Chapter 2
Soil and Its Role in the Ecosystem

Abstract Soil is highly heterogeneous body in the terrestrial ecosystem that has evolved through thousands of years of natural processes and has remained habitat for enormous biodiversity. Due variability in seasonal temperature, rainfall, parent materials and vegetation, different types of soils have been found in India; and each of these soils have distinct mineralogical compositions, physical and chemical properties. Such heterogeneity has resulted wide variations in the response of soils to polluting activities which causes differential location specific impacts. To understand the interaction of pollutants with soil constituents and their impact on agroecosystems, basic knowledge on various aspects of soil resources and its functions are essential. This chapter describes in brief, the major soil types of India and their properties, role of soil constituents on its quality, different soil forming processes, inhabiting organisms and their role in different soil nutrient cycling processes affecting crop productivity.

Keywords Soil type • Ecosystem • Organisms • Pedogenic processes • Agroecological zone • India

Soil is a highly heterogeneous body in respect of physical, chemical and biological characteristics as well as constituents and such heterogeneity arises both at micro- and macro-scale in all three dimensions. Pollutants interact quite differently with each of its constituents and hence, impact of anthropogenic activities on ecosystem varies widely. This necessitates a comprehensive understanding on soil and its role in the ecosystem by the personnel's involved in environmental impact assessment. This chapter briefly describes the important aspects of soil science mainly in the perspective of crop productivity.

Soil is a resource on which every person's life, well-being and fulfillment depend. Poor management reveals itself in terms of social and economic costs along with political repercussions. No sustainable agriculture and sustainable development is possible without this awareness. Present societies show little interest in this regard, and soil is often considered as no more than a support for human activities. We abuse the land because we regard it as a commodity for use by us but when we see it as a part of community to which we belong, we start looking at it with respect. If soil is viewed as precious resource, its use should abide by certain rules and a number of conditions so that different ecosystem functions are protected

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and sustained. In sum, soil is the source of life for humankind. Through the intermediary of plants, animals, water and minerals, the soil shelters and nourishes the people and their well being and health are dependent upon it. Soil is thus essential for humanity, whether its uses are of an agricultural, forestry, industrial, urban or ecological nature. No society can develop without using soils. Having said this, all is a question of balance between functional and renovation capacities of soil and anthropological pressure; the future is finely poised between the realization of soil potential and the pressure of human activities. Indeed, the development of human activity is linked with the functioning and properties of soils throughout the world. Anthropogenic changes in the pedosphere influence the other spheres with which it is interpenetrated *viz.;* lithosphere, hydrosphere, atmosphere and biosphere. The soil cover is thus in a pivotal position in relation to whatever local, regional or global changes the earth is undergoing. And here lies the importance of soil, its quality and the immediate environment as a core element in the issues related to sustainability and society.

The need to protect the environment will necessarily involve the knowledge and the use of natural soil functions to ensure higher quality soils, better produce quality, water and air quality and quality of life etc., through proper management and rational use of soils. Since soil itself is a component of the ecosystem comprising of soil, plant, animal, human and climate continuum, an impact on any constituents is likely to have some effects on the other parts of system. The environment of each of these components is intimately linked to one another so much so that a change in one environment might adversely or benignly affect other constituents. It is similar to throwing refuse into neighbor's premises to keep one's own environment clean leading to ultimately to the peril of all. Goswami and Rattan (1992) defined soil health, "as being a state of dynamic equilibrium between organisms and its environment in which all the metabolic activities of the former proceed optimally without any hindrance, stress or impedance from the latter".

The importance of soils to human well-being and cultural enrichment is glorified in the ancient Indian scriptures dating back to the dawn of civilization. The "Prithvi Sutra" in *Artharva Veda* narrates hymn as a prayer of goddess Prithvi, *"O mother, with yours oceans, rivers, and other bodies of water, you give us land to grow grains, on which our survival depends"*, and *"May you, our motherland, on whom are born five races of mankind, be nourished by the cloud, loved by the rain"* (Dwivedi and Tiwari 1987). Mahatma Gandhi reiterated this concept even more directly by stating *"Earth has plenty for every man's needs but not for every man's greed"* (Gandhi and Gandhi 1994).

2.1 Physical and Chemical Characteristics of Soil

Soil and land, though related, are two different entities. Land is two dimensional entity representing geographical area and landscape, while soil is a three-dimensional body with length breadth and depth and is hidden below the land surface. It is largely hidden from the outside world until it is lost and goes out of the site. It is recognized by digging a pit and exposing its profile. ‘Soil’ a dynamic phase of the earth’s outer crust serves as a delicate interface between atmosphere, hydrosphere, lithosphere, and biosphere where various biogeochemical processes occur that aid in its development to support key ecosystem functions such as plant productivity, biotic activity and water quality. The soil fractionates the hydrologic cycle in the terrestrial area into runoff, percolation and evapotranspirational components. It is a source as well as a sink to absorb, desorb, fix or release mineral elements and gases and grow plants and decompose crop residues incorporated into it. It is a living factor where millions of tiny organisms are ceaselessly working day and night, transforming the organic matter and participating in carbon and nitrogen cycles. In our habitat planet of Earth, life could not exist without soil and no soil without life. It is no wonder that the astronauts landing on the moon searched for evidence of soil, life and water there and brought with them soil samples to make detailed studies for an evidence of life. Soil is a limited and non-renewable resource but a pivot for agriculture, food security, nutritional security, environmental safety and quality of life. Since soil is pivot of natural resources, its management has to be fully integrated with eco-friendly techniques.

2.1.1 Physical Properties of Soils

The physical properties of a soil play an important role in determining its suitability for crop production. The characteristics like the supporting power and bearing capacity, tillage practices, moisture storage capacity and its availability to plants, drainage, and ease of penetration by roots, aeration, retention of plant nutrients are all intimately connected with the physical properties of the soil. Soil as medium of plant growth should also be physically fertile. The soil which supports plants is a variable mixture of solids (mineral and organic matter), liquid (water) and gases (air); and therefore is called three phase system. In a representative silt loam soil, about 50% of the total volume is occupied by solids. At the optimum moisture for plant growth, 25% of the volume occupied by water and 25% by air. Soil particle of larger in size like sand are generally visible through unaided eye (naked eye), whereas particles of colloidal in nature like clay can be seen only through electron microscope. The liquid phase, consisting of soil water also contains dissolved salts and thus it is called soil solution. The gaseous phase consists of soil air of varying composition of oxygen and carbondioxide different from that of atmospheric air. The important soil physical attributes are (a) bulk density, (b) texture, (c) structure,

(d) water holding and transmission characteristics, (e) soil color, (f) soil aeration and (g) soil temperature, which are briefly described below:

(a) Soil Bulk Density The bulk density of soil is defined as its oven dry weight per unit volume which is normally expressed as g cm^{-3} or Mg m^{-3}. Typically, a silty loam soil has bulk density around 1.33 g cm^{-3}. Soil organic matter, texture, density of mineral matter and compaction influence bulk density of soil. Soils rich in organic matter content have lower bulk density and with increase in soil profile depth, the bulk density increases gradually. Compact soils like clayey soil have higher bulk density than the light textured of sandy soil. Bulk density of a soil influences several important soil properties related to rhizosphere quality and consequently, to plant growth. Its value of more than 1.6 g cm^{-3} may restrict proper root growth in the soil.

(b) Soil Texture Quantitatively, soil texture refers to the relative proportion/distribution of different particles size fractions, which are specifically referred to as coarse sand (2.0–0.2 mm), fine sand (0.2–0.02 mm), silt (0.02–0.002 mm) and clay (less than 0.002 mm). The soil texture is considered a permanent natural attribute of the soil and therefore most often is used to specify its physical composition, having a bearing on soil behavior. Sand particles can hold little water, and thus soils dominated by sand are prone to drought. Clay is the fraction having negative charge and greater surface area per unit mass and influence the soil behavior most. The water gets absorbed by clay particles and hydrated resulted in swelling and shrinkage of soil upon wetting and drying of soil. Normal agricultural practices do not generally change soil texture. However, frequent inundation of land by flood water and application of large quantities of inorganic amendment materials (e.g. coal ash) may alter soil texture to a large extent.

(c) Soil Structure Physically a soil is a blend of inorganic particles, decaying organic materials, air and water. The inorganic particles of various sizes (sand, silt or clay fraction) generally cluster together to form complex and irregular patterns of secondary particles which are called aggregates or peds. The term ‘soil structure’ refers to the arrangements of these primary and secondary particles into a certain structural pattern. Soil structure greatly influences many soil physical processes such as water retention and movement, porosity and aeration, transport of heat, etc. The various soil management practices such as tillage, cultivation, application of fertilizer and manures, amendments (liming, gypsum) and irrigation, bring about changes in soil structure that influence other soil properties, thereby affecting root growth, water & nutrient uptake, crop growth and yield. Organic matter plays important role in the formation of stable soil aggregates of granular and crumb type soil structure. The organic root exudates and microbial decomposition products of organic materials play very important role in stable aggregates formation.

(d) Water Holding and Transmission Characteristics In soil, water gets absorbed on the surface of the soil particles as well as in the spaces between adjoining particles (intervening voids) as pore water. Distribution of particle size fractions

(texture) and their aggregation (structure) determine air-filled and water filled pore spaces in soil which ultimately regulate the exchange of gases between atmosphere and lithosphere. The major soil physical properties like soil consistency, compaction, swelling and shrinkage properties determine soil water retention and its transmission. The water is held in three forms depending on the tenacity with which it is absorbed: hygroscopic water, capillary water and gravitational or free water. The first two molecular layers of water on soil particles which have high suction are termed as 'Hygroscopic water'. Water held in capillary pores with suction ranging from 0.1 to 31 bar is known as '*Capillary water*'. With further increase in water content, when the macropores also get filled with water, it is more and more loosely held. Under the action of gravitational force, this loosely held water is liable to move downwards and hence it is known as '*Gravity water or free water*'. The drainage or deep percolation loss of water following irrigation results from the downward movement of the gravity water.

(e) Soil Color Soil color is often a ready clue to its condition and some important properties. For example, dark-colored surface soils absorb more solar radiation than light colored soils and so get warm up faster. Color is often a diagnostic feature in major soil classification and interpretation. Soil color is included in the description of a soil profile. It is also indicative of other factors such as presence of excessive salts (white), erosion etc. For determination of soil color, standard system using '*Munsell*' colour chart is used.

(f) Soil Aeration A typical mineral soil, on volume basis, contains half solid and half pore space. The solid part is consisted of mineral material and organic matter, space part is filled with water and air interchangeably. Soil aeration refers to the exchange of oxygen and carbon dioxide between the soil pore spaces and atmospheric air. The process controls the deficiency of oxygen consumed during respiration of plant roots and soil microorganisms and prevents toxicity of carbon dioxide evolved during respiration in the soil air. The term '*air capacity*' is used to describe aeration status of soil. The air capacity of soil refers to the volume of pore space filled with air when the soil is under a tension of 50 millibar. This value is also called as '*non-capillary porosity*'. It corresponds to a pore size of 0.06 mm or larger in diameter. The composition of soil is more or less similar to that of the atmospheric air except the content of carbon dioxide. In the upper layer of a soil having stable structure and ample macropores, the composition of air is taken as: nitrogen and inert gases = 79.1%, oxygen = 20.6% and carbon dioxide = 0.25%.

2.1.2 Soil Chemical Property

Soil chemical environment is regulated by number of soil chemical properties, such as, soil pH, electrical conductivity, clay mineralogy and cation exchange capacity, soil organic matters content, total and available plant nutrient status which are briefly described below.

(a) Soil pH The concentration of hydrogen and hydroxyl ions of a solution determines acidity or alkalinity. Soil reaction is denoted by pH of a soil water suspension and is an important indicator of soil health. Soil pH is the negative logarithm of the activity of H^+ in solution. Soil having pH value of <5.5 is considered acid soil. Soil pH is determined by active and potential acidity. While active acidity refers to H^+ ion concentration in soil solution, potential acidity indicates H^+ ions adsorbed on soil colloids. The former can easily be determined by measuring soil solution pH; whereas, the determination of the potential acidity additionally requires exchange of H^+ by other cation species prior to the pH measurement. The soil pH values may vary widely from pH 3 (e.g. in acid sulphate and podzolic soils) to 10 (e.g. in sodic soil). The presence of weak acids (HCO_3^-) and strong bases (Na^+ or K^+) in soil solution of alkali soils may results in high soil pH as high as pH 10.5. The soil solution H^+ ion concentration has a marked influence on nutrient release dynamics through its effect on weathering and mineralization process. It also has significant influence on soil microbial diversity composition and plant growth. Most of the crop plants grow well under near neutral soil pH value of 6.0–7.2. At low pH, Fe, Mn, and Al are highly soluble and attain toxic levels whereas at high pH, these ions become deficient. Nitrification is slow below pH 5.5. Under acid conditions, the pH-dependents NH_4^+ fixation between lattices of expanding layer silicates decreases with decreasing pH. The availability of phosphorus, primarily $H_2PO_4^-$ and HPO_4^{2-} ions, is highly pH dependent. Its availability in many soils is maximum when the pH is neutral or slightly acidic and it declines as the soil becomes strongly acidic or strongly alkaline. In general, the availability of micronutrients present in cationic forms such as Fe, Mn, Cu and Zn, increases with increase in soil acidity, whereas the availability of those present as anions, namely molybdenum and boron decreases. Therefore, the leguminous plant growth and nodulation are mostly affected by Mo deficiency rather than Al toxicity in acid soil. It has been estimated that 40, 48 and 12% of acid soil in India falls under mildly acidic (pH 5.5–6.5), moderately acidic (pH 5.0–5.5) and strongly acidic (pH <5.0) soil, respectively. Neutralization of soil acidity is normally accomplished through application of agricultural lime materials as well as compost material. Carbonates, oxides and hydroxides of calcium and magnesium are referred to as agricultural lime.

(b) Electrical Conductivity It is the measure of soluble salt content in the soil. Salt affected soils are characterized by an excess of neutral soluble salts mostly of chlorides and sulphates of calcium, magnesium and sodium. Based on the nature of soluble salts, such soils termed as *'halomorphic soils'* are generally classified into *saline and alkali* soils. Saline soils are mainly distributed in arid and semi arid regions characterized by the presence of white patches of salt crust on the surface. Growth of most crop plants is adversely affected by the presence of excessive soluble salts. Due to high evaporation and upward capillary movement of soil moisture in arid and semi-arid region, salts get accumulated on the surface soil. In dry period saline soils often show a white efflorescence of salts on their surface. For this reason they are also sometimes known as '*white alkali soils*'. When

appreciable quantities of Na^+ are present on exchange sites, Na^+ can come into solution and hence Na_2CO_3 and $NaHCO_3$ can be formed. These high soil pH conditions and presence of relatively lower salt concentrations lead to the deflocculation of clay and organic matter particles. The soil structure thus becomes water unstable. The soils are black due to the dispersed humic particles and are sometimes known as '*black alkali soils*'. The electrical conductivity is expressed as millimhos/cm at 25 °C or deci-Siemens/metre (dSm^{-1}) at 25 °C. As per the US Salinity Laboratory Staff (1954), saline soils have pH of saturation paste less than 8.5, Exchangeable Sodium Percentage (ESP) less than 15 and EC more than 4 dSm^{-1} at 25 °C. The alkali soils are characterized by pH more than 8.5, ESP more than 15 and EC lower than 4 dSm^{-1} at 25 °C. Management of saline soil is basically done by the removal of salts from saline soils through the process of leaching with water and drainage. Reclamation of alkali soils requires neutralization of alkalinity and replacement of most of the sodium ions from the soil exchange complex by the more favorable calcium ions, through the application of gypsum (calcium sulphate).

(c) Clay Mineralogy and Cation Exchange Capacity Nutrient status and behavior in soils depend on a large number of soil properties, of which types of clay mineral and total quantity of clay are most important. Soil clays consist of two main kinds of particles: (i) silicate lattice minerals (kaolinite group, montmorillonite group and illite group) and (ii) hydrous oxides of Fe and Al. The kaolinitic group of clay minerals is built up of flat units each consists of one silica sheet and one alumina sheet tightly bound to each other by equally shared oxygen and atoms. This kind of structure is characteristic of a 1:1 clay mineral. The montmorillonite group of minerals consists of two silica sheets with one alumina sheet held between them by mutually shared O-atoms. This is typical of a 2:1 clay mineral structure. In this case the units are rather weakly held to each other and easily expandable. Water and cations can thus readily be absorbed between them in these 'inner surface'. The particles are much smaller than the kaolin clays. The illite group resembles montmorillonite. It is a 2:1 clay mineral but the units are bound to each other by K^+ ions. They are therefore less expandable and their properties lie between montmorillonite and kaolinite. The hydrous oxides as their name suggests are oxides associated with water molecules. The oxides are mainly those of Fe and Al with general formulae $Fe_2O_3.H_2O$ and $Al_2O_3.H_2O$. Hydrous oxides have much less marked colloidal properties than lattice clays. They do, however, carry negative charges. The soils in which they particularly predominate are present in the tropics and semi-tropics. The presence of hydrous oxides in these soils gives rise to a high absorption capacity. The cation exchange capacity of soil is determined by the nature of clay minerals present in soil (kaolinite group: 3–15 cmol(+) kg^{-1}, montmorillonite group: 80–200 cmol(+) kg^{-1} and illite group: 20–50 cmol(+) kg^{-1}). Soils high in clay content have tendency to get dispersed with consequent increase in total surface area and micropore spaces. As a result, soil retains more water (in the capillary pores) as the clay content increases. Thus, soils rich in clay content have high cation exchange capacity and water holding capacity than soils low in clay.

(d) Soil Organic Matter Organic materials are intrinsic and essential components of all soils. It is the key component in soil that supports all life and makes soil a dynamic living system. The immense importance of soil organic matter (SOM) accrues from the facts that it (i) provides food source for soil microorganisms and soil fauna, (ii) act as store house for nitrogen, phosphorus and sulphur supply to higher plants (iii) improves various chemical and physical properties of the soil. SOM contains group of carbon containing compounds originated from living beings, of which 10–15% is non humus substance and rest 85–90% is humic substances. Soil organic matter also plays immense role in reducing toxicity of various organic and inorganic pollutants that enters the agricultural land through anthropogenic activities.

(e) Total and Available Plant Nutrient Status Soil fertility refers to the intrinsic capacity of a soil to supply all essential plant nutrients in adequate and suitable proportion for their optimal growth. Plant nutrient exist in soil both in organic and inorganic forms which constitute reserve pool for the use by microorganism and plant growth. Plant nutrients are exclusively absorbed by roots in their inorganic forms. On the contrary and unlike green plant, other living beings like man, animal and microorganisms need additional food stuff directly from organic source. An essential plant nutrient may be defined as a chemical element which is absolutely necessary for supporting normal growth, metabolism and completion of life cycle of plants. Additionally, specific function(s) of these essential elements in plants cannot be substituted by other elements. In other words, the deficiency symptom caused by any of the essential elements cannot be corrected by supplying other element. Most of the essential elements take part in plant metabolism and forms integral part of structural components of cell, enzymes and energy related compounds. Among the essential nutrients, C, H, O are derived from air and water and therefore, these are termed as non-mineral essential nutrients. All other nutrient elements are derived from soil and therefore they are called mineral essential elements. These mineral essential elements are classified as primary elements (N, P, K), secondary elements (Ca, Mg, S) and trace elements or micronutrients (Zn, Cu, Fe, Mn, Cl, B, Mo, Ni) in accordance with their amount of uptake. The essential micronutrients and other beneficial elements required for growth and metabolism of plants, animals and human beings are given in Table 2.1.

Management of the fertility of Indian soil demands it's built up and sustenance at a high level to produce adequate food for the ever increasing population. Fertilizers, therefore, constitute one of the critical farm inputs and play a significant role for achieving high crop productivity. Soil test based fertilizer recommendations ensure

Table 2.1 Essential trace element minerals for plants, animals and human beings

Species	Micronutrients	Beneficial elements
Plants	Zn, Cu, Fe, Mn, Cl, B, Mo, Ni	Si, Na, V, Sr, Co
Human beings	Fe, Mn, Zn, Cu, Se, Cr, Mo, I, F	As, B, Br, Cd, Pb, Ni, Li, Si, Zn V Co
Animals	Fe, Zn, Cu, Mn, Se, I, Mo, Co	Cr, Si, Pb, Ni, V, As, B, Sn

balanced use of fertilizers and increase yields and profits. Balanced fertilizers encompass, besides major nutrients, secondary and micronutrients whose deficiencies appear in different soils in various agro-eco-regions due to intensive cultivation. Soil testing laboratories in India generally follow identical critical limits for sufficiency or deficiency of plants nutrients, irrespective of the mineralogy or texture of soil or even crop species. However, the ideal soil testing should not only take into account of amount of available nutrient reservoirs, but also the environmental conditions of the rhizosphere which influence loss or transformation of nutrients to less available forms. Integrated plant nutrient supply management envisages the use of inorganic chemical fertilizers in combination with organic manures; legumes based cropping system, biofertilizers and other locally available nutrient sources for sustaining soil fertility and crop productivity. The combined applications of organic manure and inorganic chemical fertilizers generally produces higher crop yields than when each is applied alone. This increase in crop productivity may be due to the combined effect of nutrient supply, synergism and improvement in soil physical and biological properties. Farmyard manure (FYM) constitutes an important component for integrated nutrient management for maintaining soil fertility and yield stability.

2.2 Soil Organic Matter and Its Role in Soil Productivity

Organic materials are intrinsic and essential components of all soils. This key component in soil supports all terrestrial life forms directly or indirectly and makes soil a dynamic living system. The immense importance of soil organic matter (SOM) can be perceived from the following roles played in the ecosystem:

(a) It provides food for soil micro- flora and macro- fauna and helps in maintaining the biological activity within soil.
(b) It is the storehouse of nutrients for their supply to higher plant. Plant available inorganic nitrogen is normally quite low in soil and most of the plant requirement is met from its organic source through mineralization process (conversion of organic to inorganic nutrient form). Further, major fraction of fertilizer derived inorganic nutrients is immobilized by soil organic matter, as a result of which their loss from the system is minimized.
(c) It improves cation exchange capacity, soil buffering capacity and enhances capability to trap and exchange nutrient cations like potassium, calcium, magnesium and micronutrients like zinc, manganese, copper, iron etc.
(d) SOM helps in releasing nutrients slowly from minerals through weathering process in synchrony with their uptake rate by plant.
(e) Plant growth and development are enhanced through physiological and nutritional effects of some organic substances that are directly utilized by plants.

(f) Another important influence of SOM is improvement in soil physical properties like soil structure, porosity, water holding capacity, infiltration, soil temperature, etc., which facilitate optimum root growth and nutrient uptake.
(g) Soil organic matter also influences a variety of pedogenic processes like weathering of minerals, and their transportation leading to the soil formation.

2.2.1 Nature and Amount of Soil Organic Matter

The term SOM usually refers to those organic materials which are a part of the soil matrix. This includes: (a) the litter layer which consists of dead plant residues at the uppermost layer of the soil, (b) partly decomposed plants residues formed by the action of soil microorganisms and fauna on the litter, (c) biological organic molecules which are components of plants or animal tissues, e.g. proteins, carbohydrates, lignins, lipids, peptides, amino acids, organic acids, alcohols, etc., which are collectively called as non-humic substances, and (d) humic substances which are the stable end products of decomposition of plant and animal residues. Depending on the climatic condition, soil organic matter content in soil varies widely. In general, cool and temperate regions contain relatively more organic matter (5–10%) in the surface soil due to lower mineralization, whereas, cultivated surface soils in the tropical region contains only less than 1% SOM owing to high rate of decomposition under prevalent conditions of high temperature and moisture.

Climate (temperature and rainfall) plays one of the most important roles in determining the extent of SOM accumulation. It has been observed that SOM contents decrease to 2–3 times for each 10 °C increase in mean temperature. Apparently, the decomposition loss of SOM (to CO_2) increases more rapidly with temperature than the rate of its formation. Therefore, in warmer climates, SOM levels are generally lower than in cooler regions. In general, the activity of soil microorganisms and decomposition of SOM increases with rise in temperature from 0 to 35 °C; but above this temperature, the decomposition gets suppressed. The decomposition of OM is also influenced by rainfall and therefore, by soil moisture levels. Intensity of decomposition increases with moisture and reaches maximum at 60–80% of the maximum water holding capacity.

The second important factor influencing OM levels in soil is the nature and amount of vegetation. Vegetation provides the basic input in the form of leaf litter, branches, roots. The effect of vegetation on OM accumulation is best seen in the tropics. In the tropical evergreen forests, where litter input is very high, the soils are very rich in OM; soils under grass cover in the same region have much lower OM levels since litter input to the soil is relatively less; cultivated areas with limited vegetative cover have very low levels of OM.

Other factors, which influence OM accumulation, are soil minerals and soil texture. OM is easily lost from light textured sandy soils whereas loamy soils tend to accumulate OM. This can best be seen along river banks in areas otherwise covered by sandy soils.

Topography also influences the OM levels through soil drainage and moisture levels. Soils in depressions and valleys may accumulate more OM than those at the slopes. If all other factors remain constant, OM accumulation reach equilibrium levels with time. Further increase will not occur after a certain period of time, which is normally a few years. However, the stable fraction (humus) can persist in the soil for as long as 250–1900 years. This stable fraction takes much longer to accumulate and has an average '*turn-over period*' of about 150 years.

2.2.2 Humic Substances

Soil organic matter contains both humic and non humic substances which play an important role in nutrient release dynamics influencing plant growth. Humic fraction is relatively stable in soil than non-humic substances and constitutes largest component of SOM (85–90%). This fraction plays a major role in maintaining soil fertility and crop productivity. In general, humic substances are formed by the decomposition of dead plant debris and animal residues by soil microorganisms and fauna. They are colloid-sized, polymeric substance having dark colors (black and brown-black to yellow). The three soil fractions (on the basis of solubility in acid and alkali) of humic substances are (i) fulvic acid (FA) (ii) humic acid (HA), and (iii) humin. Fulvic acid is the most mobile fraction being soluble in water, acids and alkalis and is yellow to brownish yellow in color. Humic acid is soluble in alkali and insoluble in water and acids. It has a dark brown to black color. The most insoluble fraction of humus is humin, which is insoluble both in acid and in alkali. This fraction is strongly bound to the soil mineral matrix and is difficult to extract.

2.3 Organisms in Soil and Their Activities

Land is a dynamic living ecosystem that forms a habitat for millions of living organisms. Organisms present in soil are classified into two main groups: (i) soil flora, belonging to plant kingdom, and (ii) soil fauna, the animal forms. These are further divided into two sub-groups: macroorganisms, i.e. those organisms which are big enough to be seen by an unaided eye and microorganisms which are so small that these can be seen only after magnification using a microscope.

Soil organisms can also be classified on the basis of requirements of molecular oxygen, temperature and mode of nutrition, etc. Organisms that need O_2 for respiration and cannot survive without it are called *'obligate aerobes'* and those which are aerobic but also adapt to grow under anaerobic environment using oxidized substances like NO_3, SO_4, CO_2 etc. as terminal electron acceptor in place of O_2 during respiration are classified as '*facultative anaerobes*'. An example of such organisms of great agricultural substance in soil is the denitrifying bacteria. Certain group of microorganisms like *Clostridia, Actinomyces, Bacteroides,* *Fusobacterium and Methanobacteria* thrives well in the absence of oxygen are termed as '*obligate anaerobes*'.

The organisms have specific temperature requirements for their growth. Any change from the optimum temperature will not kill the organisms but will reduce their growth rate. *Psychrophiles* have optimum temperature for growth below 10 °C, while the group of organisms with optimum temperature between 20–35 °C is termed as *mesophiles*. This group is highly dominant and numerous in most of cultivated soils of India. A temperature higher than 45 °C favours development of *thermophiles*, commonly encountered in the compost pits.

Based on the mode of nutrition, soil organisms are classified into two groups- '*heterotrophs and autotrophs*'. '*Heterotrophs*' derive energy by oxidation of organic compounds while *autotrophs* derive their carbon from CO_2 for cell synthesis. The group of autotrophs is further sub divided into *chemoautotrophs* which get energy from the oxidation of simple reduced inorganic compounds like iron,sulphur etc. and *photoautotrophs*, which derive energy from sunlight by the process of photosynthesis.

2.3.1 Macroorganisms in Soil

The macroorganisms in soils include Acari, Collembola, Enchytracidae, Isoptera, Isopoda, Amphipoda, Diplopoda, Earthworm, Coleoptera, Mollusca, etc. Population or biomass estimation of these soil animals is highly difficult because they are not uniformly distributed in the soil and are highly mobile. Even though fewer in numbers than microorganisms, these organisms are very useful in soils as (i) they help in the decomposition of organic residues by mixing, churning or fragmentation as they eat on plant material, (ii) they form burrows and tunnels which increase soil aeration, drainage and turn in large amount of surface soil, (iii) enrich soil with organic material (as their food, ingested soil in the guts of earthworms gets converted into worm casts called '*mull humus*'), and (iv) Some of these organisms like mites, termites and acrinemites feed on soil microorganisms including plant pathogens.

Roles of Earthworms The total biomass of earthworms in soil ranges from 110 to 1100 kg ha^{-1} (furrow slice). Their population decreases on cultivation due to reduction in organic matter, with tillage which causes mechanical injuries and upon pesticide application which is toxic in nature. Earthworm cast is a rich source of nutrients, particularly N, P, Ca etc., and contains more bacteria and organic matter. Earthworms do intimate mixing of organic matter with mineral matter which increases the stabilization of clay bound carbon, depending on soil type. Earthworm-worked soils generally have high porosity, increased water holding capacity, higher water infiltration rate, more water stable aggregates and increased availability of plant nutrients. These organisms may also affect microbial population as they ingest microbes along with soil and organic matter.

Roles of Termites Termites also influence soil properties and processes through four types of activities: (i) physical modification of soil profiles by constructing mounds, sheeting and foraging runways, (ii) changes in soil texture emanating from movement of clay fractions from subsoil for construction they make (iii) changes in the nature and distribution of organic matter and plant nutrient through litter brought into nests which is digested by termites and decomposed by the microbes *in situ* (the termite-worked soil has higher CEC and exchangeable bases than surrounding soil), and (iv) the changes in soil drainage and moisture regimes upon constructing subterranean galleries.

2.3.2 Microorganisms in Soil

Bacteria The number of bacteria is highly variable depending upon soil type, nature of crop cover and climatic conditions. Generally, soils with low organic matter and sandy texture have very low population. The different bacterial genera commonly occurring in diverse soils are: *Pseudomonas, Arthrobacter, Clostridium, Bacillus, Achromobacter, Micrococcus and Agrobacterium.* The presence of enterobacteria (not strictly soil bacteria) in soils, is of great ecological significance, as it is indicative of fecal contamination. Their presence is a potential health hazard, particularly in growing crops whose edible plant parts come in direct contact with soil. Thus enteric pathogens may get into food chain and cause human diseases.

Due to their large number and rapid rate of multiplication, bacteria play a very significant role in carrying out various biochemical reactions controlling availability of plant nutrients. The processes of N_2 fixation, phosphate solubilization, organic matter decomposition and synthesis of humus, nitrification and denitrification, protein decomposition and ammonification, etc., lead to transformation of various macro- and micro-nutrients in soil and help in plant nutrition. Certain free-living soil bacteria can reduce the atmospheric nitrogen to ammonical form, thus enriching soil with plant available nitrogen. These bacteria belong to the genus *Azotobacter* and *Azotomonas*, and grow abundantly in soil which are relatively high in organic matter. The genus *Beijerinckia* and *Derxia* are unique; they can fix nitrogen in soils which are highly acidic (pH 4.0). *Clostridium* fixes nitrogen under anaerobic conditions and can be of economic significance in flooded soils. Besides these free-living bacteria, there is another group belonging to the genus *Rhizobium* which fixes nitrogen in symbiosis with the legumes forming tiny out-growths on roots called legume root nodules, the sites of nitrogen fixation. *Azospirillum*, a spiral bacterium fixes nitrogen in association with plants in rhizosphere after entering into roots without forming nodule and the process is called '*associative nitrogen fixation*'. The soil bacteria responsible for transformation of nitrate to oxide of nitrogen and gaseous nitrogen resulting in loss of fertilizer nitrogen are termed 'denitrifying bacteria'. The microbiological oxidation of ammonium to nitrate is one of the most important transformations taking place in soil which helps plant nutrition since nitrogen is predominantly taken up as NO_3 ion. This transformation is mediated by a group of bacteria called '*nitrifying bacteria*'.

Actinomycetes They are more common in dry soils and in undistributed pastures and grasslands. Like bacteria, they are more common in neutral to slightly alkaline soils. They are aerobic organisms and therefore their number is less in lowlands. As they can withstand drought conditions very well, they occur more frequently in soils undergoing dry spells. Actinomycetes are nutritionally heterotrophic and are highly adaptive to degrade wide range of organic substances, particularly those which are difficult to be decomposed by other soil organisms.

Fungi Soil fungi can now grow in wide range of soil pH but their population is more under acidic conditions because of severe competition with bacteria at neutral pH. A majority of fungi are aerobic and prefer to grow at optimum soil moisture. The contribution of these organisms in biochemical transformation under excessive moisture is negligible. Fungi are heterotrophs and therefore derive nutrition from either living plant tissues as a 'parasite', causing plant diseases or dead tissues as a 'saprophyte'. Saprophytic fungi perform a very important function in the decomposition of organic matter, particularly plant residues.

Some fungi form a symbiotic association with roots of higher plants facilitating uptake of plant nutrients, particularly of those which are less mobile. This association is known as 'mycorrhizal association'. The beneficial effect of these fungi on nutrient uptake has been attributed to three factors: (a) increased absorption of available nutrients from soil as the fungus changes root morphology; (b) increasing the nutrient availability by solubilizing insoluble nutrients like P which thus become available to plant, and (c) increasing the nutrient uptake due to faster intracellular nutrient mobility.

Algae Soil algae are chlorophyll containing organisms. They are autotrophic, and therefore their development is not restricted by organic carbon supply. They are abundant in habitats exposed to light and have sufficient moisture. Blue green algae have been reported to fix about 20 kg N per ha. Submerged soil condition in the rice fields provides an ideal environment for the growth of algae as the soil seldom dry out. A nitrogen fixing algae, '*Anabaena azollae*', forms a symbiotic association with a fresh water fern, Azollae and fixes nitrogen.

2.4 Soil Forming Processes

Soil is defined as outermost layer of earth's crust consisting of complex mixture of unconsolidated mineral and organic matter produced by the combined action of water, wind and organic matter decay. Soils are formed from hard rocks, loose and unconsolidated transported inorganic material and accumulated organic residues. Even the loose mineral materials from which soils are formed are originated by the

Table 2.2 Some important pedogenic processes

Structure development	Grouping of individual particles (clay, silt and sand) together with humus and free sesquioxides into aggregate or peds of fairly distinctive size and shape
Humification	Transformation of raw organic matter into humus
Translocation of lime	Removal of lime from the upper part of profile and its partial or total accumulation in the lower part. The process leads to the formation of a *kankar* or calcic horizon
Leaching	Removal of a constituent from soil solution e.g. soluble salts
Salinization	Accumulation of soluble salts in soil
Clay migration or lessivage	Removal of clay, particularly of fine clay in suspension from the upper layer of soil profile and its accumulation in the lower part
Braunification/rubification/ferruginisation	Release of iron from primary minerals and their dispersal as coatings on soil particles or as complexes with organic matter/clay or as discrete aggregates to impart a brown to red color to the soil
Laterization	Removal of silica from soil and accumulation of sesquioxides (goethite, gibbsite, etc.) with or without the formation of iron stone and concretions
Podzolization	Removal of iron and aluminum, often as complexes with humus, from the upper part and its deposition at some depth
Regur formation	Formation of intensively dark color complex of smectitic clay and humus. This dominant process occurs in black cotton soils
Gleization	The reduction of iron under anaerobic (waterlogged) conditions with production of bluish to greenish grey color with or without mottles or ferro-manganese concretion

Buol et al. (1997)

weathering of rock masses to stones, gravels, sands, silts, clays and soluble salts. The unconsolidated material overlaying the rocks is known as regolith. The profile of a soil with well marked horizons called A, B and C, tells the history of its formation and bears the imprint of many physical, chemical and biological processes which have led it to the present form. The common soil forming processes are given in Table 2.2. Several of these processes operate simultaneously though some may start acting sequentially. An example of the latter is translocation of clay within a profile occurs after leaching of lime or soluble salts. However, in the long run, one or two of these processes dominate and lead to the development of a soil with a distinctive profile dictated by factors of soil formation.

2.5 Types of Soil and Their Distribution

2.5.1 Soil Order

USDA Soil Taxonomy, the most accepted system of soil classification worldwide was developed by United States Department of Agriculture and the National

Cooperative Soil Survey. This system of soil classification is based on soil properties along the profiles (Table 2.3) and grouped under several levels namely: Order, Suborder, Great Group, Subgroup, Family, and Series (Table 2.4).

Table 2.3 Brief descriptions of the major soil orders in India according to soil taxonomy

Soil orders	Description
Alfisols	Soils are enriched with Fe and Al oxide minerals but lacks in $CaCO_3$ in the upper layer. Soils have diagnostic argillic horizon (rich with migrated clay), rich in exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}) contributing to base saturation of greater than 35%. Downward migration of clay is generally less during pedogenic process as compared to Ultisol.
Ultisols	Soils are typically characterized with a humus rich surface layer having lower base saturation (<35%) and mineral nutrients over a clayey B horizon. They are highly weathered and acidic soil, mostly distributed in the humid areas of the tropical and subtropical regions. The soil is enriched with kaolin type of clay mineral and metal oxide (mainly of Fe & Al) imparting red color to it. Ultisols are more extensively leached than Alfisols.
Oxisols	Oxisols are highly weathered soils having oxic subsurface diagnostic horizon with very little variation in texture along soil depth. Oxisol are formed under tropical and subtropical climate along the equatorial region. Clay-size particles dominated by hydrous oxides of iron and aluminum. Kaolinite dominates the clay minerals. Oxisol differs with Alfisol and Ultisol by not having argillic horizon in the lower depth.
Vertisols	Soils are characterized by high clay content (>30%) which is dominated by 2:1 type of clay minerals (smectite). High cation exchange capacity, low permeability, slickensides, high base saturation (Ca dominated) and medium to low organic matter content (0.5–3%) are the characteristic features of Vertisol. This soil type develops wide and deep cracks during dry season.
Mollisols	This soil type is typically identified by humus rich (imparting dark color) surface horizon developed under native grassland or forest region in the subhumid to semiarid region. Such soil is rich in base cations (>50% base saturation with dominance in exchangeable calcium and magnesium) and evolved from calcareous rich colluvial deposits. This soil type has higher humus content than Alfisol, lacks swell-shrink characteristics (as in Vertisol) and possesses higher CEC than Ultisol.
Inceptisols	Inceptisols are formed under varying climatic condition except under aridic condition. These soils are mostly formed from colluvial alluvial and loess materials and lacks diagnostic argillic pedoturbation features. These soils are relatively young and lack characteristics surface and subsurface horizons. However soil profile indicates accumulation of humus and clays which are poorly developed to indicate horizons.
Entisols	Entisols are recently formed soils from the underlying sandy parent material with little or no evidence of pedogenic horizon development in the profile. Such soils are mostly formed in the floodplain area having significant erosion-deposition activity. Entisols differ from Inceptisols by a minor subsurface build-up with transported clay.
Aridisols	Soils of arid region are formed from wide variety of parent material under extremely dry climate. Such soils are low in humus and rich in sand sized particle. Significant accumulation of migrated clay or gypsum or cemented clays are often observed in the lower layers.

Adapted from Sehgal (2002)

Table 2.4 Taxonomical order of Indian soils and their distribution

Soil order	Area (million ha)	(%)
Entisols	78.7	23.94
Inceptisols	129.6	39.43
Vertisols	26.6	8.09
Aridisols	13.3	4.05
Mollisols	1.6	0.49
Ultisols	8.4	2.55
Alfisols	42.2	12.84
Others[a]	28.2	8.58

Bhattacharyya et al. (2013)
[a]Includes glaciers, sand dunes, mangrove swamps, salt waste, water bodies, rock land and rock outcrops

From soil pollution and remediation point of view, the issues 'how a particular soil is vulnerable, resilient and resistant to pollutants/disturbances' and 'how it responses to specific management interventions' are mainly influenced by soil texture and organic carbon content of the soil. For example though coarse textured soil (Entisols or Inceptisols) is easily disturbed by polluting activities; management or remediation actions can easily restore it to some extent. Fine textured soil (Vertisols) can resist soil pollutants some extent due to its buffering capacity. However after disturbance, it is either very difficult or sometimes not possible to restore soil functions through management or remediation. Higher organic matter in a soil type (Mollisols) causes higher microbial activity, CEC and metal chelation capacity and all these lead to increase in resilience and resistance of soil to pollution.

2.5.2 *Major Soil Types of India*

The Indian soils have also been classified by the committee constituted by Indian Council of Agricultural Research (ICAR) under major types as Alluvial Soils, Black Soils, Red Soils, Laterite Soils, Mountain Soils, and Desert Soils. Physico-chemical properties, mineralogical composition, physiography, geological formations, climate were the basis for this type of classification. The extent of area and distribution of these soil types are presented in Table 2.5.

2.5.2.1 Alluvial Soil

Alluvial soil is the most important (from food production point of view) and the largest soil group of India covering about 40% of the total land area of the country. This soil type supports nearly half of Indian population and contributes to major share of agricultural wealth. The alluvial soils have been formed from the deposition materials brought by river, glaciers and sea waves; and thus the parent material

Table 2.5 Different soil types of India along with their corresponding USDA nomenclature system

Major soils (traditional name)	Extent		Distribution in states	Soil orders US soil taxonomy
	000 ha	%		
Alluvial	100,006	30.4	Andaman and Nicobar Islands, Andhra Pradesh, Arunachal Pradesh, Assam, Bihar, Delhi, Goa, Gujarat, Haryana, Himachal Pradesh, Jammu and Kashmir, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Manipur, Meghalaya, Mizoram, Nagaland, Odisha, Punjab, Puducherry, Tamil Nadu, Tripura, Uttar Pradesh, West Bengal	Alfisols, Entisols, Inceptisols, Aridisols
Coastal alluvial	10,049	3.1	Andaman and Nicobar Islands, Andhra Pradesh, Gujarat, Karnataka, Kerala, Lakshadweep, Odisha, Puducherry, Tamil Nadu, West Bengal	Inceptisols, Aridisols, Entisols
Red	87,989	26.8	Andaman and Nicobar Islands, Arunachal Pradesh, Andhra Pradesh, Assam, Delhi, Gujarat, Goa, Himachal Pradesh, Karnataka, Kerala, Madhya Pradesh, Manipur, Meghalaya, Nagaland, Mizoram, Puducherry, Rajasthan, Tripura, Tamil Nadu, Uttar Pradesh,	Alfisols, Entisols, Inceptisols, Ultisols, Mollisols, Aridisols
Laterites	18,049	5.5	Andhra Pradesh, Karnataka, Kerala, Maharashtra, Odisha, Puducherry, Tamil Nadu, West Bengal	Alfisols, Inceptisols, Ultisols
Brown forest	540	0.2	Karnataka, Maharashtra	Mollisols,Inceptisols
Hill	2262	0.7	Manipur, Nagaland, Odisha, Tripura, West Bengal	Inceptisols, Entisols
Terai	326	0.1	Sikkim, Uttar Pradesh	Mollisols, Entisols
Mountain meadow	60	–	Jammu and Kashmir	Mollisols
Sub-montane	104	–	Jammu and Kashmir	Alfisols
Black	54,682	16.6	Andhra Pradesh, Bihar, Gujarat, Madhya Pradesh, Maharashtra, Odisha, Puducherry, Rajasthan, Tamil Nadu, Uttar Pradesh	Inceptisols, Vertisols, Entisols, Mollisols, Aridisols
Desert	26,283	8.0	Gujarat, Haryana, Punjab, Rajasthan	Aridisols, Entisols, Inceptisols
Others[a]	28,305	8.6	–	–
Total	328,700	100	–	–

Bhattacharyya et al. (2013)

[a]Includes glaciers, sand dunes, mangrove swamps, salt waste, water bodies, rock land and rock outcrops in different states

of this soil has always been transported from elsewhere. In India, it is distributed widely in northern plains (starting from Punjab in the west to Assam and West Bengal in the east) and river valleys (Deltas of Mahanadi, Godavari, Krishna and Kaveri rivers in the Peninsular India). Alluvial soils are also found in coastal and northern parts of Gujarat, Great Northern plain and lower valleys of Narmada and Tapti. Alluvial soil is considered superior to other soil types due to the optimum combination of good chemical and physical conditions for proper root growth as well as having high fertility. This soil is composed of fine particles of sand, silt and clay with dominance of silt fraction along with moderate organic matter content. Geologically alluvial soil is classified into old alluvium termed as 'bangar' soil and new alluvium known as '*khaddar*' soil. Most of the new alluvial soils are found in the flood plains and deltas area along the lower part of the course of rivers and may even have nearly ten thousand years old deposits. Old alluvial soils are found on the higher side of the river valley and termed locally as '*bhangar*'. The areas having *khadar* soil are flooded almost every year and remain young with sandy/sandy loam in texture and light in colour. *Bangar* soil is silty clay/clay loam in texture with darker in color and may contain alkaline effloresces. Such old alluvial soils are relatively less fertile than new alluvial khaddar soil. Alluvial soils are generally deficient in organic carbon and nitrogen; however the soil is fertile due to presence of adequate phosphorus, potassium and calcium. Illite is predominant mineral in the clay fraction. These are deep loamy in texture having moderated cation exchange capacity, moderate to high water holding capacity and with proper irrigation it yields bumper produce of rice, wheat, sugar cane, maize, cotton, oilseeds, jute, tobacco etc. The Indo-Gangetic plains of north India are the most fertile lands and are largely irrigated, contributing 65% of the total food basket.

2.5.2.2 Black Soil

In contrast to alluvial soil, black soil has developed in-site through intense weathering processes and is locally termed as 'regur' soil (derived from Telugu word 'reguda'). Cotton is the major crops grown in black soil and hence alternatively termed as 'black cotton soil'. Parent material of such soil was formed due to solidification of lava during volcanic activity. The black soil is distributed mostly in Deccan trap covering large areas of Maharashtra, Madhya Pradesh, Chhattisgarh and Gujarat. It is also found in some parts of Krishna and Godavari river valleys, covering parts of Andhra Pradesh, Karnataka and some parts of Tamil Nadu. Black cotton soil is high in clay content and has high water holding capacity. Generally, black soils are rich in potash and calcium, but poor in phosphate content. Due to its high clay content, such soil develops deep and wide cracks during hot dry season; but becomes sticky during rainy season imparting poor physical condition in the context of crop cultivation. Therefore workable soil moisture range for tillage operation is very narrow and the soil is required to be tilled immediately after the first or the pre-monsoon shower. Black soil found near the valleys or lowlands is deep, dark and highly fertile; whereas, such soil located upland is low in fertility.

Due to its high water holding capacity and rich in nutrients, black soil is best suited for producing wheat, cotton, sugar cane, rice, millets, linseed, tobacco and oilseeds.

2.5.2.3 Red Soil

The red soil occupies about 10% of the total geographical area in India and is spread across almost whole of the Tamil Nadu, parts of Karnataka, southeast Maharashtra, eastern parts of Andhra Pradesh, Madhya Pradesh, Orissa and Jharkhand. It also extends to large parts of south Bihar, western districts of West Bengal, the eastern parts of Rajasthan; few districts of Uttar Pradesh; and parts of Nagaland, Assam, Mizoram, Manipur, Tripura and Meghalaya. Red soil has been formed from the weathering of iron rich acid granites (igneous) parent material and gneisses (metamorphic) rocks in a warm, moist climate under deciduous or mixed forests. Though soil texture of red soils is mostly loamy in texture, it may vary widely from sandy to clayey in nature. Such soil may have thin organic surface layer. It may be rich in potash, but poor in organic carbon, nitrogen, phosphorus and calcium. As result such soil has low fertility and is difficult to till. The red soils respond well to fertilizers and irrigation and give excellent yields of wheat, rice, pulses, cotton, millets, tobacco, oil seeds, potatoes and fruits.

2.5.2.4 Laterite Soil

The word ‘laterite’ is derived from a Latin word ‘*later*’ which means ‘brick’ due to the tendency of the soil to harden upon exposure. The laterite soil is formed from the parent material rich in iron and aluminum under high temperature and rainfall condition of climate. It is also found in the high altitude areas of plateau regions and has been widely spread on the summits of the Eastern Ghats, Western Ghats, Rajmahal Hills, Satpuras, Vindhyas and Malwa plateau. It is abundantly found in southern Maharashtra, and hilly parts of Orissa, Meghalaya and Assam, Karnataka, West Bengal, Kerala, Andhra Pradesh and Bihar. Laterite soils are poor in soil fertility due to prominent leaching process that takes place in intense rainfall areas. During leaching process, calcium and silica is lost from soil profile leaving behind high iron and aluminum content. Hence, laterite soils are poor in lime (calcium and magnesium), organic carbon and nitrogen, while rich in iron, aluminum and potash.

Red and laterite soils (Alfisols) have good amount of sesquioxides, low in organic matter and have a large proportion of kaolinite and non-expanding illitic clay fractions. Laterite and associated soils are less water retentive and are thus more drought-prone. The physical constraints to crop production in red and lateritic soils are hardening of soil, low water-holding capacity, reduced soil volume due to concretions, occurrence of hard plinthite or petroplinthite, drought related stress, low cation exchange capacity, low organic matter, high acidity, iron and aluminium toxicity, high phosphorus fixation and severe erosion. Laterite soil is composed of less clay and more gravel which leads to poor soil fertility. But under proper manuring and irrigation, the laterite soil is productive for crops like cashew nuts, ragi, rice, tea, coffee, rubber, coconut, arecanut, etc. In addition, laterite soil is highly suitable for making bricks.

2.5.2.5 Mountain Soil

The mountain soil is normally found on the hill slopes covered with forests and such soil accounts for around 8.7% of the total geographical area of India. It is distributed in valley basins of Himalayan region, in the Western and Eastern Ghats and in some parts of the Peninsular India. The mountain soil typically contains high humus due to organic matter deposition from forest cover. However, it is poor in potash, phosphorus and calcium. Mountain soil is highly heterogenous and its characteristics vary from place to place due to changes in parent material, climate and vegetation. The mountain soil is normally acidic, grey in colour and its textural class varies widely from loamy/silty on valley sides to coarse-grained in the upper slopes. Such soils are highly suitable for plantation crops like tea, coffee, spices and tropical fruits in Karnataka, Tamil Nadu and Kerala. In the Himalayan region, crops like wheat, maize, barley and temperate fruits can be produced under proper fertilizer management.

2.5.2.6 Desert Soil

Arid and semi-arid regions having less than 50 cm of annual rainfall have predominantly sandy textured desert soils. The desert soil is mostly found in Rajasthan and the adjoining areas of Haryana, Punjab and the Rann of Kachchh in Gujarat. Desert soils are mostly developed in-situ where sands originate from mechanical disintegration of parent rocks under hot-dry climate. However, this may also develop from wind-laden loess materials. The soil in the desert area has nearly 90–95% sand particle and with very less amount of clay content (5–10%). Due to high evapotranspiration and less rainfall, some desert soils are saline in nature. Such soils are generally poor in organic matter and nitrogen. Phosphate content may be as high as that in alluvial soil. Due to water shortage in arid regions and also poor water holding capacity of desert soil, additional irrigation facility is required to produce variety of crops like wheat, millets, barley, maize, pulses, cotton etc.

2.5.3 Major Soil Types Under Different Agro-Ecological Zones (AEZ) of the Country

On the basis of climate characteristics, length of crop growing period and soil type, total geographical area of India has been classified into 20 agro-ecological zones (AEZ) for devising effective land use plan and farming strategy for various regions (Table 2.6 and Fig. 2.1) (Sehgal 2002).

Table 2.6 Taxonomical order of Indian soils and their distribution

AEZ No.	Location	Climate type	Soil type
1.	Western Himalayas	Cold arid ecoregion	Shallow, loamy skeletal soils
2.	Western Plain, Kachchh and part of Kathiawar Peninsula	Hot arid ecoregion	Desert and saline soils
3.	Deccan plateau	Hot arid eco-subregion	Red and black soils
4.	Northern Plain (and Central Highlands) including Aravallis	Hot semi-arid ecoregion	Alluvium derived soils
5.	Central (Malwa) Highlands, Gujarat plains and Kathiawar Peninsula	Hot semi-arid ecoregion	Medium and deep clayey black soils
6.	Deccan Plateau	Hot semi-arid ecoregion	Shallow and medium (dominant) black soils
7.	Deccan Plateau (Telangana) and Eastern Ghats	Hot semi-arid ecoregion	Red and black soils
8.	Eastern Ghats and Tamil Nadu Uplands and Deccan (Karnataka) Plateau	Hot semi-arid ecoregion	Red loamy soils
9.	Northern Plain	Hot sub-humid (dry) eco-region	Alluvium derived soils
10.	Central Highlands (Malwa and Bundelkhand)	Hot sub-humid (dry) ecoregion	Red and black soils
11.	Chattisgarh Mahanadi Basin	Hot sub-humid (dry) ecoregion	Red and yellow soils
12.	Eastern Plateau (Chhotanagpur) and Eastern Ghats	Hot sub-humid ecoregion	Red and lateritic soils
13.	Eastern Plain	Hot sub-humid (moist) ecoregion	Alluvium derived soils
14.	Western Himalayas	Warm subhumid (to humid with inclusion of perhumid) ecoregion	Brown forest and Podzolic soils
15.	Assam and Bengal Plain	Hot sub-humid (moist) to humid (inclusion of perhumid) ecoregion	Alluvium derived soils
16.	Eastern Himalayas	Warm perhumid ecoregion	Brown and red hill soils
17.	North-eastern Hills (Purvachal)	Warm perhumid ecoregion	Red and lateritic soils
18.	Eastern Coastal Plain	Hot subhumid to semiarid ecoregion	Coastal alluvium derived soils
19.	Western Ghats and Coastal Plain	Hot humid-perhumid ecoregion	Red, lateritic and alluvium derived soils
20.	Islands of Andaman-Nicobar and Lakshadweep	Hot humid to perhumid island ecoregion	Red loamy and sandy soils

Adapted from Sehgal (2002)

Fig. 2.1 Agro-Ecological Regions of India (Adapted from Sehgal 2002)

2.6 Relationship Between Soil and Vegetation and Concept of Top Soil

Soil, which is considered as common terrestrial substrate serves as a medium for plant growth. Therefore, soil properties like texture, structure, water retention, depth and nutrient status have major influence on species diversity and vegetation establishment of any site. On the other side, vegetation and its species diversity plays significant role in different pedogenic processes leading to soil formation.

Fundamental soil equation (Jenny 1958) states nature of soil in a given location is dependent of several factors:

$$Soil = \int (climate, parent\ material, relief, organisms, time)$$

Similarly, Major (1951) proposed equation for plant community in which same environmental factors responsible for Jenny's above soil formation equation are also responsible for the vegetation that is produced :

$$Vegetation = \int (climate, parent\ material, relief, organisms, time)$$

Above equations also indicate that specific plant community and soil type in an area are mutually associated for their development. This further indicates that all strata on the landscape with the same type of soil should have same vegetation community, the same plant association, and the same habitat type. However several studies conducted in this area either supported such association or failed to establish any relationship between these two entities (soils and vegetation) (Hironaka et al. 1990). Studies of Koptsik et al. (2003) revealed a significant correlation between the species diversity of plant community and soil properties. Soil factors acidity, concentrations of exchangeable calcium, potassium, and magnesium, influenced variations of species diversity indices for vascular plants and bryophytes in forest ecosystem. Likewise strong relationship was observed between plant diversity index and soil functional diversity (Rodríguez-Loinaz et al. 2008). On the contrary, inconsistent results were observed while predicting tree site index using selected soil properties (Copeland 1958; Monserud et al. 1990).

Several authors (Daubenmire et al. 1968; Daubenmire 1979; Neiman 1988; Jensen et al. 1990; Tisdale and Bramble-Brodahl 1983) have attempted to correlate predominant vegetation community and soils. The results have been mostly inconclusive (Hironaka et al. 1990). These failures indicate that either relationship between soil and vegetation does not exist or some underlying fundamental causes have been overlooked. Johnson and Simon (1987) observed influence of ash and loess (aeolian deposit) on species diversity of grasses and shrubs. For example, bluebunch wheatgrass, scabland and xeric shrubland communities existed on soils having little influence from loess deposits; whereas fescue-prairie junegrass and mesic shrubland communities occur on soils that are considerably influenced by loess. Likewise, forest species diversity was considerably influenced by ash (volcanic origin) content of the soil. However, researchers were unable to extrapolate such findings (correlations between soils and vegetation) outside their area of study. Similarly, a study from central western New South Wales, USA showed poor associations between soil landscapes and vegetation types; where specific type of vegetation was associated with several soil landscapes or soil types and specific soil type or landscape was normally linked with several vegetation types (Rankin et al. 2007). In a study at Himalayan region of China, high tree diversity, height and vegetative cover were linked to good soil quality and favorable topographic positions with lower solar incident radiation, runoff and soil erosion potential (Xu et al. 2008). Plant diversity was mainly correlated with soil water content, and clay content. In a flood plain area of Argentina, nature and type of plant communities varied with drainage, pH and exchangeable sodium percentage in the soil of the area and such vegetative diversity was related to hydromorphic, hydrohalomorphic or halomorphic characteristics of soil (Debelis et al. 2005). Changes in soil chemical environment due to entry of pollutants can have tremendous impact on species diversity and density of natural vegetation. Only tolerant species and varieties proliferate, while the population of sensitive species goes down.

Information generated thus indicates that correlation between selected soil properties and vegetation had been successfully established by several researchers in different parts of the world. However, these conclusions were found only locally significant and could not be applicable elsewhere. Because of huge variation that persists in classification units of soil and vegetation, universal relationship or correlation has not been found to exist between soils and habitat type. Further it is relatively difficult to confirm the correctness of above assumption pertaining to vegetation due to absence of undisturbed vegetation across various geographical and climatic regions.

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