil functions using a schematic diagram.

Q 10. Why do you think soil is a medium of plant growth?

Q11. Do you think soil has a memory? Explain in brief.

Suggested Further Reading

Brady, N.C. and Weil, R.R. (2002) *The Nature and Properties of Soils*. 13th Edition. Pearson Education (Singapore), Delhi.

Bear, Firman E. (Editor) (1969) *Chemistry of the Soil*, International Edition.

Soil Survey Staff (2014) *Keys to Soil Taxonomy*. 12th Edition. USDA-NRCS, Washington, DC.

Definitions

1. Soil: *Soil can be viewed as the independent dynamic body of nature that acquires properties in accordance with the forces which act upon it.*
2. Soil profile: *A soil profile may be defined as a vertical section of the soils that is exposed when a soil is dug down the surface.*
3. Soil horizon: *A soil horizon is a layer generally parallel to the soil surface.*
4. Top soil: *Surface horizon varying from 0-15 and 15-25 cm depths and mostly consisting of the 'A' horizon in the agricultural lands is referred to as topsoil.*
5. Sub soil: *Sub soil refers to the 'B' horizon in the soil which is characterized by the accumulated materials from surface horizons and are often rich in clay that possess more cation exchange capacity.*
6. Bulk Density: *Bulk density refers to weight or mass of soil per unit volume. In other words, it is the weight of bulk of the soil which includes all the soil components such as solid (mineral + organic), water and air.*
7. Particle Density: *It refers to weight or mass of particles present in unit volume of soil.*
8. Ecosystem: An ecosystem is a dynamic complex of plant, animal and microorganism communities including the nonliving environment and all these components interact among themselves.
9. Soil habitat: *Soil is the habitat of organisms which include microbes and higher animals and these are extremely beneficial to soil physical and chemical processes that influence soil fertility and productivity.*

10. Soil porosity: *It refers to the capacity of soils to drain water carrying water soluble nutrients which is controls by micro and macro pores present in soils.*
11. Soil composition: *It refers to the inorganic and organic materials with which soil is made up of; usually inorganic part is 99% whereas organic matter hardly consist of ~1% in a mineral soil.*
12. Soil air: *It refers to air within the soil consisting of oxygen, nitrogen and carbon-di-oxide and water vapour. Interestingly carbon-di-oxide in soil is 1/10th of the atmosphere.*
13. Soil water: *Soil water refers to the water present in soils at a given time which varies depending on the soil composition and climate.*