Fig. 20.4. Certain most common living organisms (biota) inhabiting the soil.

2. **Production of toxins.** In the absence of oxygen some soil microbes secrete chemicals, such as, aldehydes, organic acids, etc. which may show toxic effects on many plants. Examples of toxin secreting organisms may be found in fungi, bacteria and algae. *Fusarium lini,* which causes wilt of flax (Alasi) secretes HCN, a deadly poisonous substance and *Fusarium udum,* a fungus causing wilt of pigeon pea (Arhar) secretes fusaric acid in the roots of the host plants. These toxic chemicals secreted by fungi may be responsible for causing wilt in the flax and arhar (*Cajanus cajan*).

3. **Production of growth stimulating substances.** Many soil organisms including soil fungi and bacteria produce growth stimulating substances such as 3-Indol acetic acid, Gibberellins and Gibberellic acid in the soil. *Fusarium* species too have been found to secrete Gibberellin and Gibberellic acid ($C_{19}H_{22}O_6$).

4. **Nitrogen fixation.** Many bacteria inhabiting the root nodules of leguminous plants (*Rhizobium*), nitrogen-fixing bacteria living free in the soil (*Azotobacter, Clostridium pasteurianum*), actinomycetes, fungi, purple bacteria and a number of blue-green algae are known to fix free atmospheric nitrogen gas into nitrogenous compounds, such as nitrates and nitrites, etc., and thereby increase the fertility of the soil. It has been established that in each hectare of ordinary soil every year 25—50 kg of nitrogen are fixed and in cultivated soil and in soil containing legume plants 35 to 60 kg and 100 to 400 kg of nitrogen are fixed respectively. *Anabaena, Nostoc, Microcystis* are important nitrogen fixing blue-green algae. De and Fritsch (1938) have found that certain blue-green algae are able to fix 20 lbs of atmospheric nitrogen per acre in a rice field. They increase the yield of rice from 15 per cent to 25 per cent. Singh, R.N. and Relwani and others have also shown experimentally that some blue-green algae fix nitrogen in the paddy soils.

5. **Soil mixing.** Many organisms by their mechanical activities help in mixing and weathering of soil. Roots of the higher plants take active part in the disintegration of rocky mass and also make the compact soil loose. Many rodents, insects and earthworms turn over the soil and sometimes also expose the rock surface for physical and chemical weathering. Burrowing animals, such as rodents, bring soil from deeper regions to the surface. The excreta of soil animal is deposited on the surface of soil in the form of casts which increases the fertility of the soil.

6. **Soil aeration improvement.** Soil micro-organisms improve aeration of soil. Burrowing worms are also helpful in improving the aeration and percolation.

7. **Improvement in aggregation of soil particles.** Bacteria, blue-green algae, and some other micro-organisms secrete mucilaginous substances which bind the soil particles into soil aggregates.

8. **Injury to plants.** Not all the soil organisms are beneficial in their properties and behaviour. Some microbes become parasites of higher plants and cause considerable damage. Nematodes are important animals which cause a number of diseases in plants. Besides these, many soil bacteria and fungi cause many diseases, such as damping off, seedling blight, root rot, mildew diseases in a number of crops.

QUESTIONS

1. Define the soil. Discuss briefly the different components of soil.
2. What is humus? Give and account of composition and properties of humus and mention its important roles in the soil.
3. Discuss the biological system of soil in detail and mention the role of micro-organisms in soil.

21

ORIGIN AND FORMATION OF SOIL

Soils are derived from parent rocks by the process called weathering. In the weathering process, rocks are disintegrated and decomposed into smaller pieces by physical, chemical and biological agencies. The products of weathering are called regoliths which are small particles of rock materials. These particles are basic materials which under the influence of pedogenic or soil forming process finally develop into mature soil. C.F. Marbut (1926) states that "a mature soil is one that has assumed the profile features characteristic of predominant soils on the smooth uplands within the general climatic and botanic regions in which it is found."

The processes of soil formation from the rocks can be presented as follows :

Consolidated parent rocks ——(Weathering)——→ small particles of parental material or regolith

Mature soil with profile differentiation. ←——(Pedogenesis)—— regolith

Weathering is the initial stage and the soil forming processes or pedogenic stages come afterwards. Practically no definite line can be drawn where weathering process terminates and pedogenesis takes its way. In fact, both these processes run simultaneously. **Weathering processes** lead to disintegration or degradation of complex mineral substances that are locked up in the rocks and eventually simple compounds are formed. The **pedogenesis** or **soil forming process**, on the other hand, are constructive and are of bio-geochemical nature in which biological influences play important role.

Rock is a chemical mixture in which a number of minerals are locked up in very complex forms. The chemical and physical properties of minerals composing the rock directly govern the properties of the rock. The principal minerals which occur in the earth crust are listed in Table 21.1.

Table 21.1. Chemical composition of some common soil minerals

Minerals	*Chemical Constituents*
A. Sand and silt minerals	
1. Quartz or silica	SiO_2
2. Feldspars	
(*a*) Orthoclase	$K_2Al_2Si_6O_{16}$
(*b*) Plagioclase	$NaAlSi_2O_8$
(*c*) Calcium feldspar	$CaAl_2Si_2O_8$
3. Micas	
(*a*) Muscovite	$KAl_2\ (AlSi_3O)_{10}(OH)_2$
(*b*) Biotite	K. Mg, Fe, Al silicate
4. Pyroxenes	(Mg, Fe) SiO_3
5. Amphiboles	(Mg, Fe), $(Si_4O_{11})_2\ (OH)_2$
6. Olivine and serpentine	$(Mg, Fe)_2\ SiO_4$
7. Calcite; magnesite; and dolomite	$CaCO_3$, $MgCO_3$; and ($CaCO_3$, $MgCO_3$)
8. Iron oxides	
(*a*) Haematite	Fe_2O_3
(*b*) Magnetite	Fe_3O_4
(c) Limonite	FeO (OH), xH_2O
B. Clay minerals	
1. Kaolin	Al_2O_3, $2SiO_2$, $2H_2O$
2. Montmorillonite	(Ca, MgO) Al_2O_3, $5SiO_3$, $5H_2O$

Besides these, there are a number of other minerals also, such as Tourmaline (Borosilicates of aluminium with alkali metals and iron and magnesium), Rutile (Titanium oxide), Zircon (Zirconium oxide), Gauconite (hydrated silicates of iron and potassium). These minerals are found in very small quantities in the soil.

According to Clark (1924), the major minerals in the earth's crust occur in the following approximate proportion :

Feldspars 58%; amphiboles and pyroxenes 16%; quartz 13%; micas 4%; and remaining portion consists of accessory minerals. (Ref : *Data of Geochemistry*. U.S. Geological Survey Bull. 770.1924).

Rocks are generally classified into three types on the basis of their origin and structure. These are as under :

(1) igneous rocks,

(2) sedimentary rocks,

(3) metamorphic rocks.

1. **Igneous rocks.** These are formed by cooling and solidification of molten magma or lava which escapes through fissures from the interior of the earth. The solidification may occur at great depths resulting in the *plutonic rocks,* or at moderate depth in the earth forming the so-called *intrusive rocks,* or on the surface of the earth forming the *extrusive* or *effusive rocks*. Extrusive rocks are formed as a result of volcanic activities.

Table 21.2. Classification, characteristics and mineral composition of the principal soil-forming rocks (Wallwork, 1970)

Class of rock	*Mode of formation of rock*	*Type*	*Description of rock-types*	*Principal minerals of soil-forming rocks*
A. Igneous rocks	Formed by cooling of molten megma (lava)	1. Granite	Usually light in colour, coarse to medium grain	Quarts, feldspar, mica, amphibole, iron oxides
		2. Diorite	Grey to dark in colour, coarse to medium grain	Feldspar, amphibole, iron oxide, biotite
		3. Basalt	Dark to black in colour, dense to fine grain	Feldspar, pyroxene, iron oxide, biotite
B. Sedimentary rocks	Formed by deposition of weathered minerals which are derived from igneous rocks	1. Shales	Light to dark in colour, thinly laminated	Clay minerals, quartz
		2. Sand stone	Light to red in colour, granular and porous	Quartz, clay minerals, iron oxides, calcium carbonate
		3. Lime-stone	Light grey, red, brown, or black in colour, fine grained and compact	Calcite, dolomite, iron oxide, clay minerals
C. Metamorphic rocks	Formed by change of pre-existing rock (*i.e.*, igneous or sedimentary) through heat and pressure	1. Gneiss	With light and dark bands	Much as in granite from which it is formed
		2. Schist	Foliated structure	Much as in basalt or shale from which it is formed
		3. Slate	Grey to black in colour, compact and uniform texture	Composition similar to shale from which it is formed
		4. Quartzite	Light to brown in colour, compact and uniform texture	Similar in composition to sandstone from which it is formed
		5. Marble	Light, red, green or black in colour, compact, fine to coarse texture	Calcite, dolomite formed from limestone

Important igneous rocks involved in the weathering process are Granite, Basalt, Gabbro, Diabase, Syenite, Andesite etc. They are composed of primary minerals such as quartz, feldspars and biotite, augite and hornblende.

2. **Sedimentary rocks.** These develop due to gradual accumulation and consolidation of *weathering product* or *mineral particles* brought by wind or water on the surface of earth. Such rocks are characterised by the presence of distinct sediments or layers in them. Some important examples of sedimentary rocks are limestone, shale, conglomerate, sandstone, siltstone, etc. Calcite, clays, quartz and dolomite are the common dominant minerals in them. Sedimentary rocks do not weather as rapidly as the igneous rocks.

3. **Metamorphic rocks.** These are formed after transformation of igneous and sedimentary rocks when they are subjected to intense heat and pressure and are influenced chemically by active liquids and gases. Important metamorphic rocks which take part in weathering process are slate (formed from shale), marble (formed from limestone), schist (formed from shale) and quartzite (from sandstone). Dominant minerals are quartz, clays and calcite.

On the basis of their silica content, rocks have also been classified into acidic, basic and intermediate rocks.

Acidic rocks	*Basic rocks*	*Intermediate rocks*
Silica content 65-75% Examples : sand- stone, granite etc.	Silica content 40-55% Examples : gabbro, basalt, limestone etc.	Silica content 55-65% Examples; syenite, diorite, andesite etc.

Wallwork (1970) has summarised the details of the principal soil forming rocks in Table 21.2

WEATHERING PROCESS

It is a process in which the massive consolidated rocks are broken down into smaller particles and eventually into the individual minerals of which they are composed. As a result of weathering the rock fragments and the minerals are changed to new minerals either by alteration or by complete chemical changes.

Weathering processes are distinguished into the following three types on the basis of nature of agencies which bring about weathering :

(1) Physical weathering,

(2) Chemical weathering, and

(3) Biological weathering or Biogeochemical weathering.

1. Physical Weathering

Physical weathering of rocks is a mechanical process which is brought about by a number of factors, such as :

(A) Temperature,

(B) Water,

(C) Wind.

(A) **Temperature.** It causes breakdown of rocks in the following **ways** :

(*i*) **Differential expansion and contraction of materials.** Minerals composing the rock show different degrees of expansion (coefficient of expansion). These minerals expand in the high temperature of day and contract when the temperature falls. The differential expansion and contraction of different minerals set up internal tension and produce cracks in the rocks and thus the rocks weather into finer and finer particles.

(*ii*) **Exfoliation.** The arrangement of layers in rock is called expliation. Layer differentiation is not common in all types of rocks. The upper layer of rocks expand and contract faster than those of deeper region. The temperature changes bring about separation and disintegration of the layers of rocks. This process is known as exfoliation.

(*iii*) **Frost action.** Sometimes, temperature of rocks reaches below freezing point. This causes accumulation and freezing of water in the crevices and rock joints. In freezing, water expands to about 9 per cent of its original volume and exerts a pressure of approximately 150 tons per square feet which is more than enough to break the rocks.

(B) **Water.** Water causes weathering of rocks in the following ways :

(*i*) **Rain.** Natural water falling either in the form of rain drops or as hail storm on the surface of rocks with beating effect bring about abrasion of massive rocks into smaller particles.

(*ii*) **Running water.** Rapidly flowing water rolls the heavy rock masses (rock boulders) along the bottom of stream and grinds them into finer particles.

(*iii*) **Wave action.** It is most active in sea shores. The water waves striking with great force on the rock surface break and grind the rock into pieces.

(*iv*) **Glacier formation.** At mountain tops, ice formation takes place in the winter season. When the summer approaches, ice starts melting and glaciers (huge sliding masses of ice) move downwardly on the slopes. In the glacier movement, the rocks are corroded and finally broken into sand particles (Fig. 21.1).

(C) **Wind.** Rapid stormy wind carrying suspended sand particles causes the abrasion of exposed rock. The Fig. 21.2 shows rocks which were subjected to wind erosion.

2. Chemical Weathering

Chemical weathering brings about disappearance of original rock minerals either completely or partly. In this process secondary products may be formed from parent materials. This process is also known as chemical transformation. Presence of moisture and air is very essential in the chemical weathering. This is why chemical weathering is not so effective in desert.

The chemical weathering takes place in the following ways :

(*i*) **Solution.** Solvent action of water helps in the weathering of rocks. It dissolves soluble minerals of rocks. Solution helps in the removal of weathered materials but total loss is negligible. Solvent action is increased in presence of CO_2 and organic acids formed by decomposing dead organic remains of plants and animals. Sodium, potassium, calcium and magnesium are easily removed from rocks in dissolved state.

Fig. 21.1. Moving glaciers cause cutting and crushing of the bed rocks.

Fig. 21.2. Effect of wind on the rocks.

(*ii*) **Hydrolysis.** It is essentially an exchange of constituent parts between water and rock minerals. When water reacts with strong base it produces hydroxides. The soluble products of hydrolysis are usually removed by water. Sometimes soluble products may react with insoluble ones and form clays. Hydroxides in presence of CO_2 change to carbonates and bicarbonates. Water in ionised state acts as a weak acid on silicious matter, *e.g.*,

$$KAlSi_3O_8 + HOH \rightarrow HAlSi_3O_8 + KOH$$

$$2HALSi_3O_8 + 8HOH \text{ ® } Al_2O_3 . 3H_2O + 6H_2SiO_3$$

(*iii*) **Oxidation.** It means addition of oxygen to mineral compounds. The reaction produces oxides which when dissolve in water weaken the rock and bring about weathering. Iron, aluminium, manganese oxides and sulphides are easily oxidised.

$$\underset{\text{(Ferrous oxide)}}{4FeO + O_2} \text{ ® } \underset{\text{(Ferric oxide)}}{2Fe_2O_3}$$

(*iv*) **Reduction.** It means removal of oxygen from minerals, *e.g.*,

$$2Fe_2O_3 \text{ ® } 4FeO + O_2$$

Reduction takes place in the deep zone where oxygen is not available.

(*v*) **Carbonation.** It occurs simultaneously with hydrolysis. In this process, CO_2 unites with water to produce carbonic acid which is a weak acid.

$$CO_2 + H_2O \text{ ® } H_2CO_3 \text{ (Carbonic acid)}$$

The carbonic acid reacts with hydroxides of soil forming minerals and forms insoluble carbonates. Sometimes it dissolves minerals and thus weakens the rock promoting thereby the weathering. Carbonation of hydroxides results in the formation of carbonates and bicarbonates, *e.g.*,

$$Ca(OH)_2 + CO_2 \text{ ® } CaCO_3 + H_2O \xrightarrow{+Co_2} Ca(HCO_3)_2$$

(*vi*) **Hydration.** In this process, water molecules become chemically attached to particular rock material, for example :

$$\underset{\text{(Hematite)}}{2Fe_2O_3 + 3H_2O} \text{ ® } \underset{\text{(Limonite)}}{2Fe_2O_3.3H_2O.}$$

Soil forming minerals in the rock do not contain any water. They undergo hydration when they come in contact with water. In this process, the volume of the parental material increases and hydrated materials become soft and more readily weatherable.

3. Biological Weathering

Many organisms play important roles in the weathering of rocks through physical and chemical means. Important organisms concerned with the decomposition of rocks are lichens, bacteria, fungi, higher plants, nematodes and other soil microbes. Lichens and some other organisms in presence of moisture secrete carbonic acid which corrodes the rock.

The presence of roots on the surface of rock exerts a considerable pressure by which rocks are broken into smaller fragments. The root exudates also weaken the rocks and weather them to a small extent.

Joffe (1949) states that there is no biogeochemical weathering. According to him, it is either physical or chemical weathering by biological agencies.

SOIL FORMING PROCESS

The surface rocks of the earth are weathered and as a result of weathering, small particles of parental materials are formed. The weathering process continues until all the essential elements locked up in the rocks become available to all sorts of organisms. Simultaneously with weathering process, pedogenesis or soil forming process also runs which leads weathered materials to develop into mature soil with well differentiated soil profiles and biological system.

Soil Profile

Weathering of parental rocks results in the development of several loose layers or horizons of weathered materials. Biological system, addition of organic matter (humus) and interaction between organic and mineral compounds make the horizons more distinct. The complete succession of horizons down to the level of undifferentiated parent materials is called ***soil profile***. In other words, it is vertical section of earth crust showing different layers or horizons of soil.

The soil profile may be divided into the following three zones or horizons (Fig. 21.3) :

(1) A horizon (top soil or the zone of extraction),

(2) B horizon (subsoil or subsurface zone), and

(3) C horizon (Regolith).

Some workers have recognised D horizon below C horizon.

1. **A horizon.** It is the top soil which consists of mineral matter and organic residues. The soluble chemicals are leached away by water.

Upper zone or horizon A is very loose and it supports vegetation. Because it is full of organic elements and minerals, the top soil is very fertile. The thickness of A horizon varies from one to ten feet. A horizon is differentiated into several sublayers which are Aoo, Ao, A_1, A_2, A_3. These can be distinguished by their distinct colours and textures.

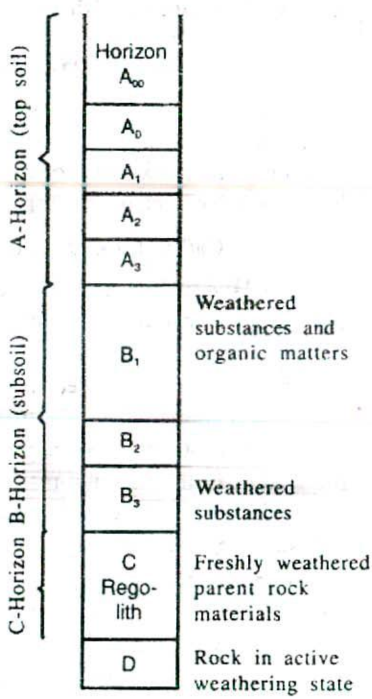


Fig. 21.3. Soil profile.

2. **B horizon.** A zone of soil present below the top soil or A horizon is called B horizon. It is also known as subsoil. In this zone, the weathered substances or minerals are deposited and organic residues are present in very small quantities. This horizon is *lighter in colour* than A horizon. B horizon can also be differentiated into several subzones, as B_1, B_2, B_3 and so on, on the basis of colour and texture. Upper subzone of B horizon, which is just below the top soil (A horizon), is looser than lower subzones.

3. **C horizon (regolith).** Below B horizon and above the surface of weathered rock, there is a third horizon, the C horizon or zone of regolith. It is formed of freshly weathered parental materials.

Below the C horizon, there may be found rock in active weathering state. This is recognized as a fourth zone or **D horizon** by some workers.

Morphological Characteristics of Soil Profile

The following morphological characteristics are recorded in respect of each of the horizons :

Colour, texture, structure, consistence, concretions, calcareousness, roots, etc.

Colour. Colour is one of the most noticeable characteristics of a soil. As we examine a soil profile, we are likely to see definite changes in colour from the surface through the subsoil and underlying parent material. The colours of the surface and subsoil may be classified as follow :

Surface soil—Dark, moderately dark, light, very light.

Subsoil—Dull, mottled, bright.

As a rule, the surface soil is darker than the subsoil since it contains more organic matter. Subsoil colour is less affected by organic matter than surface soil colour.

Texture. The soil particles which resulted from weathering vary greatly in size. They are classified on the basis of size into gravel, sand, silt, and clay.

Most soils are mixtures of the various sized particles except that many contain no gravel and some very little sand. If a soil contains considerable quantities of atleast two sizes of particles, it is known as loam. It may be called a gravelly loam, sandy loam, silty loam, or clay loam, depending on the size of particle that predominates in the mixture. If however, a mixture consists mostly of one size of particle, it is not called as loam.

Structure. Structure means the aggregation or arrangement of the soil particles into clusters or shape of various sizes. Structure does not change soil texture. The structure of soil particles may be crumb, granular, angular, sub-angular, blocky, prismatic, platy and columnar type. Details are given in the next chapter.

Consistence. Consistence is a term expressing the degree of cohesion of the soils and the resistance opposed to forces tending to deform or rupture the aggregates.

Consistence of soil materials is determined at dry, moist and wet conditions. The terms used are :

Dry — Loose, soft, slightly hard, hard, very hard, extremely hard.

Moist — Loose, very friable, firm, very firm, extremely firm.

Wet — Non-plastic, slightly plastic, plastic, very plastic, non-sticky, slightly sticky, sticky, very sticky.

Concretions. Iron and maganese concretions alone have no definite meaning, although their presence usually indicates that conditions of alternate oxidation and reduction have taken place. Presence of calcium carbonate concretions throughout the profile and on the surface may be the result of rodent action. These concretions at deeper layers may indicate the usual depth of penetration of rainwater.

Calcareousness. Soil horizons are tested with dilute HCl and based upon the briskness of the effervescence, they are classified as weakly, moderately and strongly calcareous. Calcareousness has an effect on the availability of plant nutrients.

Roots. The abundance of roots in each horizon is normally recorded in terms of few, common, abundant etc.

Other features like presence of clay, pores etc. within each horizon are also recorded.

Soil-forming Processes

The soil profile is formed by interaction of various pedogenic factors under a special set of conditions.

The following fundamental processes namely ***humification*** and ***eluviation* and *illuviation*** develop a profile. These are described below :

(*i*) **Humification.** Top layer of the soil, called A horizon, contains abundant dead remains of plants, animals and other products of microbial metabolism. These products undergo decomposition which may produce some soluble organic compounds and some amorphous incompletely decomposed black coloured organic residue, the ***humus***. The process of humus formation is called ***humification***. The humus and organic compounds become mixed with the fine particles of weathered rock. Some soluble organic compounds are removed from the top soil by water which percolates downwardly through humus mixed soil.

(*ii*) **Eluviation and illuviation.** Water is important agent which helps in the development of soil profile. While percolating downwardly through mineral and organic substances of A horizon or top soil, it removes a number of soluble chemicals from the top soil. This process of washing away of soil constituents is termed as ***eluviation*** (meaning wash out) and the surface layer from which components are lost is called ***eluvial layer*** or A horizon. The eluviated substances move downwardly and are deposited in the lower zone or B horizon which is called ***illuvial layer*** (meaning 'wash in'). The process of accumulation of eluviated materials is called ***illuviation***.

The fundamental soil-forming processes involved in the development of soil profile are described below :

(*i*) **Gleization.** This process takes place in wet and cold Tundra regions where saline conditions do not exist. In this process there develops a compact structureless and sticky surface layer. This layer is blue-green in colour, poorly aerated and has reduced content of iron compounds. It favours surface accumulation of peat materials and undergoes a series of chemical, physical and biological changes which produce a characteristic soil.

(*ii*) **Podzolisation.** In temperate zones where climate is cold and moist, the rate of decomposition is slow and in the decomposition process acids are produced which make the soil acidic. The acidic unproductive soil is called **podzol** and the process is called **podzolisation**. In the process of podzolisation humus and some minerals including dissolved Si, Fe and Al salts from A horizon move downwardly with percolating water and accumulate in the lower horizons. This process is more effective in sandy base-poor parent materials under intense leaching and thick vegetational cover.

(*iii*) **Laterisation.** In tropical and subtropical regions, when rainfall occurs the organic matter and minerals are leached away and hydroxides of aluminium and iron are precipitated in the form of residue which is called **laterite**. This process is termed as ***laterisation***.

In this process, silica is completely removed. Laterites usually do not show well differentiated horizons.

Podzol and laterites are collectively described as **pedalfer** group' (iron accumulating group).

(*iv*) **Calcification.** In subhumid and dry regions, due to lack of excessive moisture the soil accumulates considerable amount of soluble materials and carbonates of calcium and magnesium are deposited in B horizon. The soil having such features is called ***pedocal*** (calcium accumulating soil). Pedocals are not acidic and calcium content in them is very high. This process is common in grasslands.

Hydromorphic profile development. Such soil-forming processes result in swamp, bog, marsh and peat soils and occur under conditions when percolation is restricted and certain horizons become saturated with water. These two conditions result in the development of anaerobic conditions, as well as beginning of more chemical reduction processes.

Factors Affecting Soil Formation

These are outlined as under :

(1) Climate,

(2) Biosphere,

(3) Parent material,

(4) Relief,

(5) Time.

All these factors are interrelated and complementary to one another. Some of them may be more influential under a particular set of conditions in determining the nature of soil while the others may be less influencing. Any soil property is a collective function or the effects of all pedogenic factors.

Joffe (1949) creates the following two categories in the soil forming factors :

(*i*) **Active factors.** These include agents which supply energy for soil formation. Climate and biosphere are the two important active factors.

(*ii*) **Passive factors.** These include the sources of soil forming mass and the conditions affecting it. Parent material, relief and time are the three passive factors.

1. **Climate.** It shows the following effects on pedogenesis :

(*i*) Heavy rainfall and high relative humidity favour the soil formation or pedogenesis. Low rainfall and low relative humidity show retarding effects on the process.

(*ii*) Severe erosion of materials by wind also affects the process adversely.

(*iii*) Horizons tend to develop faster under cool and humid forest conditions.

2. **Biological factors influencing the pedogenesis.** Biological agents affect the soil formation in a number of ways :

(*i*) Large number of burrowing animals upturn the deep soils and thus disturb the soil profile development.

(*ii*) Man's activities, such as manuring, ploughing, drainage, irrigation, cropping system, reclamation also affect the pedogenesis to a great extent.

(*iii*) Addition of organic residues and mixing them with minerals promote the differentiation of soil profile.

(*iv*) Vegetation exerts its main influence on pedogenesis through the amount and nature of organic matter which it adds to the soil and by checking the soil erosion.

3. **Nature of soil forming parental material mass.** This affects pedogenesis in the following ways :

(*i*) High percentage of clay in the weathered materials has retarding effect on pedogenesis.

(*ii*) Resistant parental materials, such as granite if present in parent material mass, do not promote the soil formation.

(*iii*) Excessive sandyness of parent materials reduces the rate of soil formation.

(*iv*) Materials with low silt and clay percentages do not differentiate into soil profile quickly.

(*v*) Heavy accumulation of soil materials also has retarding effects.

(*vi*) High lime content in the parent material checks profile differentiation.

Time. Length of time required for soil formation depends upon many interrelated factors, such as climate, biosphere, nature of parent materials, etc.

Relief. Some of the important effects of relief in the pedogenesis are as follows :

Topography determines the drainage condition and groundwater level in the soil. High water table shows influence in the horizon differentiation. Very steep slopes do not promote pedogenesis because of the fact that deposition of parent materials is affected by downwardly flowing water. If anyhow soil is formed, water content in such a soil is very poor.

Soil materials on moderate slopes promote deeper profile development and more luxuriant vegetation than in soil on steep slopes.

In soil survey Manual of U.S. Department of Agriculture (USDA) the interrelationship of pedogenic factors has been concluded as follows :

"Soil characteristics in any one place result from the combined influence of climate and living matter, upon the parent rock materials, as conditioned by relief (topography), over periods of time including the effects of the cultural environment and man's use of soil."

QUESTIONS

1. What are different minerals composing the rocks? Give an account of different weathering processes which bring about breakdown of mineral rocks.
2. Give an account of soil forming process and discuss the effects of various factors on pedogenesis.
3. Write short notes on :
   (*i*) Humification.
   (*ii*) Eluviation and illuviation.
   (*iii*) Soil profile.

22

PROPERTIES OF SOILS

A. PHYSICAL PROPERTIES OF SOILS

Physical properties of the soil can be discussed under the following heads :

(1) Soil separates and texture,
(2) Structure of soil,
(3) Weight and soil density,
(4) Porosity of soil,
(5) Permeability of soil,
(6) Soil colour,
(7) Temperature of soil, and
(8) Soil Plasticity, Cohesion and Adhesion.

1. Soil Separates and Soil Textures

Mineral fraction of soil consists of particles of various sizes. According to their size, soil particles are grouped into the following types (Table 22.1).

Table 22.1. Soil separates

	Name of soil particle	*Diameter range of soil particle in millimetre*
1.	Coarse particles or gravels	More than 2.00
2.	Coarse sands	2.00—0.20
3.	Fine sands	0.20—0.02
4.	Silts	0.02—0.002
5.	Clays	Below 0.002

The particle sizes of above groups are suggested by International Society of Soil Science. In India, international system of particle differentiation is commonly followed. The particle types are generally called 'soil separates' or 'soil fractions'.

Amount of soil separates is determined by a process known as mechanical analysis. In this process, soil sample is crushed and screened through a 2 mm round hole sieve. The screened soil is then homogeneously dispersed in water and allowed to settle.

In suspension, particles of largest dimensions will settle first and those of smaller dimensions will settle afterwards. Individual soil separates are identified on the basis of their respective diameter ranges.

Soil separates (sand, silt and clay) differ not only in their sizes but also in their bearing on some of the important factors affecting plant growth, such as, soil aeration, workability, movement and availability of water and nutrients. Important characteristics of different soil separates are as follows :

Sand. This fraction of soil consists of loose and friable particles of 2.203—.02 mm diameter. Sand particles can be seen by unaided eye. These particles, although inactive, constitute the framework of the soil. They play less important role in physicochemical activities. When coated with clay, these sand particles take very active part in chemical reactions. Sands increase the size of pore spaces between soil particles and thus, facilitate the movement of air and water in the soil.

Silt. It consists of soil particles of intermediate sizes between sand and clay (diam range .02—.002 mm). Silt, when wet, feels plastic but in dry state feels like flour or talcum. Coarse silt shows little physicochemical activities but finer grades play important role in some chemical processes. Silty soil has got larger exposed surface area than the sandy soil. Silty soils contain sufficient quantities of nutrients, both organic and inorganic. That is why they are very fertile. Soils rich in silt possess great water holding capacity. Such soils are good for agriculture.

Clay. This soil fraction contains smallest particles than silt (below .002 mm diameter) which exhibit plasticity and smoothness when wet and hardness when dry. Owing to their smallest size and colloidal nature, the clay particles expose extremely large surface area. They take very active part in physicochemical reactions of the soil. Clay soils have fine pores, poor drainage and aeration and thus they have highest water holding capacity. The clay acts as store house for water and nutrients.

Some soils are fine, while others are coarse. It is so because of the fact that the relative percentage of sand, silt and clay differ from soil to soil. The relative percentage of soil separates of a given soil is referred to as soil texture. Texture of soil for a given horizon is almost a permanent character, because it remains unchanged over a long period of time. The relative percentages of soil separates of average samples are almost infinite in possible combinations. It is, therefore, necessary to establish limits of variations among soil fractions so as to group them into textural classes. The common textural classes, as recognised by USDA (U.S. Department of Agriculture) are given in the following table. These classes are recognised on the basis of relative percentage of separates; sand, silt and clay (Table 22.2).

Table 22.2. Soil textural classes

Soil classes or textural name	Range in relative percentages of soil separates		
	Sand	Silt	Clay
Sandy soil	85—100	0—15	0—10
Loamy sand	70—90	0—30	0—15
Sandy loam	43—80	0—50	0—20
Loam	23—52	28—50	7—27
Silt loam	0—50	50—88	0—27
Silt	0—20	88—100	0—12
Sandy clay loam	45—80	0—28	20—35
Clay loam	20—45	15—53	27—40
Silty clay loam	0—20	40—73	27—40
Sandy clay	45—65	0—20	35—45
Silty clay	0—20	40—60	40—60
Clay	0—45	0—40	40—100

This chart is adapted from fraction system of U.S.D.A.

If relative percentages of soil separates are known, the soil can be given textural name. For this purpose equilateral triangles are used. The most widely used Equilateral triangles are international equilateral triangle and the one used by USDA (Figs. 22.1, 22.2). These consist of three angles and its area is divided into twelve groups representing twelve different textural classes. Each group covers definite range of percentages of sand, silt, and clay. In the triangles, left side line represents the clay %, right side line represents percentage of silt and base represents percentage of sand. Each arm of the triangle is divided into ten divisions representing soil separate's percentage. These divisions are further divided into ten small divisions; each small division represents one per cent of soil separate. The percentages of sand, silt, and clay obtained after mechanical analysis of the given soil are read on the equilateral triangle. In using the diagram as indicated the percentages of silt and clay should be located on silt and clay lines respectively. The line in case of silt is then projected inward parallel to clay side of the triangle and in case of clay it should be projected parallel to the sand side. The three lines; one representing sand percentage, other representing silt percentage and the third clay percentage meet at a point in the triangle. The compartment in which the point falls indicates textural name for the given soil sample.

The knowledge of soil texture is of great help in the classification of soil and in determination of degree of weathering of rock.

2. Structure of Soil

Sand, silt and clay are found in aggregated form. Arrangement of these soil particles on certain defined patterns is called *soil structure*. The natural aggregates of soil particles are called *peds,* whereas an artificially formed

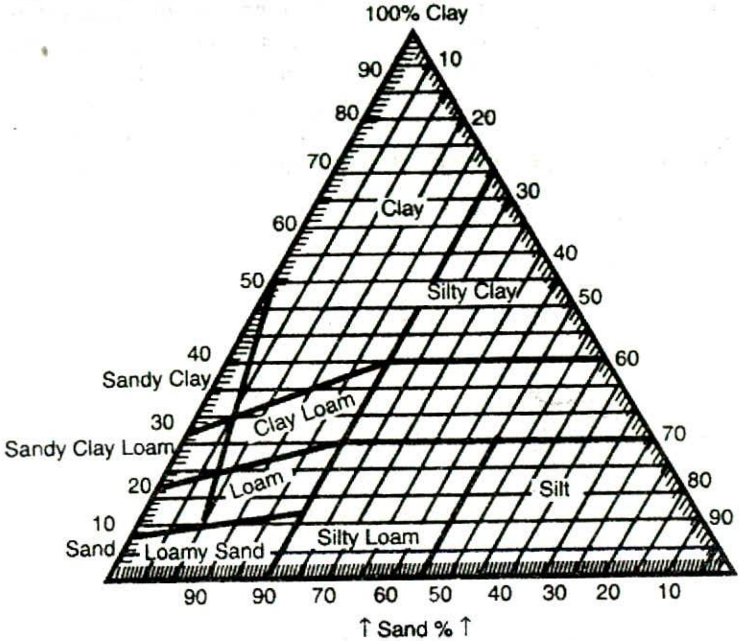


Fig. 22.1. International equilateral triangle for textural classification of the soil.

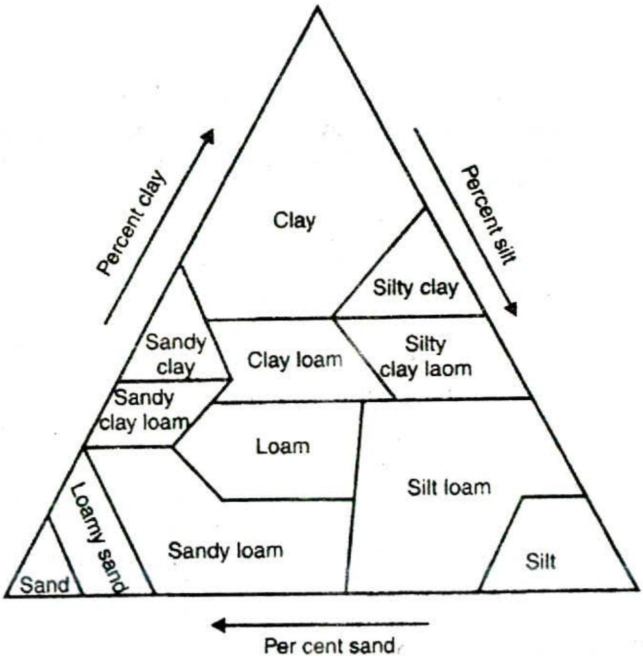


Fig. 22.2. Equilateral triangle used by USDA for textural classes of soil.

soil mass is called *clod.* Ped differs from *fragment* because the latter refers to the broken ped. Ped differs from concretion in the sense that the latter is formed in the soil by precipitation of salts dissolved in percolating water. Soil structure also reveals the colour, texture and chemical composition of soil aggregates. Soil structure is influenced by air, moisture, organic matter, micro-organisms and root growth. When many particles or peds are aggregated into cluster, a compound particle is formed.

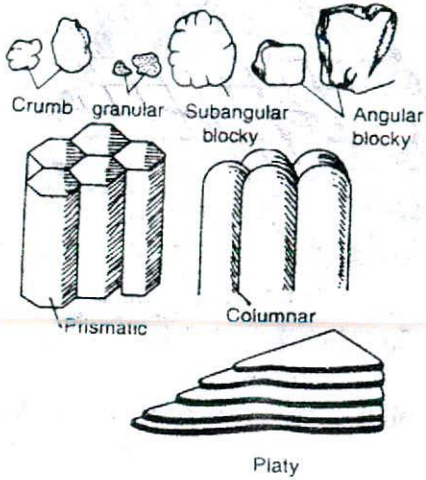


Fig. 22.3. Soil structure.

Soil structure is described under the following three categories :

A. Type. This indicates the shapes or forms and arrangement of peds. Peds may be of various shapes, such as granular, crumb, angular blocky, subangular blocky; platy and prismatic (Fig. 22.3). Different types of peds and their properties are described in (Table 22.3).

Table 22.3. Types of peds

Type of ped	*Properties*
(1) Granular	Small, spheroidal and nonporous.
(2) Crumb	Small, porous and spheroidal.
(3) Angular blocky	Block-like with sharp ends, one end may be pointed.
(4) Subangular blocky	Block-like but bounded by other aggregates.
(5) Platy	Plate like, sometimes plates are overlapped.
(6) Prismatic or Columnar	Prism like but without rounded surface.

B. Size Class. Whether

(*i*) very fine or very thin or

(*ii*) fine or thin

(*iii*) medium or

(*iv*) coarse or thick or

(*v*) very coarse or very thick

C. Grade. This indicates the degree of distinctness of peds. It is described under the following four categories :

(*i*) **Structureless :** Peds not distinct, *i.e.*, cement or sand like condition.

(*ii*) **Weak :** Peds distinct and rarely durable.

(*iii*) **Moderate :** Peds moderately well developed, fairly durable and distinct.

(*iv*) **Strong :** Peds well developed, quite durable and distinct.

3. Density and Soil Weight

Density of soil is the mass per unit volume. It is expressed in terms of gm per cubic centimeter. Average density of the soil is 2.65 gms per cubic centimeter. Density of soil varies greatly depending upon the degree of weathering. For this reason soil density is expressed in two generally accepted forms :

(*i*) particle density or true density; and

(*ii*) bulk density.

(*i*) **Particle density.** Density of solid portion of soil is called particle density. It is sum total of densities of individual organic and inorganic particles. Average particle density of organic soil varies from 1.2 to 1.7 gms per cc and that of inorganic fraction varies from 2.6 to 2.78 gms/cc. Particle density may be calculated as : $\frac{\text{weight of solids}}{\text{volume of soils}}$ Particle density divided by density of water gives the specific gravity or relative weight number.

Specific gravity of soil particles = $\frac{\text{particle density}}{\text{density of water}}$.

(*ii*) **Bulk density or apparent density.** Dry weight of unit volume of soil inclusive of pore spaces is called bulk density. It is expressed in terms of gm per cc or lbs per cubic foot. It is lesser than the particle density of the soil. Bulk density of soil may be calculated as : $\frac{\text{weight of soil}}{\text{volume of soil}}$ Bulk density of the soil divided by density of water gives volume weight or apparent specific gravity of soil. Bulk density of soil changes with the change in total pore space present in the soil and it gives a good estimate of the porosity of soil. Average density of soil in bulk is 1.5 gm/cc. Organic soils have low bulk density as compared to mineral soils.

Soil weight varies in relation to textural classes. Average weight of loam or sandy soil is 80—110 pounds/cubic foot but that of clay ranges between 70 and 100 pounds/cubic foot.

4. Porosity of Soil

The spaces occupied by air and water between particles in a given volume of soil are called pore spaces. The percentage of soil volume occupied by pore space or by the interstitial spaces is called porosity of the soil. It depends upon the texture, structure, compactness and organic content of the soil. Porosity of the soil increases with the increase in the percentage of organic matter in the soil. Porosity of soil also decreases as the soil particles become much smaller in their dimension because of decrease in pore spaces. It also decreases with depth of the soil. The pore spaces are responsible for better plant growth because they contain enough air and moisture. Percentage of solids in soils can be determined by comparing bulk density and particle density and multiplying by hundred.

$$\text{Percentage of solids} = \frac{\text{bulk density}}{\text{particle density}} \times 100$$

This percentage of solids subtracted from total volume (100%) will give the percentage of pore space. Hence, the formula :

$$100\% - \left[\frac{\text{bulk density}}{\text{particle density}} \times 100\right] = \text{percentage of pore space.}$$

Depending upon the size of pores, pore spaces fall into two categories. These are :

(1) Micropore spaces (capillary pore spaces)

(2) Macropore spaces (non-capillary pore spaces)

Capillary pore spaces can hold more water and restrict the free movement of water and air in soil to a considerable extent, whereas macropore spaces have little water holding capacity and allow free movement of moisture and air in the soil under normal conditions.

5. Permeability of Soil

The characteristic of soil that determines the movement of water through pore spaces is referred to as soil permeability.

Soil permeability, because it is directly dependent on the pore size, will be higher for the soil with large number of macropore spaces than that for compact soil with a large number of micropore spaces (capillary spaces). Permeability of soil also varies with moisture status and usually decreases with the gradual desiccation of soil. In the arid regions, groundwater moves upwardly through capillary action and bring sodium, potassium and calcium salts with it in dissolved state on the surface of soil. The water evaporates and inorganic salts precipitate on the surface of the soil. As a result of this, the soil becomes less permeable and the productive capacity of soil is reduced.

6. Soil Colour

Soils exhibit a variety of colours. Soil colour may be inherited from the parental material (***i.e., lithochromic***) or sometimes it may be due to soil forming processes (***acquired* or *genetic colour***). The variations in the soil colour are due to organic substances, iron compounds, silica, lime and other inorganic compounds.

The organic substances impart black or dark greyish black colour to the soil. Iron compounds are responsible for brown, red and yellow colours of soils. Iron oxides in combination with organic substances impart brown colour which is most common soil colour. Silica, lime and some other inorganic compounds give light white and grey tinges to the soil.

Soil colour influences greatly the soil temperature. The dark coloured soils absorb heat more readily than light coloured soils. The work of Ramdas, L.A. and David, R.K. (1936) at Poona showed that black cotton soil absorbed 86% of the total solar radiations falling on the soil surface as against 40% by the grey alluvial soil. Soil colour is used as an important criterion for description and classification of soil. Many soils are named after their prominent colours, such as black cotton soil, red-yellow latosol, grey hydromorphic soils and so on.

7. Soil Temperature

The chief sources of soil heat are solar radiations and heat generated in the decomposition of dead organic matters in the soil and heat formed in the interior of earth. The soil temperature greatly affects the physico-chemical and biological processes of the soil. Temperature of soil depends upon the temperature of atmospheric air and on moisture content. It is controlled by climate, colour of soil, slope, and altitude of the land and also by vegetational cover of the soil. The average annual temperature of soil is generally higher than that of its surrounding atmosphere. Ramdas and M.S. Katti (1934) recorded surface temperature of black cotton soil as high as 165°F at Poona (Maharashtra), India. Surface temperature of soil shows considerable fluctuations but soil temperature below certain depth remains more or less constant and is not affected by diurnal or regional temperature changes.

Studies made by Leather at Pusa Research Institute in Bihar (India) showed that diurnal temperature difference at the level 12 inches below the soil surface was only 1°C and at a depth of 24'' it seldom exceeded 0.1°C. At the depth of 3 or 4 feet, the temperature remains almost constant.

8. Soil Plasticity, Cohesion and Adhesion

Soil plasticity is a property that enables the moist soil to change shape when some force is applied over it and to retain this shape even after the removal of the force from it. The plasticity of soil depends on the cohesion and adhesion of soil materials. Cohesion refers to the attraction of substances of like characteristics, such as, that of one water molecule for another. Adhesion refers to the attraction of substances of unlike characteristics.

Soil consistency depends on the texture and amount of inorganic and organic colloids, structure and moisture contents of soil. With the decrease in the moisture contents soils gradually tend to become less sticky and less plastic and finally they become hard and coherent. Plastic soils have great cohesion force. It is only because of cohesion property the moist clay soils frequently develop cracks when they become dry (Fig. 22.4).

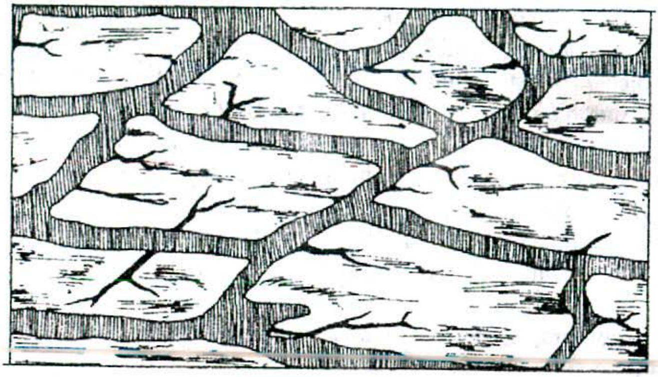


Fig. 22.4. Diagram showing soil cracking due to shrinkage.

B. CHEMICAL PROPERTIES OF SOILS

Chemical properties of soils can be described under the following heads

(1) Inorganic matters of soil,
(2) Organic matters in soil,
(3) Colloidal properties of soil particles, and
(4) Soil reactions and Buffering action,
  (*i*) Acidic soils,
  (*ii*) Basic soils,

1. Inorganic Matters of Soil

From the accounts given in the description of weathering process it is clear that compounds of aluminium, silicon, calcium, magnesium, iron, potassium and sodium are chief inorganic constituents of soils. Besides these, the soils also contain small quantities of several other inorganic compounds, such as those of boron, magnesium, copper, zinc, molybdenum, cobalt, iodine, fluorine etc. The amounts of these chemicals vary in soils of different places. Chemical composition of soil of one horizon differs greatly from the composition of soil in the other horizon.

2. Organic Matters in Soil

Organic component of the soil consists of substances of organic origin; living and dead. In sandy soil of arid zone, it is found in very poor quantity (one or less than one per cent) but in peaty soil, it may be as high as 90%. When the plants and animals die, their dead remains are subjected to decomposition. As a result of decomposition a number of different organic products or compounds are formed from the original residues. In the course of decomposition, the original materials are converted into dark coloured organic complexes, called *humus*. Sometimes living micro-organisms add sufficient amount of organic matters in soil in the form of metabolic wastes. Chemists have been attempting to unravel the details of humus composition since the earliest days of soil science, and have got much success but much is yet to be discovered. In terms of specific elements, the organic component of soil contains compounds of carbon, hydrogen, oxygen, phosphorus, nitrogen, sulphur and small amount of other elements also. Only small fraction of total organic matter is soluble in water but majority of them are soluble in alkali solution. Chemically humus contains the following organic molecules :

A. Amino Acids

(*i*) Glutamic acid
(*ii*) Alanine
(*iii*) Valine
(*iv*) Proline
(*v*) Cystine
(*vi*) Phenyl alanine

B. Proteins

(*I*) *Purines*
  (*i*) Guanine
  (*ii*) Adenine
(*II*) *Pyramidines*
  (*i*) Cytosine
  (*ii*) Thymine
  (*iii*) Uracil

C. Aromatic Molecules

D. Uronic Acids

(*i*) Glucuronic acid
(*ii*) Galacturonic acid
(*iii*) Lactic acid

E. Aliphatic Acids

(*i*) Acetic acid
(*ii*) Formic acid
(*iii*) Succinic acid

F. Aminosugars

(*i*) Glucosamine
(*ii*) N. Acetylglucosamine

G. Pentose Sugars

(*i*) Xylose
(*ii*) Arabinose
(*iii*) Ribose

H. Hexose Sugars

(*i*) Glucose

(*ii*) Galactose

(*iii*) Manose

I. Sugar Alcohols

(*i*) Inosital

(*ii*) Mannitol

J. Methyl Sugars

(*i*) Rhamnose

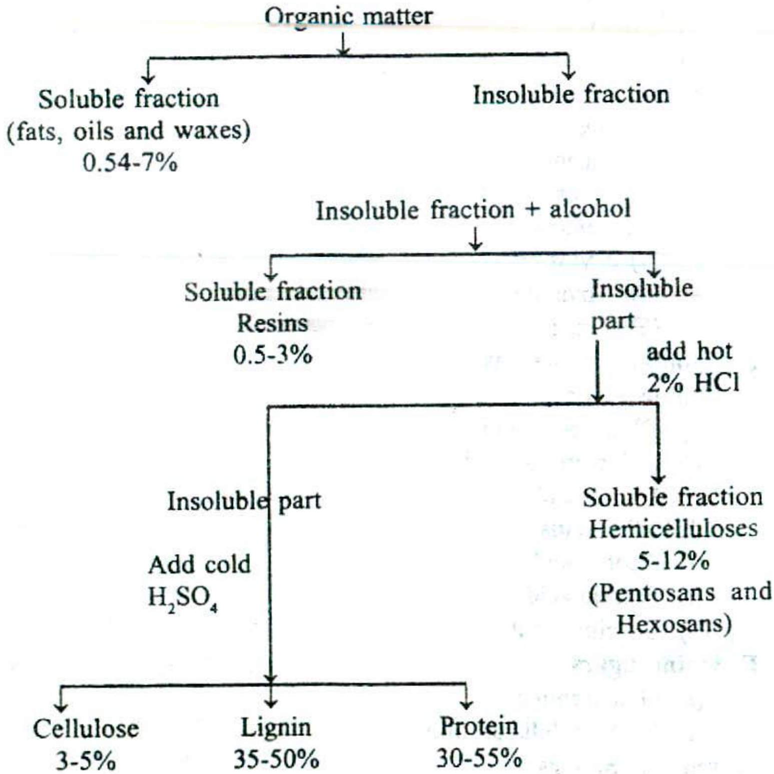
(*ii*) Fucose

(*iii*) 2-O, methyl D-xylose

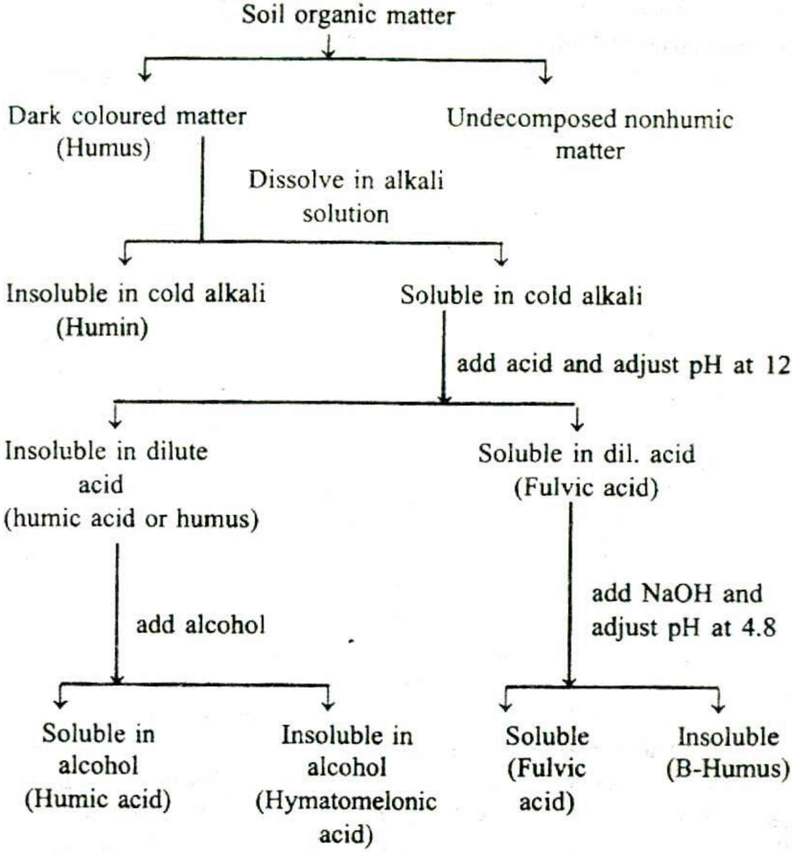
(*iv*) 2-O, methyl D-arabinose

Besides these compounds locked up in the humus fraction, the soil also contains fats, oils, waxes, resins, tannin, lignin and some pigments.

Waksman and Stevans have proposed the following method for separation of different organic compounds present in the soil :



Another modified method for separation of the various organic compounds from the soil is as follows :



The fractions are not pure chemical compounds but are in the form of mixtures of several substances. They are found in colloidal state in the soil.

3. Colloidal Properties of Soil Particles

There are two types of substances namely crystalloids and colloids.

Crystalloids are those crystalline solid substances which form true solution on being mixed with other substances. In true solution, crystal particles cannot be seen with the help of microscope.

The word colloid first coined by Grahm (1849) is derived from Greek words *kolla* meaning glue and *eoids* meaning appearance, *i.e.,* glue like in appearance. Colloid is really speaking amorphous state of the substances which do not form true solution if mixed with other substances. The particles of colloidal substances float in the solvent in suspension state but do not tend to settle at the bottom. Colloids are not found in ionic or molecular form but are found in aggregates of atoms or molecules. Colloidal system or suspension contains two phases which are :

(*i*) dispersion phase, *i.e.*, medium in which the particles are suspended, and

(*ii*) dispersed phase, *i.e.*, suspended particles.

Colloidal suspension may be of different kinds, such as

(1) Suspension of liquid, in liquid, as milk (fats in water).

(2) Suspension of solid in liquid as India ink (or clay suspension in water).

(3) Suspension of solid in gas, as smoke (coal particles suspended in air).

(4) Suspension of liquid in gas, *e.g.*, cloud and fogs in atmosphere.

The commonest colloids are those which remain suspended in a liquid medium.

If the colloidal suspension exhibits properties of fluid, it is called *sol,* but sometimes sols exhibit solid like behaviour and form solid or nearly so. This condition is called *gel.* Some sols form reversible gel while the others form irreversible gel. Some of the important properties of colloids in general are as follows :

1. **Particle size.** Crystalloids and colloids differ from each other in their size range. Particles of crystalloid in true solution are 0.2 to 1 mμ (millimicron) while those of colloids in suspension are 1 to 200 mμ.

2. **Adsorption.** Because the colloidal particles of dispersed phase are very small, they have got large exposed surface areas. Owing to their large exposed surface areas, these colloidal particles show great adsorptive capacity. In adsorption, particles of particular substances come to lie on the surface of colloids and they do not enter deep in the colloidal particles.

3. **Electrical properties.** The electrically charged colloids are termed as *micelles.* Colloids have some electrical charge on them. They may be charged either positively or negatively. Colloidal particles of one electrical charge have tendency to attract colloids of opposite charge. In the soil, clay particles are negatively charged, thus they attract cations (+ charged ions).

Colloid particles differ from electrolytes in the fact that when electric current is passed in the colloidal suspension, all the colloidal particles are attracted towards one electrode or the other depending upon the nature of charge they carry on them. This phenomenon is called *electrophoresis.* The electrolytes, when dissolved in solvent dissociate into two types of ions among which half will bear positive charge (cations) and remaining half will bear negative charge (anions). When electric current is passed in the solution of electrolyte all the positively charged ions will accumulate on negative pole and remaining negatively charged ions will collect on positive pole.

4. **Coagulation or flocculation of colloidal particles.** Colloidal particles in the suspension can be coagulated either by heating or by adding some substances which contain opposite charged ions. When substances carrying positive ions are added in suspension containing negatively charged

colloid particles, ions will move and accumulate on the surface of colloids carrying opposite charge. Finally a stage comes when colloidal particles cannot attract more opposite charged ions. This is called *isoelectric point*. As a result of ion accumulation on their surface, the colloids first become large and heavier and finally they tend to settle at the bottom in floccules. This process is known as ***flocculation***.

5. **Tyndal phenomenon.** Colloidal particles in suspension can be seen when a strong beam of light is passed through suspension and observer looks it from the place at right angle to the path of light. The colloidal particles become visible as strongly illuminated particles and they appear bigger than normal size. This phenomenon is known as "Tyndal effect".

6. **Brownian movement.** Colloidal particles when suspended in dispersion medium show a characteristic continuous zig-zag motion, called ***Brownian movement***. This type of movement was first observed by English botanist Robert Brown, hence it is called Brownian movement. The movement is exhibited because of characteristic collision of one particle with others. This prevents the particles from settling down.

7. **Dialysis.** Because colloidal particles in suspension are larger than the particles of crystalloid in true solution and are larger than the diameter of pores of porous membranes, *e.g.*, parchment membrane, they are not allowed to be filtered down and are retained by the membrane. Thus, they can be separated in pure state from the mixture of crystalloids and colloids by filtration process. This separation process is known as *dialysis*.

Colloidal Fraction of Soil

There are two types of colloids in the soil. These are

(1) mineral colloids or clay colloids, and

(2) organic or humus colloids.

These two colloidal fractions of soil are very intimate to each other and it is very difficult to separate them. The inorganic colloids occur as very fine particles and organic colloids occur in the form of humus particles. The soil colloid particles show almost all the characteristics of typical colloidal system, *i.e.*, adsorption, Tyndal effect, Brownian movement, coagulation, electrophoresis, dialysis etc.

1. **Clay colloids.** As regards the size, clay fraction of soil contains both non-colloidal and colloidal particles. Some clay particles may be as large as .002 mm in diameter but some may be smaller than normal colloid size (normal size of colloid particle is from 1 to 200 mμ). The clay particles are formed mainly of silica, alumina, iron and combined water. Colloidal clay may also contain rich accumulation of plant nutrients. Early researchers of soil science have described clay colloids as spherical particles and their sizes were mentioned in terms of their diameters, but recent electron micrographs reveal that particles occur in layers or plates and each clay particle appears as if it is composed of a large number of plate-like units.

These units or flakes of clay are held together by a force of attraction. The plate-like clay particles expose large surface area on which moisture and cations (+ ions) are held. The finer the clay particles the greater will be the percentage of hygroscopic moisture.

If clay is suspended in distilled water, shaken, and then a little NH_4OH is added to suspension and allowed to settle, after a few minutes large particles settle down but finer particles remain in suspended state. When a little limewater is added to suspension, fine suspended particles increase in size and form small floccules which have a tendency to settle down. Thus, finer clay particles show flocculation property. Now if some acid is added, the floccules are broken and the clay particles will return to their normal size. This process is known as ***deflocculation***.

The clay particles are negatively charged, hence they can hold thousands of positively charged ions of mineral nutrients on their surfaces.

The clay colloids are lyophilic (water loving). So, they are important from the standpoint of the adsorption of large quantity of water (perhaps, 5-10 layers of water molecules are held on the surface of clay colloid).

2. **Organic colloids or humus colloids.** Organic colloids in the soil are chiefly due to presence of humus. The humus contains 8% each of lignin, protein, polyuronides (sugars and uronic acid complex). Organic colloids may be present in appreciable proportion in the soils. In sandy soil, it forms major part of colloids. In peaty soil, organic colloids may be more than 50%. These colloids show adsorptive capacity many times greater than clay colloids. Organic colloids are negatively charged like clay colloids. Addition of organic colloids to the sandy soil increases temporarily its moisture and nutrient retaining capacity.

Cation Exchange

Since the soil colloids (clay and organic colloids) have negative charges on them, they attract and hold positive ions (cations). When cations are added to the soils such as Ca^{++} in the form of lime, K^+ ions in the form of potassium fertilizer, and NH_4^+ in the form of ammonium fertilizer, the adsorption of cations will take place on the surface of colloid micelle and this will be accompanied by release of one or more ions held by colloid micelle. This is known as *cationic exchange.* For example, suppose that colloid micelle has one half of its capacity satisfied with Ca^{++} ions, one quarter with K^+ ion and remaining one quarter with H^+ ions. Now the colloid is treated with KCl solution. The K^+ ions will first replace Ca^{++} ions and then H^+ ions. The Ca^{++} and H^+ ions will combine with Cl^- ions of KCl and will form $CaCl_2$ and HCl respectively.

The cation exchange in the soil may take place between :

(1) cations present in the soil solutions and those already present on surface of soil colloids,

(2) cations released by plant roots and those present on the surface of soil colloids, and

(3) cations present on the surface of two clay crystals either two organic colloids or an organic colloid and a clay colloid.

Exchange reaction is very quick and reversible and the exchange of ions continues till equilibrium is attained. All cations are not adsorbed with equal ease. Some are easily adsorbed while others are replaced with difficulty. Divalent cations are more effective than the monovalent ones. Hydrogen is exception because it is held by colloids most tenaciously and it is most powerful replacer of cations. Replacing capacities of some cations are compared here : $H^+ > Ca^{++} > Mg^{++}, K^+ > Na^+$

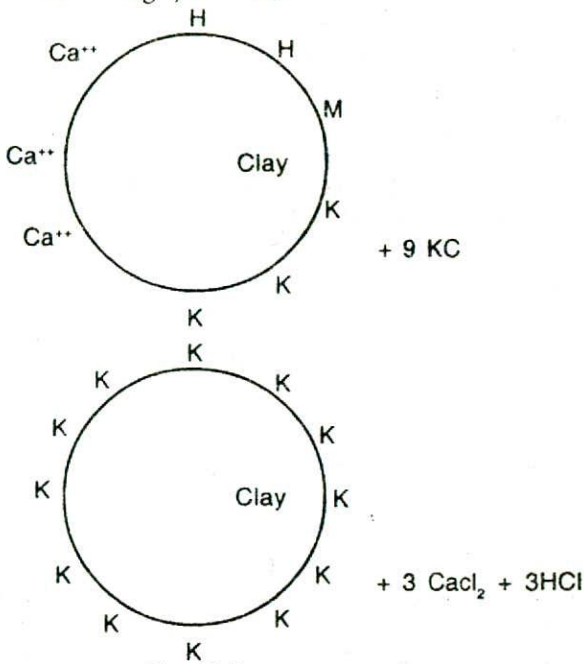


Fig. 22.5.

The number of cations adsorbed per unit weight of one hundred grams dry soil is called **cation exchange capacity**. More scientifically, cation exchange capacity of soil is the sum total of exchangeable cations adsorbed per unit weight of one hundred gms of dry soil.

Factors which are responsible for cation exchange or base exchange are as follows :

(1) relative concentration and number of cations present in the soil,

(2) replacing capacity of the ions, and

(3) number of charges on the ions.

Anion Exchange

Soils rich in organic colloids show anion exchange also. In this process, negatively charged ions held by colloids are replaced by OH^-, $H_2PO_4^-$, SO_4^{--}, and NO_3^- ions. The relative order of exchange is

$$OH^- > H_2PO_4^- > SO_4^{++} > NO_3^-$$

Among these anions, exchange of PO_4^{---} ions is most important. SO_4^{--} and NO_3^- are not retained in the soil for long period of time, hence not available for anionic exchange. Laterite soils have high adsorptive and fixation capacity for PO_4^{---} than black soils.

Anionic and cationic exchange reactions are important in agriculture. Several soil scientists have shown that the capacity of soil to exchange cations is the best index of soil fertility. The predominance of desirable ions in the exchange complex brings about good physical cations and favourably influences the microbial activities in the soil, such as ammonification, nitrification, etc. The knowledge of cation and anion exchange is of great help in reclaiming acidic and saline or alkaline soils.

4. Soil Reaction

Many chemical properties of soils centre round soil reaction. As regards their nature, some soils are neutral, some are acidic and some basic. The acidity, alkalinity and neutrality of soils are described in terms of hydrogen ion concentrations or pH values. In order to understand soil reaction, the knowledge of pH is very necessary. It can be understood in the following ways :

Water dissociates into H^+ ion and OH^- ion. Hence the ionic constant of water can be represented as follows :

$$\text{Ionic constant of water} = \frac{[H^+][OH^-]}{[H_2O]}$$

But the rate of dissociation of water is so slow that ionization constant of water can be expressed simply as product of concentration of H^+ and OH^- ions, thus ionization constant of water $Kw=[H^+][OH^-]$. Concentration of H^+ and OH^- ions are expressed in terms of equivalents per litre. Only one molecule in ten million water molecules is in dissociated condition.

At neutrality, H^+ concentration is 0.0000001 or 10^{-7} gm of hydrogen per litre solution. The ionization constant of water is 10^{-14} at 25°C and thus in any aqueous system products of H^+ and OH^- ion concentration is 10^{-14}. Now, the above equation can be written as :

$$10^{-14} = [H^+][OH^-]$$

This can also be represented in the following way by dividing both sides in one and taking logarithms.

$$\text{Hence, } \log \frac{1}{[K_w]} = \log \frac{1}{[OH^-]} + \log \frac{1}{[H^+]} = 14$$

The value of $\log \frac{1}{[H^+]}$ and $\log \frac{1}{[OH^-]}$ are generally called pH and pOH respectively. These pH and pOH are indices of the acidity and alkalinity respectively. Thus, pH can be defined as negative logarithms of the H^+ ion concentration. When the system is neutral, pH will be equal to pOH and when Kw is 10^{-14}, the value of pH and pOH at neutral point will be 7 for each. When pH value is less than 7, it is acidic. The pH value above 7 indicates alkalinity. If in a system, hydrogen ion concentration is 1/.000001 or 000001 gm/litre, the pH value will be 6. It is more clear from the following calculation :

$$pH = \log \frac{1}{[H^+]} = \log \frac{1}{000001} \text{ or } \log 10,00,000 = 6.$$

Thus at pH value of 6, the H^+ ion concentration is increased 10 times than the H^+ concentration at pH value of 7. Like this, at every lower point H^+ ion concentration will increase by a multiple of 10.

As the product of H^+ ion and OH^- ion concentrations at neutrality is always 10^{-14}, the pOH can be determined from pH value. Suppose, pH value of a solution is 6, the pOH value will be 8 ($10^{-6} + 10^{-8} = 10^{-14}$). pH scale is divided into 14 divisions or pH units from 1 to 14. Soil with pH value of 7 is neutral, that below pH 7 is acidic and that with pH value above 7 is alkaline.

From the pH value intensity of acidity in the soil is expressed but these values are not the measure of total acidity because they do not indicate the reserved acidity or relative acidity. For example, there are two soil samples which have similar pH values but they require different quantities of lime for neutralization. It means that the quantities of acids are different in the given weight of above two soils.

Buffer Action

It refers to the resistance to change in pH of a system. Such solutions as are reasonably permanent in pH value even after addition of some alkali or acid to them are called solution with reserved acidity or alkalinity or more often "buffer solutions". Suppose, a certain amount of acid is added to distilled water, the resulting solution will show acidic reaction and that will have a pH below 7, but if the same quantity of acid is added to a neutral soil suspension there would be very minor change in pH. This property of soil to resist a change in pH is called "buffer action".

Buffer solutions are usually formed of a mixture of salt of weak acid and acid itself in various proportions, as for example, a mixture of sodium acetate and acetic acid if added to water will result in a buffer solution. In the mixture solution we have mainly sodium ions and acetate ions. In water there will be some H^+ and OH^- ions. In buffer solution, acetate ions are in excess, owing to presence of well ionised sodium acetate. If H^+ ions are added to this solutions they will combine with acetate ions to give acetic acid of low ionisation power.

$$H^+ + \text{acetate}^- \rightleftharpoons \text{acetic acid}$$

$$K = \frac{[H^+][\text{acetate}^-]}{[\text{acetic acid}]}$$

Hence, there wiil be a little increase in pH. The addition of acid to buffer solution then makes little difference in the pH value.

Buffering in Soil

Soils have got good buffering capacity. Therefore, it is necessary to add considerably large amount of acids or alkalies in order to bring about any change in the original pH of soil. Buffering action is due to presence of large quantity of weak acids and their salts in the soil. Phosphates, carbonates, bicarbonates and other salts of weak inorganic acids and corresponding acids themselves are important buffering agents in the soils. Besides these, colloids associated with cations are important buffering agents. The buffering action of soil is directly governed by the amount and nature of clay and organic or humus colloids present in it.

Buffering action of soil is important in agriculture in the following respects :

(1) ***Stabilization of pH.*** This protects the higher plants and micro-organisms form direct adverse and injurious effects of sudden change in soil reaction.

(2) ***Amount of amendments necessary to correct the soil reaction.*** The greater is the buffering capacity of soil the larger will be the amount of the amendments such as lime, sulphur etc. to correct the acidity or alkalinity.

ACID SOILS

Soils with pH values below 7 are acid soils. In the regions of high rainfall, soils are acidic in their reaction because of the facts that soluble basic salts such as those of Ca, Mg, K, Na are leached away by drainage water and insoluble acidic residues composed chiefly of oxides and silicates of iron, silicon, aluminium are left which accumulate in pretty high amount. These salts are acidic in reaction, hence the soils are acidic. Besides that reason, there may be other causes also which produce acidity in the soil. Important factors which produce acidity in soil are as follows :

(1) Continuous removal of lime and other base elements by crops and accumulation of acids contained in the manures.

(2) Application of acid forming fertilizers in the soil.

(3) Microbial action.

(4) Formation of soil on the acidic rocks.

In India, acid soils occur in the high rainfall areas covering about 25 million hectares of land with a pH below 5.5 and 23 million hectares of land with a pH between 5.6 and 6.5. These estimates are calculated by Bhaumik, H.D. and Donahue, Roy, L., 1964 (Reference: Soil acidity and the use of lime in India. Farm Information unit, Directorate of Extension, Ministry of Food and Agriculture, Government of India). In India, acid soils occur in Assam, Meghalaya, Arunachal Pradesh, Mizoram, Nagaland, NEFA, Manipur, Tripura, West Bengal, Bihar, Uttar Pradesh, Himachal Pradesh, Jammu Kashmir, M.P., Maharashtra, Kerala, Karnataka, Tamil

Nadu and Andhra Pradesh. Punjab, Haryana, Rajasthan and Gujarat are the only states in India where acid soils do not occur.

Very few plants can grow well in strong acid soils. Soil acidity below pH value of 5.5 is generally injurious to plants. Plant roots are badly affected if the pH value exceed limits of tolerance for particular crops. High degree of soil acidity (pH 5 to 6.5) decreases the availability of plant nutrients particularly phosphorus, calcium, magnesium, molybdenum, iron, manganese, potassium, sulphur, nitrogen, boron, copper and zinc. It also affects adversely the important microbiological processes, such as nitrogen fixation by *Azotobacter, Clostridium* and nodule inhabiting bacteria (*Rhizobia*) of leguminous plants.

Origin of Acid Soils

Several factors are responsible for the origin of acid soils. Generally climate, hydrologic cycle, vegetation, parent rocks and human interference play important roles in the origin and development of acid soils. Acid soils occur generally in humid regions where the rainfall is regular and very heavy. Dry regions are devoid of acid soils.

Climate. In humid regions where evaporation is less than precipitation, chances for the development of acid soils are good. For the development of acid soils it is also necessary that water percolating down the soil profiles must reach the water table. In India, it is believed that the regions with acid soils must receive more than 750 mm annual rainfall. The regions with annual rainfall 1350 mm may have acid soils with pH value 5.0 or even lower than that. In temperate regions the acid soils can develop even if the rainfall is scanty. In hilly regions where the loss of water through evaporation is very slow due to very low temperature the conditions for the development of acid soils are very favourable, although the rainfall is scanty there.

Vegetation cover. In temperate regions or hilly areas covered with conifers the acid soils can develop easily. According to Bloomfield (1953), the foliage leaves of conifers lack alkali elements and their mineralization process is very slow. When the leaf-litter on the ground is degraded, organic acids are released which gradually make the soils acidic. Plants found in the coastal regions and marshy places after death and decay produce acids which render the soils acidic.

Parental rocks. Though the development of acid soils is possible on all types of rocks and parental rock materials in presence of favourable climate and vegetation, yet the development of acid soils on alkaline rocks take longer time as compared to the acid soils developing on the acidic parental rocks. Acid soils develop more quickly from parental rock materials with simple composition than from the parental rock materials of complex composition. It is so on account of presence of less adsorbed cations, poor buffering capacity and quick percolation of water through them.

Topography. Slopy places with good drainage conditions are supposed to be good for the development of acid soils. On hill slopes, the development of acid soils is easy. Acid soils do not develop generally in river basins.

The plains with good drainage may also develop acid soils in due course of time.

Human interference. Continuous efforts by man for developing permanently submerged areas into cultivable land, or for improving drainage in submerged or saline lands, regular use of nitrogen fertilizers like ammonium sulphate which cause acidity in the soils are responsible for decrease of soil pH.

In urban areas, industrial wastes containing sulphur or sulphur dioxide also contribute much in the development of acid soils.

Classification of Acid Soils

According to the intensity of acidity, the acid soils are of the following five types :

(1) Slight acidic (pH range 6.6 to 6.1)
(2) Medium acidic (pH 6.0 to 5.6)
(3) Strong acidic (pH 5.5 to 5.1)
(4) Very strong acidic (pH 5.0 to 4.6)
(5) Extremely strong acidic (pH 4.5 or lower)

Acid soils occurring in different climatic regions are classified as follows :

(*i*) Acid soils of temperate climate including podzol, brown podzol, grey brown podzol, brown forest soils, and grey forest soils.
(*ii*) Acid soil of tropical and subtropical climates including yellow podzolic soil, lateritic soil and latosols.
(*iii*) Acid soils of other great soil groups including wet soils (hydromorphic soils), washed peaty soils, mucky, cat-clay (acid sulphate) soils. Cat-clay or acid sulphate soils with pH 3.5 or lower are and soils. They abound in organic material as well as H_2SO_4.

According to soil classification system (1970) developed by U.S. Soil Scientists, soils of the world have been classified into 10 soil orders. Among these Aridisols, Vertisols and Mollisols are devoid of acid soils and the remaining 7 orders contain acid soils. But acid soils occur mainly in three orders : Oxisols, Alfisols and Histosols.

In modern soil classification soil orders have been divided into suborders. Suborders *Humox, Humod, Aqualf* and *Udalf* include acid soils.

In modern system of soil classification, acid sulphate soils have been assigned separate position and these soils have been placed in a group called *sulpha-aquepts*. This group includes soils in which the top horizon contains sulphuric horizon at some level or the other in top 25 cm thick layer. This is mineral or organic sublayer marked with yellow colouration due to xarocite. Acid sulphate soils of tropics possibly belong to *Typic Sulpha-aquepts* and those of temperate regions are mainly *Typic Sulpha-aquepts* and *Hapla aquepts*. Mineral and organic soils rich in sulphur which remain regularly submerged are referred to as *sulphidic soils*. Since such soils develop under the influence of saline water which is rich in sulphur, they are placed in *Halic* subgroup.

Mandal (1974) has classified acid soils of India into the following seven groups :

(1) Laterite soils

(2) Lateritic and laterite red soils

(3) Mixed yellow red soils

(4) Ferruginous red soils

(5) Podzolic soils

(6) Terai soils

(7) Peaty soils.

In this classification, acid sulphate soils and degraded alkali soils have not been assigned proper places. Nevertheless, it would be appropriate if they are classed with acid soils as the pH levels of such soils indicate that they are acidic in nature.

Recently Mishra, S.G. (1976) has suggested that the acid soils should be classified into the following two categories on the basis of organic contents in them :

(1) Acid mineral soils (organic matter less than 20%)

(2) Acid organic soils (organic matter 20% or more)

1. **Acid mineral soils.** Such soils are further classified into the following three subgroups :

(*i*) **Acid mineral soils rich in organic matter in upper layer.** Such soils are commonly found in temperate and sub-temperate regions and develop by podzolisation process. Since these regions are covered with thick forest vegetation, the surfaces of such soils are covered with decomposing organic matter. The degradation of organic matter results in the production of various organic acids, such as citric acid, acetic acid, oxalic acid and so on. Microbial degradation of organic matter also produces CO_2 which combines with water to form carbonic acid (H_2CO_3). These acids along with rain water percolate down through soil profiles. Along with these acids and rain water sesquioxides are also leached out from the upper horizons and become deposited in lower horizons. This depletion of sesquioxides from the top layer and their accumulation in lower sublayers is referred to as *Podzolisation* and such soils are called Podzols.

(*ii*) **Acid mineral soils devoid of organic layer.** Acid mineral soils found in plains usually do not possess organic layer. Such soils originate mainly as a result of *laterisation* and partly due to podzolisation process. Laterite soils, Red soils, and hydromorphic acid soils found in India belong to this category. Such soils originate in the following ways :

(*a*) CO_2 of atmosphere as well as of soil dissolves in water to form carbonic acid (H_2CO_3) which, when percolates down the soil profiles, degrades carbonates and primary minerals present in the soils and makes the soil acidic.

b) In tropics, at high temperatures maximum degradation of silica tàkes place and in top soil layer the quantity of sesquioxides increases. This process is referred to as *laterisation*. Laterite and Red loam soils found in India have probably originated through this process.

At low temperatures Yellow Red Podzolic and Grey Podzolic soils originate which are less acidic.

(*iii*) **Degraded alkali soils.** The top layer of some alkali soils shows a pH value less than 7 due to desalinisation or dealkalization. Such soils are referred to as degraded alkali soils. In this process. The alkali salts are washed by irrigation or rain water and exchangeable Na^+ ions of soils are displaced by H^+ ions of water.

2. **Acid organic soils.** According to the amount of organic matter, acid organic soils can be classified into the following two types :

(*i*) Peaty Soils

(*ii*) Mucky Soils

(*i*) *Peaty soils.* Peaty soil are characterised by presence of poorly degraded organic matter. In India, peaty soils occur in Kashmir, Himachal Pradesh, Assam and other states.

(*ii*) *Mucky soils.* Such soils contain highly degraded organic matter. They have relatively higher pH values than the peaty soils. Thus they are less acidic. Mucky soils are also found in Kashmir, Himachal Pradesh, Assam, and some other states.

Effects of Soil Acidity on Plants

Soil acidity affects the plants both directly and indirectly. These effects are briefly mentioned below :

1. **Direct influences.** These are as follows :

(*a*) Toxic effects of low H^+ ion concentrations on root tissues.

(*b*) Influence of soil acidity on the permeability of the plasma membrane for cations.

(*c*) Disturbance in the balance between basic and acid constituents through roots.

(*d*) Affects enzymatic processes since enzymes are particularly sensitive to pH changes. Different crop plants have their specific optimum pH requirement. Rice; oat and linseed can endure a fairly acidic reaction (pH = 5.0) while barley, sugar-beet, lucern etc. can tolerate a fairly alkaline reaction (pH = 8.0)

2. **Indirect effects.** These are listed below :

(*a*) Availability of various nutrients, *e.g.*, phosphorous, copper, and zinc.

(*b*) High solubility and availability of elements like aluminium, manganese and iron in toxic amount due to high acidity in the soil.

(*c*) Deficiency of some nutrients such as calcium and potassium due to soil acidity.

(*d*) Prevalence of plant diseases.

(*e*) Beneficial activities of soil microbes are adversely affected.

Reclamation of Acid Soils or Correction of Soil Acidity

Acidity of soil is due to predominance of H^+ ions over OH^- ions, the bulk of H^+ ions being held in close association with clay-organic colloid complex. Strong acid soils are not much productive. The soils which are less productive owing to high degree of acidity can be made more productive by liming (application lime).

When lime is added to moist soil, the soil solution becomes charged with cations and the exchangeable hydrogen and aluminium ions on clay-organic colloid complex as well as the H^+ ions in soil solution are displaced by calcium ions. Hydrogen combines with OH^- to form neutral water or with CO_3^- or HCO_3^- to form unstable H_2CO_3 which readily dissociates to form CO_2 and water.

Acidity of soil can also be corrected by adding exchangeable Mg^{++} to exchange complex. But addition of Ca^{++} or Mg^{++} or both to the soil will not necessarily solve the problem of soil acidity. The important points to be considered in liming are : (*i*) the salts of these elements which are going to supply these ions (Ca^{++} or Mg^{++}) and (*ii*) the overall reactions of salts in the soils. Salts of strong acids as gypsum ($CaSO_4$) or calcium chloride ($CaCl_2$) can be applied to supply calcium ions to the soils but it is worth considering what will be the effects of these salts on soil acidity. The application of these salts will indeed increase the acidity in the soil, instead of decreasing it. Therefore it is suggested that calcium salts of strong acids must not be applied for correcting the acidity of soils.

Liming materials. More than 90 per cent of the lime used in agriculture for reclamation of acid soils is generally in the form of calcium carbonate, some in calcium and magnesium carbonates, and much smaller quantity in the form of calcium oxide or calcium hydroxide. To a chemist lime is calcium oxide but to a farmer, agronomist or soil scientist lime usually means calcium carbonate or calcium carbonate equivalents.

The common liming materials used for reclamation of acid soils are as follows :

(1) Calcic limestone ($CaCO_3$) which is ground limestone.

(2) Dolomite ($CaCO_3.MgCO_3$).

(3) Quick lime (CaO) which is burnt limestone.

(4) Hydrated (slaked) lime [$Ca(OH)_2$].

(5) Coral shell lime.

(6) Marl or chalk ($CaCO_3$).

(7) *Slags.* Obtained as by-products from iron and steel plants, slags are used in agriculture for reclaiming acid soils. The slags are of three types :

(*i*) blast furnace slags, (*ii*) basic slag and (*iii*) electric furnace slag. These slags are rich in phosphorus and mixture of CaO and $Ca(OH)_2$. Besides, Ca, Ma, Al, silicates are also present in them.

(8) *Press-mud.* It is obtained from carbonation plants of sugar mills and some other matters containing calcium are used to decrease acidity in the soils.

(9) *Miscellaneous sources of lime.* Such as, wood ash, ground oyster shells, by-product lime resulting from paper mills, tanneries, water softening plants, and by product $CaCO_3$ form fertilizer factories using gypsum process (such as Sindri Fertilizer Factory, Bihar, India).

The rate of lime application should always be determined after soil testing. When excessive amount of lime is applied to sandy soils low in humus, injury to plants may be caused which may be attributed to one or more of reasons listed below :

(1) Boron deficiency.

(2) Iron, manganese or zinc deficiency.

(3) Reduced availability of phosphorus to a critically low level.

(4) Reduced potassium uptake.

Such injurious effects may be reduced by application of large amount of compost manure, green manure crops, phosphorus fertilizers, boron or a mixture of minor elements.

While applying liming agents of acid soils, the following points must be taken into consideration.

(*i*) The liming agents should be used in highly powdered state. The smaller the particles of liming agents the greater will be their effectiveness in correcting the soil acidity.

(*ii*) Liming materials should be in direct contact with clay organic exchange complex so that H^+ ions of exchange complex may be easily displaced by Ca^{++} ions.

(*iii*) Liming agents should be applied to soils at least one month before sowing the crops or they should be applied thorougly mixed with soils just after harvesting the crops.

Important Roles of Liming Agents in Soils

(1) Liming agents reduce soil acidity and stabilize pH of the soils.

$$\text{Acid-clay} + Ca(OH)_2 \rightarrow \text{Ca-clay} + H_2O$$

(2) Lime makes phosphorus more available. This is true mainly because in acid soils phosphorus is fixed by soluble iron and aluminium. Liming reduces the solubility of iron and aluminium and therefore less phosphorus is held in these insoluble and unavailable forms.

(3) Lime makes potassium more efficient in plant nutrition. When K is in sufficient amount in soil plants absorb more potassium than is actually needed but at the same time when lime is available in plenty, plants take up more calcium and less potassium. Economically liming is more desirable because plants absorb more cheap Ca and less of expensive potassium.

(4) Lime enhances the decomposition of organic matter, thereby increases the availability of nitrogen and other nutrients locked up in complex forms to plants.

(5) Lime promotes beneficial activities of soil bacteria.

(6) Liming programme extended over a period of years improves the physical conditions of the soil by causing granulation of soil particles, decreasing its bulk density, and increasing its infiltration rate.

(7) Ca and Mg found in liming agents, particularly in Dolomite act as essential elements in the nutrition of plants.

(8) Lime converts toxic elements such as aluminium, Mn, Fe of the soil in insoluble and harmless compounds.

Acid Tolerance in Crops

Some plants are adversely affected and they suffer injuries when grown in acid soils. Familiar crops which can endure fairly acidic soil conditions are oat, rice and linseed and those which are not adapted to acid soils are wheat, barley, cabbage, *sorghum* (Jowar), tobacco, lettuce, spinach, onion, eggplant or brinjal.

SALINE AND ALKALI SOILS

Saline soils represent a group of soils in which percentages of soluble salts, usually chlorides and sulphates of the alkali bases are very high. The pH of saline soils are always high. In India saline soils occur in many provinces, as U.P., West Bengal, Punjab, Bihar, Orissa, Maharashtra, Tamil Nadu, M.P., Andhra Pradesh, Gujarat, Delhi and Rajasthan covering an area of about 7 million hectares.

There are 4 major tracts in India where salinity problem is acute. These are (*a*) the arid tract of Rajasthan and Gujarat, (*b*) semi-arid alluvial tracts of Punjab, Haryana and Uttar Pradesh, (*c*) the arid and semi-arid tracts of Southern States, and (*d*) the coastal alluvium.

In U.P., the saline (usar) soils are distributed in Kanpur, Lucknow, Hardoi, Unnao, Allahabad, Rai Bareli, Azamgarh and many other districts covering about 1.29 million hectares. In Punjab alone saline soil covers about 2 million hectare area. In U.P. and Punjab the saline soils are increasing gradually in area. These lands are known by a variety of names in local agricultural parlance. By far the most common of them is *usar* derived from the Sanskrit word *Ushtra* meaning sterile or barren. Other terms like *reh*, char, *lone*, *thur* or *shora* are also popular. The word *alkali* is of Arabic origin meaning ash-like and is used to designate hard and intractable soils generally known by the names *rakkar*, *kallar*, *bara* and *bari*.

The salty soils are of three types :

(*i*) **Saline or solonchak or white alkali soils.** In these, salinity is caused by soluble salts other than alkali salts. They have high soluble salts and low exchangeable sodium.

(*ii*) **Alkali or sodic or solonetz or black alkali soils.** These are formed by accumulation of alkalies, such as Na, K etc. in excess. Such soils have low salt content but high exchangeable sodium.

(*iii*) **Saline-alkali soils.** In these alkali and other soluble salts have combined effects. They are also called *saline sodic* as they have high salt content and high exchangeable sodium. The United States Salinity Laboratory recently designated these soils scientifically on the basis of soil analysis following the ideas of Sigmond and Gedroiz (1954) (Table 22.4).

Table 22.4. Three classes of salty soil

Soil Property	*Saline soil*	*Alkali soil*	*Saline-alkali soil*
1. Conductivity of saturated extract (ECe)	more than 4 m mhos/cm at 25°C	less than 4 m mhos/cm at 25°C	greater than 4 m mhos/cm at 25°C
2. Exchangeable sodium percentage (ESP)	less than 15	greater than 15	greater than 15
3. pH range	usually below 8.5	between 8.5 and 10	above 8.6

Soils in which salinity is mainly due to accumulation of alkali salts are called alkali soils or usar soils. High alkalinity in the soil adversely affects the plant growth, thereby reduces the crop yield. Such sterile or unproductive soils are called barren soils. The main salts present in the alkali soils are Na_2SO_4, K_2SO_4, NaCl, and KCl.

Types of alkali soils. These soils are of two types :

(*i*) Black alkali soils—In these soils, Na_2CO_3 is found in excess.

(*ii*) White alkali soils—In this group, NaCl is in excess.

Russians call such soils as *solonchack*. Bertholet thought that Na_2CO_3 was formed in black alkali soil by interaction of NaCl and $CaCO_3$.

$$2NaCl + CaCO_3 = Na_2CO_3 + CaCl_2$$

Factors Which Make the Soils Alkaline

These are :

1. Poor drainage in arid region,
2. Rapid evaporation of alkaline soil solution, and
3. Excess uptake of alkaline salts and little percolation.

In arid and semi-arid regions, the rainfall is too low to leach or remove the saline matter from the top soils. Besides this, water along with dissolved alkali salts moves upward by capillary action which on reaching to the soil surface evaporates and the salts accumulate in the form of a hard layer or pan in the subsoil. This hard layer is responsible for impermeability of such soils.

Miller is of the opinion that many plants absorb excess acidic ions, *e.g.*, NO^-_3, than the basic ions. This excessive removal of acidic ions results in the accumulation of basic ions which make the soil alkaline.

According to a chemical hypothesis, alkali soils may result in the following steps :

(*a*) reaction between NaCl or KCl and soil (S) :

$NaCl + S(Soil) \rightarrow Na\ (S) + Cl\ ion$

(*b*) then the soluble products are leached away from the soil surface by drainage water, and

(*c*) finally, reaction between insoluble Na (S) complex and carbonates :

$$2\ Na\ (S) + CaCO_3 \rightarrow \underset{(alkaline)}{Ca\ (S)} + \underset{(alkaline)}{Na_2CO_3}$$

Effects of alkali salts on vegetation. The alkali salts show the following effects on plants :

(*i*) Due to excessive accumulation of salts, concentration of soil solution, becomes high. This decreases absorption of nutrients by plants and causes plasmolysis of cell cytoplasm in the plants which may be fatal sometimes. All these effects are responsible for stunted growth of plants.

(*ii*) If sodium is absorbed by the plants in excess, it shows toxic effects. Chloride salt of alkaline elements cause the death of trees. $BaCO_3$ and BaCl are toxic to all plants.

(*iii*) Presence of excess salts in the soil retards the germination of seeds and growth of seedlings. Plants die before bearing fruits.

(*iv*) Alkali salts in the soil also affect the plant growth by reducing the size of leaves. In alkali soil, plant roots remain superficial, bark of stem turns brown or black, green tissues are less developed.

Alkali tolerance in plant. Some plants are resistant to alkali salts. Barley, wheat, oats *sorghum*, sugar-beet, berseem are best suited to grown in alkaline soil. Cotton and grapes are also alkali tolerants. Uppal *et al* (1961) prepared a list of crops that can be grown at various stages of reclamation and can be categorized as high, medium and low salt tolerant crops. *High salt tolerant crops* are *Dhaincha,* paddy, sugar cane in *kharif* and oat, berseem, lucerne, sanji (*Trigonella* spp), and barley in rabi. *Medium salt tolerant crops* to be tried during second stage of reclamation are castor, cotton, jowar, bajra, and maize for *kharif* and mustard and wheat for *rabi*.

Low salt tolerant crops. These are sesamum, moong, urd, arhar, and sannhemp in *kharif* and gram, peas, linseed during *rabi*.

Uppal *et al* also listed *babul, dhak, jhand, khair, chokra, neem, Lasora, Sisham,* siris, *bahera* and *reonjha* as those trees that can be planted on saline alkali soils. The alkali tolerance of plants depends upon :

(*i*) Physiological constitution of cell cytoplasm of the plant.

(*ii*) Length of roots. Shallow roots are more affected by alkalinity than the deeper roots.

(*iii*) Alkali salts reduce and correct the soil acidity and improve the physical conditions of the soils.

(*iv*) Calcium salts provide calcium to the plants.

(*v*) Many alkali salts change toxic elements, such as aluminium and Mn into their harmless compounds.

Reclamation or Saline-Alkali Soils

The excessive accumulation of alkali salts in the soils is injurious for plants growth. It is necessary, therefore, to reduce the percentage of salts to optimum or normal level so that plants may grow luxuriantly in such soils. There are several methods of reclamation which can be grouped as follows :

(*A*) Chemical method in which some chemicals are added to the soil in order to bring the alkalinity to desired level.

(*B*) Mechanical practices such as improving drainage and leaching, mechanical shattering of clay pans, and scrapping.

(*C*) Cultural method (growing salt tolerant plants).

Since fundamental causes in various groups of salty soils are different, their reclaiming techniques are different. Hence, these are discussed separately.

1. Reclamation of Alkali Soils

Alkali soils are best reclaimed by the following methods :

(A) Chemical method. (1) By cationic exchange (replacement of alkali from soil colloids by calcium ions). Application of calcium sulphate (gypsum) in the soil reduces alkalinity to a great extent and makes the soil fertile. The reaction proceeds in the following way :

$$2\text{Na-clay} + CaSO_4 \rightarrow Na_2SO_4 + \text{Calcium-clay}$$
$$Na_2CO_3 + CaSO_4 \rightarrow CaCO_3 + Na_2SO_4$$

Good drainage leaches away Na_2SO_4.

(2) Alkali salt percentage can also be reduced in the soil by the use of acid forming chemical amendments such as sulphur, ferrous sulphate and limestone. Sulphur, when applied to the soil, oxidises and forms sulphuric acid which converts carbonates of sodium and potassium to Na_2SO_4 and K_2SO_4 respectively that may be removed from top soil by drainage water.

The amount of gypsum and sulphur required to reclaim the alkali soils will be different depending upon the degree of alkalinity, drainage and buffering capacity of soils.

The types of reaction which occur when an amendment is applied to an alkali soil are given below :

(1) **With Sulphur**

(*i*) $2S + 3O_2 = 2SO_3$

(*ii*) $SO_3 + H_2O = H_2SO_4$

In the next step, if soil is calcareous—

(*iii*) $H_2SO_4 + CaCO_3 = CaSO_4 + CO_2 + H_2O$

(*iv*) $2\text{Na—Clay} + CaSO_4 = \text{Ca-Clay} + Na_2SO_4$

But if the soil is non-calcareous—

(*iii*) $2Na—Clay + H_2SO_4 = 2H—clay + Na_2SO_4$

(2) **With lime-sulphur**

(*i*) $CaS_5 + 8O_2 + 4H_2O = CaSO_4 + 4H_2SO_4$

Now if the soil is calcareous—

(*ii*) $H_2SO_4 + CaCO_3 = CaSO_4 + CO_2 + H_2O$

(*iii*) $2Na—Clay + CaSO_4 = Ca—Clay + Na_2SO_4$

But if the soil is non-calcareous—

(*ii*) $10Na—Clay + 4H_2SO_4 + CaSO_4 = 8H—Clay + Ca—Clay + 5\ Na_2SO_4$

(3) **With ferrous sulphate**

(*i*) $FeSO_4 + H_2O = H_2SO_4 + FeO$

Now if the soil is calcareous—

(*ii*) $H_2SO_4 + CaCO_3 = CaSO_4 + CO_2 + H_2O$

(*iii*) $2Na—Clay + CaSO_4 = Ca—Clay + Na_2SO_4$

But if the soil is non-calcareous—

(*ii*) $2Na—Clay + H_2SO_4 = 2H—Clay + Na_2SO_4$

(4) **With limestone on non-calcareous soils**

(*i*) $Na—Clay + H_2O = H—Clay + NaOH$

(*ii*) $2H—Clay + 2NaOH + CaCO_3 = Ca—Clay + Na_2CO_3 + 2H_2O$

(5) **With any H-Clay**

(*i*) $2H—Clay + CaCO_3 = Ca—Clay + CO_2 + H_2O$

The use of pyrite (FeS_2) as an amendment is a recent development in the chemical amelioration and reclamation of alkali soils. In presence of moisture and air, pyrite is converted into sulphuric acid which then replaces exchangeable sodium by hydrogen or calcium released from insoluble calcium present in the soil. In addition it is said to correct iron deficiency and lime induced iron chlorosis in alkali soils. It is important to mention that the formation of H_2SO_4 in the soil by the application of pyrite may take place through chemical and microbiological actions. Pyrite is oxidised according to the following equation suggested by Bloomfield (1973).

$FeS_2 + 2Fe^{+3} = 3Fe^{+2} + 2S$ (Chemical)

Sulphur thus formed could be the substrate for *thioxidants* which convert it into H_2SO_4.

$S + 3\ (O) + H_2O = H_2SO_4$

Temple and Kochler (1954) explained the action of *ferroxidans* on the formation of H_2SO_4 as follows :

$FeS + H_2O + 7O = FeSO_4 + H_2SO_4$

$2FeSO_4 + O + H_2SO_4 = Fe_2(SO_4)_3 + H_2O$

$FeSO_4$ formed in the above reaction may be converted into H_2SO_4 by hydrolysis.

$FeSO_4 + H_2O \rightarrow H_2SO_4 + FeO$

In brief, the pyrite is oxidized in soils to ferrous sulphate and sulphuric acid as depicted in the following equation :

$2FeS_2 + 2H_2O + 7O_2 = 2FeSO_4 + 2H_2SO_4$

Both sulphuric acid and ferrous sulphate help in reclamation of calcareous as well as non-calcareous salt affected soils by lowering the pH and solubilising free calcium from calcium carbonate present. The reactions are given below :

In salt affected calcareous soils :

Ia. $CaCO_3 + H_2SO_4 = CaSO_4 + CO_2 + H_2O$

Ib. $2Na\text{—}Clay + CaSO_4 = Ca\text{—}Clay + Na_2SO_4$

II. $FeSO_4 + H_2O \rightarrow FeO + H_2SO_4$

H_2SO_4 formed in reaction II reacts as per equations Ia and Ib

III. H_2SO_4 also neutralizes $NaHCO_3$ and Na_2CO_3 present in these soils.

$2NaHCO_3 + H_2SO_4 \rightarrow Na_2SO_4 + 2H_2O + 2CO_2$

$Na_2CO_3 + H_2SO_4 \rightarrow Na_2SO_4 + H_2O + CO_2$

But if the soil is non-calcareous :

(I) $2Na\text{–}Clay + H_2SO_4 = 2H\text{—}Clay + Na_2SO_4$

(II) $FeSO_4 + H_2O = FeO + H_2SO_4$

H_2SO_4 formed in reaction II acts in similar manner as in reaction I.

(3) *Dhar's method.* In India, Dr. Neel Ratan Dhar (1935) succeeded in reducing the alkalinity and salinity of the soil by the use of molasses (Hindi—raab) and press-mud. For one acre land he recommended the mixture of the following substances :

(*i*) 2 tons of molasses, (*ii*) 1-2 tons of press-mud (a waste product of sugar industry), and (*iii*) 50-100 pounds of P_2O_5 in the form of basic slag.

The molasses is fermented by soil microbes and as a result of fermentation organic acids are produced which lower the alkalinity and increase the availability of phosphates. The press-mud contains Ca which forms calcium salts that reduce the content of exchangeable sodium. Phosphate helps in the microbial fixation of nitrogen into nitrogenous compounds in the soil.

(B) Mechanical methods. The alkali salts are removed by

(1) scraper or by rapidly moving streams of water,

(2) deep ploughing of the land which reduces the alkalinity and makes the soil more permeable.

(3) application of green manures of *Dhaincha,* guar, jantar (*Sesbania aculeata*) has been found most successful in reclamation of alkali and saline soils.

(4) spreading of straw and dried grasses and leaves on the alkaline soil.

(C) Cultural method. Growing of alkali tolerant crops and plants, such as sugar-beet, rice, patsann (*Hibiscus cannabinus*), wild indigo and babul in such soils successfully reduces alkalinity. Rice is commonly the first crop grown on salty lands to be reclaimed. In Punjab, the usual practice of reclamation of salty lands involves growing of paddy after first initial leaching, followed by berseem or senji which has higher water requirement than *Dhaincha* as green manure, which is followed by sugar cane and then wheat or cotton. Introduction of leguminous crops helps in building up of nitrogen supply and opens the soils. *Dhaincha*—paddy—berseem rotation has been found to be the best cropping pattern on mild type of alkali soils in Punjab region. In U.P. also, paddy or *dhaincha*-paddy are the usual crops taken during first stage of reclamation of salty soils. This is followed by berseem or barley in winter. Pulse crops like gram or peas show poor performance.

II. Reclamation of saline soil. Saline soil can be reclaimed by the following methods :

(1) By lowering the water table 5-6 feet below the surface. In slopy area, it can be done by making network of 5-6 feet deep trenches at right angles to the slopes. In course of 2 or 3 successive leaching, harmful salts are removed. A deep ploughing is also helpful in reclamation of saline soil. This also makes the soil loose and thus facilitates the downward movement of salty water in the soil.

(2) Salt tolerant crops, *e.g.*, rice, sugar cane, barley and castor gradually remove salts from the soil.

(3) In case of saline soils which do not contain calcium salts, the addition of $CaSO_4$ (gypsum) is beneficial. Supply of calcium in the soil can indirectly be maintained by addition of organic matters which on decomposition produce CO_2. The CO_2 gas, so produced, combines with insoluble calcium carbonate in moist condition to form soluble calcium bicarbonate. This also reduces alkalinity.

(4) Application of green manure, organic manures, organic residues, acids or acid formers is yet another good way to reduce salinity.

III. Reclamation of saline-alkaline soil. Here the problem of reclamation is two-fold because of

(*a*) heavy accumulation of different types of salts,

(*b*) poor percolation due to the presence of hard clay pan and highly dispersed sodium clay.

Such soil can be reclaimed by :

(*i*) *Mechanical shatterning of clay pans.* This helps in downward movement of water.

(*ii*) *Application of gypsum in the soil.* This is followed by flushing with plenty of water.

(*iii*) *Green manuring* with Dhaincha (*Sesbenia aculeata*).

(*iv*) *Growing of salt tolerant plants, e.g.*, paddy in kharif and oat and barley in rabi seasons are recommended for such soils.

Schoonover (1959) worked on the soils of India and enlisted the following technical requirements for reclamation of saline and alkaline soils :

(1) necessity of good drainage.

(2) Availability of sufficient water to wash the excess salts from the top soils.

(3) Good soil management including land levelling, good bunding for irrigation and recent and advanced agronomic practices.

(4) Protection of soil from erosions.

(5) Good quality of irrigation water.

QUESTIONS

1. Discuss in brief chemical properties of soil.
2. Give a brief account of physical properties of soil.
3. Write short notes on : (*i*) soil pH, (*ii*) ionic exchanges in the soil, (*iii*) Buffer action.
4. Discuss the origin, classification and effects of acids soils and mention the methods of reclamation of acid soils.
5. What are the different types of salty soils and how do they originate? Discuss the various methods of reclamation of alkali soils, saline soils and saline alkaline soils.
6. Write brief description about the following :

   (*a*) Usar (*b*) Cation exchange (*c*) Tyndal phenomenon (*d*) Brownian Movement (*e*) Flocculation.

23

PRINCIPLES OF SOIL CLASSIFICATION AND SOIL SURVEYS AND CHIEF SOIL TYPES OF INDIA

CLASSIFICATION OF SOILS

Soils are of various types as regard their physical, chemical and biological properties. Soil samples collected from distant places and from different climatic regions may show considerable resemblances and differences in their physical, chemical and biological properties. In order to make the study of soils convenient, soils are classified into well defined categories. The classification of soils, in brief, aims mainly at the orderly and systematic arrangement of soils on the basis of resemblances and differences in their physical, chemical and biological properties. As in biological systems plants and animals are classified into classes, orders, suborders, families, etc., the soils are also classified into well defined classificatory units as orders, suborders, great soil groups and subgroups. Lower classificatory units in the soil classification are families, series, types and phases.

Soil orders

These are the largest categories. They are described into the following groups :

(*a*) **Zonal soil.** This is characterised by well differentiated profile. Soil develops on well drained parental rock where environmental factors are little active.

(*b*) **Intrazonal soil.** In this group, soils show well differentiated profiles which may be influenced by climatic and biological factors.

(*c*) **Azonal soil.** It is characterised by the absence of profile. Soil may be in the formation stage and it may be either too immature or may be subjected to extreme environmental influences. Such soils are formed on rocky slopes or on steeps in the form of alluvial deposits, coarse sand deposits, etc.

Suborders of Soils

These are recognised on the basis of factors that influence soil formation and the distinguishing features of soil groups itself, as for example, cold and arid soils are direct products of climatic conditions. Similarly, grassland, transitional land and forest soils are products of combined effects of climates divided into great soil groups.

Soil Series

It consists of a group of soils with similar profile differentiation and similar horizon characteristics, such as colour, thickness, structure, reaction and approximate organic contents. Textures of surface soils are not taken into consideration in the recognition of soil series. Soil series are usually named after town, river or other geographic places near which they are first identified, for example, Miami series which was first recognized in Miami river shades in Ohio (U.S.A.).

Soil Types

Soil types are subdivisions of soil series. They are recognised on the basis of soil texture. The names of soil types are given after series names and the terms describing texture of the surface soils, for example, Indogangetic alluvial soil in which Indogangetic plains are the place of occurrence and alluvium is the texture of surface soil.

Soil Phase

Soil types are sometimes further divided into phase on the basis of slopes, stoniness, degree of erosion and surface characteristics.

In classification of soil, the following descending sequence is followed :

Order
Suborder
Great soil group
Series
Soil type
Soil phase

Some Soil Classifications

Middelburg, H.A., proposed a tentative scheme of classification for tropical and subtropical soils (Reference : Transactions; Formal International Congress of Soil Science, Part 4 : 139-147) The scheme is presented in Table 23.1.

Table 23.1. Soil classification

Order 1	*Suborders* 2	*Great soil groups* 3
Zonal	(1) Humid regions	(1) Podzolic yellow soils with black humic top soils (2) Red yellow podzolic soils

(*Contd.*)

1	2	3
		(3) Non-laterised red soils
		(4) Laterised red soils
		(5) Degraded grey and black clay soils
		(6) Illuvial soils
	(2) Arid region (Desert soils)	(1) Red desert soil
		(2) Dark desert soil
Intrazonal	(1) Calcimorphic Soils (Calcareous soils)	(1) Red soil (developed over lime stone)
		(2) Black soil (developed over lime stone)
		(3) Red soil (developed over marls)
		(4) Black soil (developed over marls)
	(2) Halomorphic	(1) Saline soil
	(3) Hydromorphic soil	(1) Ground water lateritic soil
		(2) Planosols
		(3) Organic soil
Azonal	Lithosols Regosols Alluvial soil	

On the basis of properties of soils, recently a new system of soil classification has been proposed by E. Joseph Larsen (Soil Conservation, 30, No. 5, Dec. 1964). The scheme has now become official Soil classification system for United States Department of Agriculture (USDA) from January 1, 1965. Brief outline of this classification is given in Table 23.2.

Table 23.2. Comprehensive soil classification of U.S.D.A.

Soil order 1	*Important characteristics* 2	*Old equivalent type* 3
1. Entisols	No stratification	Azonal soils
2. Vertisols	Excess of clay	Grummusols
3. Inceptisols	Usually moist, incomplete weathering, no clay, Fe and Al oxide saturated layers absent	Humic clay soils, brown forest soils
4. Aridisols	Low organic matter, more than six months dryness in a year	Desert soils, sierozens, solonchak
5. Mollisols	Almost black, organic upper horizon, high base content	Chestnut, chernozemes, rendzinas, prairie soils, brown forest soils, solonetz
6. Spodosols	Amorphous substances excessively present in middle horizons	Podzol, brown podzols, ground water podzol
7. Alfisols	Brown upper layer, high base content, excess clay in middle layers, usually moist	Brown soil, chernozem, half bog soil, planosols, grey-brown podzols, noncalcic brown soils

(Contd.)

Soil order 1	Important characteristics 2	Old equivalent type 3
8. Ultisols	Normally moist, low base content, clay content high	Reddish yellow podzol, reddish brown laterite
9. Oxisols	Fully weathered, excess of Fe and Al hydroxides, and clay in middle layers	Laterite, latosols
10. Histosols	Excess of organic matter	Bog soils

SOIL SURVEY

Soil survey is the study and mapping of soils in the fields. It is starting point for all soil researches. The following are the main objectives of soil survey :

(1) To describe and classify soils giving uniform system of classification with uniform nomenclature in order to correlate the soils of different area.

(2) To show distribution of different soils in the field (soil mapping).

(3) To provide data for making interpretations as to the adaptability of particular soils for agricultural purpose and also for many other purposes (as in soil management). Soil surveys are of the following three types :

(1) Detailed

(2) Reconnaissance

(3) Detailed reconnaissance

1. Detailed Soil Survey

In this, soil boundaries are plotted accurately on maps on the basis of observations made throughout the surveyed area. In this, geographical distribution of soil is also described. Detailed soil surveys are important in the sense that they provide informations needed for planning land use and management and formulating agricultural research and extension programmes.

2. Reconnaissance Survey

In this, soil boundaries are plotted from the observations made at intervals.

3. Detailed Reconnaissance Survey

In this, a part of surveyed area is plotted on the map by detailed method and remainder by reconnaissance method. In mapping of soils either aerial photographs are taken or good topographic maps are made.

In mapping of cultivated areas, generally a scale of four inches to a mile is used but detailed or special maps are made on scales of six inches, eight inches or twelve inches to a mile. In India, soil surveys are being carried out by central and provincial agencies. Some surveys of limited areas have been conducted for specific objectives, such as fertility surveys, surveys for soil classification, survey from geological point of view, for physicochemical properties of surface sample and surveys for genetic classification. Pre and post-irrigation surveys have also been used for limited areas under command of big irrigation projects to determine the nature, quality and the concentration of soluble salts in different horizons of soil. In India, a few generalized soil maps have been prepared under the auspices of International Society of Soil Science, Geological Survey of India and I.A.R.I. (Indian Agricultural Research Institute), New Delhi. The latest soil map of India is given in Fig. 23.1.

Aerial Photo-interpretation for Soil Surveys

Normally the scales recommended for detailed survey are 1 : 10,000 or 1 : 25,000. In such surveys, the air photos serve as an ideal base for plotting soil boundaries. This is on account of the wealth of pictorial detail available in the air photo, thus rendering orientation and navigation very easy. Normally a limited use of pocket stereoscope is made for delineating boundaries based on relief and other features. The final soil map in such surveys as well as the base photo are prepared on large scale.

Medium and Small Scale Map

Aerial photo-interpretation is of greater utility in this case. The degree of utility increases from medium to small scale. The procedure for photo-interpretation is based mainly on the principle that physiographic units have unique soil pattern. The scale recommended for semi-detailed reconnaissance surveys are 1 : 25,000 to 1 : 1,00,000 and 1 : 2,50,000. In similarity to the techniques used by geologists and foresters, the soil scientists also make use of such elements as relief, slope, geological features vegetation, tone, textures, pattern etc.

Systematic Photo-interpretation

The most favoured method adopted by soil scientists involved delineation of the soil boundaries by air photos which are sub-divisions of physiographic units. In the next stage, they select sample areas that represent all the delineations of the photo-interpretation. These consist of long, narrow areas which cut across as many sub-divisions as possible. Detailed soil observations are taken in each of the delineation of the interpretation. Based upon the number of such observations, the soil of each unit are classified and related to the photo-interpretation unit. Thus soil composition of each unit is established.

With the finding of the sample areas as basic, the remaining aerial photographs are interpreted by the principle of extrapolation of knowledge gained in the sample area studies. It may be mentioned that this "adjusted photo-interpretation" is very often a partial revision of the Pre-field interpretation done in the office.

Final phase comprise a "selective ground check". This achieves the testing of the validity of the adjusted photo-interpretation. The resulting field sheet namely air photos contain the correct soil boundaries.

CHIEF SOIL TYPES OF INDIA

Depending upon the mode of origin, soils can be classified into two main groups :

(*i*) Sedimentary or residual soils

(*ii*) Transported soils

(*i*) **Residual soils.** These soils are formed from the disintegrated rocky material and remain at the same places where they are formed.

(*ii*) **Transported soils.** These are shifted soils and are brought from one place to another by various agencies. They are of different types such as :

(1) *Illuvial soils* :— Soils that move due to gravitational influence.

(2) *Alluvial soils* :— Soil is brought by running water.

(3) *Glacial soils* :— Soil is brought or transported to a particular place by glaciers.

(4) *Aeolian soils* :— Wind moved soils, *e.g.*,

(1) Dune sands of variable fineness,

(2) Volcanic ash,

(3) Loess, silt like material.

Geographically soils of India are divided into three groups :

(*i*) Mature soils of Peninsular India (include red soils, black soils, lateritic soil).

(*ii*) Alluvial soils of Indogangetic plain.

(*iii*) Scanty soils of Himalayas.

Soils of India are classified into the following main groups :

(1) Laterite or Lateritic soils,

(2) Black cotton soils or 'regur',

(3) Red soils including red loam, yellow earths etc.

(4) Alluvial soils including deltaic coastal and inland alluvium,

(5) Alkali soils and saline soils,

(6) Peaty and other organic soils of forests,

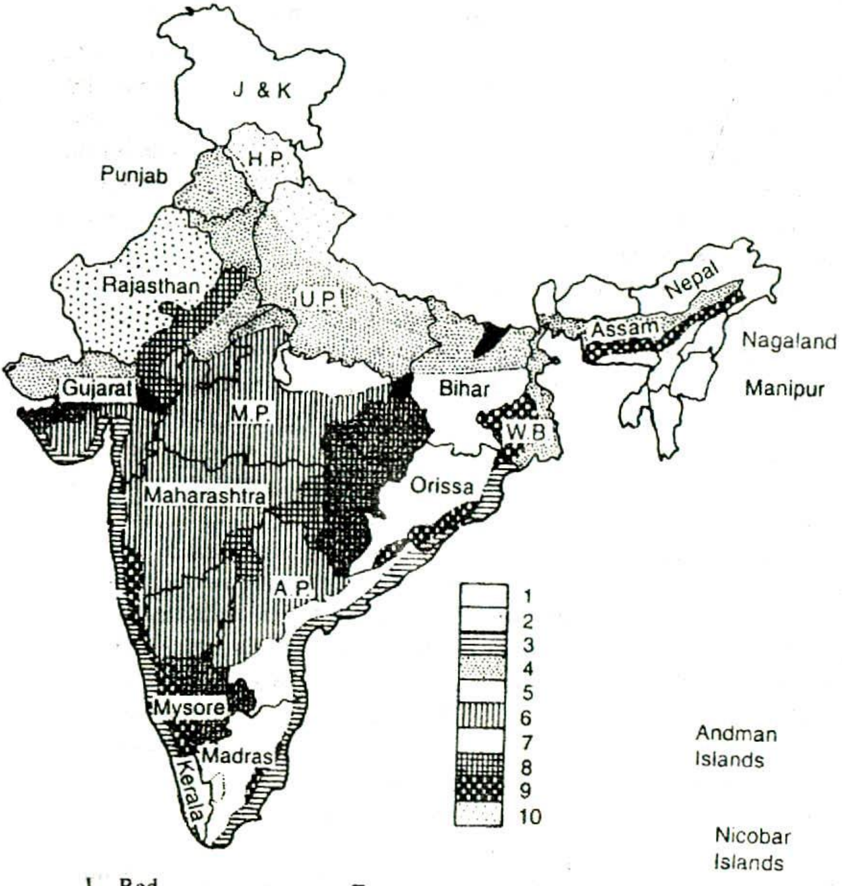
(7) Desert soils or arid soils,

(8) Scanty soils of mountains and hills.

1. Laterite or Lateritic Soil

Laterite is generally reddish or yellowish red in colour which turns black on exposure to sun. This group of soil occupies belts of various widths around the peninsular zone. Such soils occur on the plateau of Malwa, Madhya Pradesh, Central India, Bihar, Orissa, Tamil Nadu, Eastern and Western Ghats, Assam, Bengal, Hyderabad covering a total area of about 2,48,000 square kilometres.

Origin of lateritic soils is still a matter of dispute. According to some soil scientists, the rocks rich in aluminium can produce such soils. Important rocks which produce such soils are *greisze,* sand stone, basaltic rocks and granite. These are residual or sedimentary rocks. Laterites are formed in the region of high rainfall and with alternating wet and dry seasons. When the alkali and silica are leached away the residual compounds rich in aluminium and iron oxides form such soils. Lateritic soils are compact and composed of hydrated oxides of aluminium and iron with small amount of manganese and titanium oxides. When soil is broken and carried to lower levels by water it again becomes cemented into compact indurated honey-combed mass.



1. Red
2. Red and yellow soils — Red soil
3. Coastal alluvial soils
4. Alluvial soil — Alluvial soil
5. Desert sail
6. Shallow black soil
7. Black soil — Black soil
8. Peat soil
9. Laterite soil
10. Mountain or Scanty soil.

Fig. 23.1. Important soil types of India.

Lateritic soil is usually poor in lime, magnesia, nitrogen, phosphate, and potash. Humus is present in abundance in this soil. Base exchange capacity is low. Soil is good for agriculture purpose. Valley soils can produce good crops of rice and sugar cane.

2. Black Cotton Soils or Regur

(*Regada = Black*)

These soils are black in colour and best suited for cotton cultivation. It is locally known as regur in some provinces. Black soils are distributed in Tamil Nadu, South-east Mumbai, Eastern Hyderabad, Maharashtra, Western M.P., parts of Mysore, Andhra Pradesh, Gujarat, Southern districts of Orissa, Bundi and Tonk districts of north Rajasthan, and Bundelkhand region of U.P. covering total area of approximately 5,46,000 square kilometres. The soil is derived from Deccan and Raj Mahal trap rocks and ferruginous gneisses and schists in Chennai.

According to Theofold, the black soil is associated with Deccan trap. Apparently, it is derived by the decomposition of trap rocks and its blackish colour is due to presence of superficial iron in the rocks.

According to Hislop, it is of subaerial origin or it has been formed by the alternate deposition of organic soil and the primary deposition of weathering products of almost all the rocks. According to some other workers, it is produced by assimilation of humus of different argillaceous soils derived from the decomposition of trap rocks.

According to Ramaswamy Sivan, it is formed due to accumulation of black coloured light soil particles. The surface fraction consists of small transparent or semi-transparent grains cemented together by dark coloured matrix which is a mixture of double hydrated ferrous and aluminium silicate.

The colour of regur soil varies from place to place. Regur soils are mostly dark grey to black in colour. The soil is clayey (clay content 40—60%) or loamy. The soil is characterised by high percentage of calcium and magnesium carbonates, iron oxides and alumina. It is sticky in wet condition and contracts on drying resulting in cracks or heavy fissures. The soil is poor in phosphorus and rich in nitrogen and organic matter.

Black soil is very productive. Water retaining capacity is much high. The base exchange capacity is also very high. Among the crops, cotton is the best suited. Other crops suited to black soils are wheat, millet, gram, pea, etc. The soil requires proper irrigational facilities. Black soils have been categorised into different groups which are based upon the depth of their formation. These groups are :

(*i*) **Shallow black soils (Depth ranges from 30 to 50 cms).** These soils are derived from basalts of Deccan trap.

(*ii*) **Medium black soils (Depth ranges from 50 to 120 cms).** They are derived from a variety of rocks including basaltic trap, Dharwar schists, basic granites, gneisses, hornblende and chlorite schists.

(*iii*) **Deep black soil (Depth ranges from 120 to 200 cms).** These are derived from basaltic traps in Deccan plateau and are commonly identified as "regur soils". Distribution of irregular nodules of lime (Kankar) throughout is regular feature of this subgroup of black soil.

3. Red Soil Including Red Loam, and Yellow Earth

These soils are distributed in India mainly in the peninsular regions. The soils occur mainly in M.P., S.E. Mumbai, Mysore, Andhra Pradesh, West Bengal, Assam, Orissa, Chhota Nagpur covering a total area of about 3,50,000 square kilometres. Red soils are also found in some parts of Bihar and in Mirzapur, Hamirpur, Banda and Jhansi districts of U.P. and territory of East Aravali hills in Rajasthan.

The red soils develop from metamorphic sediments of granite gneisses and schists.

The red soils of valleys and plains are dark and fertile. These are composed of silica and aluminium with free quartz or sands. Soils are low in bases and base exchange capacity. These soils are characterised by absence of lime nodules (Kankars). Percentages of humus and other organic nutrients are very poor in red soil. Ferrous oxide is precipitated after evaporation of water from the soil. They are neutral to acidic in their reaction. Soils are generally rich in potash but nitrogen content is low. The red soils are light, friable and porous. Their water-absorbing capacity is very low. Cultivation on such soils depends upon irrigation and rainfall.

4. Alluvial Soils including Deltaic Coastal and Inland Alluvium or Alluvial Soils of Indogangetic Plains and River Basins

It is the largest soil group in India covering a total area of about 15,00,000 square kilometres. Soil is distributed in parts of Rajasthan, Punjab, U.P., Bihar, West Bengal and Orissa.

The soil is best suited for agriculture provided rains occur regularly. Alluvial soils are suitable for cultivation of wheat, rice, cotton, maize, millet, oils, sugar cane, groundnut, vegetables and jute.

The various kinds of alluvial soils have same origin. They are formed from the materials transported by rivers over long period of time. The soils are found in the valleys of Brahmaputra in Assam; Narmada and Tapti rivers in M.P.; Godawari, Krishna and Kaveri in the south; Yamuna, Ganga and their tributaries; Gandak, Gomati, Ghagra and others in U.P.

The soils are immature and can be divided into two geological groups, namely, old and new alluvial sub-divisions. The old alluvial soils, also called 'Bangar', are the soils of uplands and are composed of massive clay or compact silt. These are mixed with sands and kankars or lime nodules and are pale brown or dark in colour. The old alluvial soils are in the process of denudation. The new alluvial soil group, also known as *Khadar,* is sandy with less kankars. It is light in colour.

The soils of dry regions are rich in K, P and alkalies. CaO and FeO are present in varying amounts. In Brahmaputra and Ganga valleys and in Assam plains, the great *Khadar* is low in lime, K, and Mg contents.

In dry regions of India, alluvial soils contain KNO_3 and alkali in excess. Scanty rainfall, high temperature and natural drainage are chief conditions which result in the accumulation of salts in the form of underground obstructions and impervious clay pans which inhibit the leaching. These factors are also responsible for the development of barren land (usar) which is useless for cultivation.

The deltaic soils of Ganga and Brahmaputra are rich in humus and are loamy, and hence they are fertile. But by floods, surface soils are removed and also replaced by fresh silty soils. This induces the soil fertility. Alluvial soils of peninsular regions including those of Narbada and Tapti valleys are very fertile. In eastern ghats, the deltaic soils of Godawari, Krishna and Kaveri rivers are black, humid and sandy. The soils of Orissa are sandy and swampy with fine texture. They are rich in potash.

Soils of Chennai are transported by rivers and consist of alternate layers of sands and silts. The alluvial soils of Gujarat, locally known as *Goradu,* consists of brown clay and *kankars*. Soils are poor in organic content and nitrogen but rich in potash. Such soils are very common in north Gujarat and Ahmedabad.

Yellow and red alluvial soils of M.P. are found in the basin of Mahanadi river covering Balaghat, Durgapur, Raipur and Bilaspur districts. These soils are grouped as *Bhata, Matasi, Dorsa,* and *Kanhar* as these are found at different altitudes.

Bhata is barren soil consisting of red gravels and sands. This is found on uplands.

Matasi is yellow loamy clay soil.

Dorsa is dark coloured clay soil of slopes.

Kanhar is darker and heavier than *Matasi* and *Dorsa* and is deposited in low lying areas.

The alluvial soils of U.P. are divided into the following four regions :

(*a*) Alluvial soil of West and North U.P. (light texture)

(*b*) Alluvial soil of East U.P. (heavy texture)

(*c*) Alluvial soil of Central region consisting of old alluvium which is neither too light nor too heavy, *i.e.,* this is intermediate in texture.

(*d*) Alluvial soil of north-east U.P which contains $CaCO_3$ and other salts and shows alkaline reaction.

5. Alkali and Saline Soils

In these soils, percentage of salts is very high. These soils are distributed in Kanpur, Lucknow, Hardoi, Unnao, Raibareli, Azamgarh and many other districts of U.P., Punjab, West Bengal, Bihar, Orissa, Maharashtra, Tamil Nadu, M.P., A.P., Gujarat and Delhi covering an area of about 70,00,000 hectares. Some soils are salty mainly due to presence of alkali salts in them. They are called alkali soils. In some soils salts other than alkali are present.

These are commonly referred to as saline soils or non-alkali saline soils. Alkali soils are barren and are also called usars in Hindi.

The detailed accounts on saline and alkali soils have already been given in the chemical properties of soils.

6. Peaty and other Organic Soils of Forests

Peaty soils are also known as peaty saline soils. At some places it is called *Kari*. The peaty soils are peculiar blue coloured soils. The waterlogged peaty soils appear in the low lying submerged areas. They are also termed as marshy soils. The peculiar colouration is due to presence of free aluminium and ferrous compounds. Organic matters are accumulated in poorly decomposed conditions on account of the lack of oxidation and poor drainage conditions. Peaty soils are distributed in coastal tracts of Orissa, West Bengal (in Sunderban), North Bihar, Almora in U.P., S.E. Tamil Nadu and Kerala covering an area of about 150 square kilometres. Soils are rich in humus and are acidic. Sometimes water soluble alkali salts are also accumulated in the soils. During monsoon period these soils are flooded with water.

7. Desert Soils or Arid Soils

Desert soils are commonly found in arid and semi-arid zones in India, *e.g.*, North-Western Rajasthan and South Punjab (between Indus river in west and Aravali hills in the east) covering a total area of about 1,42,000 square kilometres. In arid area, rainfall is very poor (upto 62.5 cm) and temperature goes very high during the summers. The soils in these areas are coarse textured regosols and wind moved sand and sand-dunes. Soils are salty and they contain good amount of alkalies and humus content. Their water holding capacity is very low. At several places due to poor rainfall soils become barren but they can be reclaimed to normal conditions provided irrigational facilities are available. The scarcity of water and excessive accumulation of salts make the soils unfit for cultivation. This is why vegetation is very poor, forests are totally absent and desert is spreading progressively eastward in Rajasthan.

Considerable attention is being given these days for checking desertification and for converting the desert land into fertile area. Recently Central Arid Zone Research Institute, Jodhpur, has recommended the stabilization of sand by growing thick vegetation in the area. Central Arid Zone Research Institute has further recommended the cultivation of many indigenous and exotic varieties of trees, grasses and salt tolerant species which grow in desert conditions. Important plants well suited to desert land are *Calligonum polygonoides, Leptadenia, Crotolaria,* some grasses and herbs like *Citrulus, Rhynchosia,* etc. Some trees of deserts are *Prosopis, Acacia, Albizzia lebbeck, Dalburgia sissoo,* etc.

8. Scanty Soils of Hills and Mountains

Mountain or hill soils are distributed in India from north-west to eastern part of the country up to 12,000 feet altitude. At higher altitudes, entire soil surface is covered with snow. Mountain and hill soils are loose and are young or immature. In these soils, A horizon is formed on the surface of rocks directly. Soil particles are loosely aggregated in soft sandy beds. The scanty soils may be of two types :

(1) acidic soils with acidic humus.

(2) basic soils having high base status.

In foothill areas of Kumaon and Garhwal districts, soils are coarse and gravel type mixed with clay and iron salts. In these areas at the altitude of 5,000 to 11,000 feet sal forests and pine forests are common. Important crops grown on such soils are wheat, maize and tea. The soils of hilly regions of Assam and Darjeeling contain high degree of organic matter, nitrogen and minerals. These soils are acidic in reaction.

The Himalayan region of U.P. consists of soils known as Bhabar, Terai and Plains.

The soils of Himachal Pradesh may be divided into low, mid and high hill soils and mountain soils.

The Himalayan soils can further be divided into the following soil groups on the basis of distribution and types of vegetation.

(*i*) **Terai soil.** It is distributed near the foothills of Simla. Soil is clayey in composition and has got high water retaining capacity and humus content. Hence, it is very fertile.

(*ii*) **Tea soils.** These are found in Assam, Dehradun, and Darjeeling. Soils are light loamy with low lime contents. Rainfall is extremely high. Soils are well suited for the plantation of tea.

(*iii*) **Igneous soil.** This soil is derived from granite rocks. It is fertile and good for cultivation purpose.

(*iv*) **Soils of older rocks.** Such soils are found in Nainital. They are rich in clay and iron contents thus suitable for cultivation of certain crops and vegetables.

(*v*) **Lime stone soil.** It occurs near Mussoorie. Rice is the main crop of this hill soil.

Important tree species suitable for planting in different soil groups are given in Table 23.3.

Table 23.3. Important tree species suitable for planting in soils of different climatic regions :

	1 *Species*	2 *Sites*	3 *Soil Groups*	4 *Uses*	5 *Remarks*
A.	**Temperate Region**				
	(*i*) Himalayan				
1.	*Alnus nepalensis* (units)	River banks ravines & newly formed soil	Brown hill soils (on sand stones & shales) Sandy	Timber & fuel	Large tree grown by direct sowing or transplanting
2.	*Alnus nitida*	-do-	-do-	-do-	-do-

(*Contd.*)

	1	2	3	4	5
3.	*Betula* (Bhuj)	Broken marginal land	Brown hill soil	Plywood, furniture etc.	Medium sized tree grown by sowing or trans-planting
4.	*Cedrous deodara*	Understocked, degraded, forest blanks site (Ref-orestation for better quality timber)	Sub-mountain podzolic soil & Brown hill soil	Railway slip-pers general carpentary	Most important durable timber spp.
5.	*Junglans regia*	Village marginal broken land in moist locality	Brown hill soil	Timber fur-niture gum-stock, fruit	Large tree grown by entire transplanting and also by direct sowing
6.	*Populus nigra*	Dry valleys	-do-	Light timber matchwood, fuel ornamental	Grown by branch cuttings
7.	*Prunus cerasoides* (Padam)	Marginal land around villages	-do-	Fuel, fodder, timber wood used for religious ceremonies, good for bee-keeping	Medium tree, grown by entire transplanting and also by branch cutting
8.	*Pinus Wal-lichiana*	Understocked, degraded and forest blanks (for reforestation and enrichment plan-tation)	Brown hill soil and Pedzolic soil	Timber and pulp wood and resign	Very good tim-ber spp. grown by direct sowing and transplanting
9.	*Quercus lamel-losa*	Marginal land	Brown hill deep soils	Agricultural implements, medicinal, tussar silk rearing	Large tree of eastern parts grown by Direct sowing
10.	*Salix alba*	Broken marginal land	Brown hill soils and Pod-solic soils	Cricket bats matchwood, tool handles, fuel & fodder	Large tree grown by branch cutting
11.	**B. Southern Hill tops of Tamil Nadu and Kerala**				
	(*i*) ***Eucalyptus globulus***	Village common land, forest blanks, barren hill slopes	Mixed red and black soil, red sandy soil	Timber, fuel, paper pulp, essen-tial oil	Large tree grown by planting
12.	The wattles *Acacia mearnsi Acacia mela-noxylon Acacia dealbata Acacia decurrens*	Marginal lands & cutup land around village, barren hill slopes	Mixed red & black soil, red sandy soil	Timber fuel, paper pulp, essential oil	Large tree grown by entire transplanting

(Contd.)

1		2	3	4	5
13.	*Pinus petula*	-do-	-do-	Timber, resin pulpwood	Large exotic pine, quick growing grown by entire transplanting
B.	**Subtropical Region** (*i*) Himalayan Foothills and Central Indian hills				
1.	(*ii*) *Albizzia lebbeck*	Open lands & along pathways	Deep black to medium black	Timber fuel & fodder	Grown by direct sowing transplanting & cuttings
2.	*Bauhinia variegata* (Kachnar)	Marginal land & field edges	Brown hill soil	Gum, fodder, flower buds eaten, bark yields dye and medicine	Grown by entire transplanting and direct sowing
3.	*Celtis austrails*	-do-	-do-	Timber, fuel, fodder, sports goods, utensils	Grown by entire transplanting and branch cuttings
4.	*Dalbergia Sissoo*	Marginal land village common, land, road sides and other open denuded areas	Alluvial soils	Timber, furniture plywood fuel fuel & fodder	Grown by entire transplanting, root and shoot cuttings and direct sowing
5.	*Emblica officinalis* (aonla)	Grounds near homesteads and on field edges	Brown hill soil & medium black soil	Fruit, Tanin, timber, fuel, fodder	Grown by transplanting or sowing
6.	*Eucalyptus grendis*	Marginal land		Timber, paper pulp, fuel, medicine	Grown by transplanting or sowing
7.	*Ficus religiosa* (Pipal)	Avenues	Brown hill soil	Religious tree, timber for packing, cases, fuel, fodder	Grown by branch cutting
8.	*Grevillea robusta*	Avenues tea gardens	Brown hill soil, medium black soil	Ornamental, timber, shade tree for tea gardens	Large tree grown by direct sowing
9.	*Morus alba*	Marginal land	Tarai soil, Brown hill soil, alluvial soil	Fruits, edible leaves for silk worm feeding timber, sports goods & fodder	Medium tree grown by entire transplanting, direct sowing or branch cutting
10.	*Pinus roxburghii*	Denuded hill slopes, understocked and degraded forest areas, forest blanks	Brown hill soil	Best timber goods paper pulp	Large tree grown by transplanting and sowing

(*Contd.*)

	1	2	3	4	5
	(*ii*) **East Indian Hills & Parts of Western Ghats**				
1.	*Acrocarpus fraxinifolius*	Marginal lands and village commons, Degraded understocked forest areas	Brown hill soil	Fuel, box-wood, boards, planks	Large tree grown by entire transplanting or by direct sowing
2.	*Ailanthus grandis* (gogal)	Village commons, and road side understocked and degraded forest area	Tarai sandy soil, red loamy soil	Plywood, ornamental	Large tree grown by entire transplanting or direct sowing
3.	*Grewia elastica* (dhaman)	Field edges	Brown hill soil	Fuel, fodder, timber	Medium tree grown by entire transplanting
4.	*Michelia Champaca* (Champa)	Home steads, marginal land, village commons & degraded forest area	Brown hill soil	Decorative timber, fuel, ornamental	-do-
C.	**Tropical Region** (*i*) **High rainfall areas of Western Ghats, W.B. & Assam**				
1.	*Anacardium ocidentub* (Cashew nut)	Mainly in coastal area	Coastal sandy soil, red sandy soil & lateritic soil	Fruit, essential oil	
2.	*Casuarina equisatifolia* (Saru)	Mainly in coastal areas, ideal for fuel wood lots	-do-	Timber, fuel, ornamental	Fast growing spp., grown by entire transplanting
3.	*Dalbergia latifolia* (The rose wood)	Marginal land, field edges, village commons, coffee gardens understocked & degraded forest	Red loamy soil & sub-mountain podzolic soils	Timber, fuel Large tree, grown by entire transplanting	
4.	*Gmelina arborea*	Village commons, forest blanks	Red loamy soil by entire	Medium tree, grown transplanting	
5.	*Syzygium Cumini* (Jamun)	Open lands, village boundaries, & along road side	-do-	-do-	
	(*ii*) **Medium rainfall area of Indo-Gangetic**				

(*Contd.*)

	1	2	3	4	5
	Plains & the Peninsula (Moist tropical)				
1.	*Acacia auriculiformis*	Marginal land and sand dunes	Alluvial soils, sandy soils	Timber, fuel, namental	Medium tree, grown by entire transplanting
2.	*Acacia nilotica* (Babul, Kikar)	Field boundaries, open fields, marginal lands & village commons	Alluvial soils & medium black soil	Timber, fuel, fodder, tanin and gum	-do-
3.	*Ailanthus excelsa*	Marginal land village commons	-do-	Timber, packing cases, fishing Boats & boards, bark, medicinal, fodder	Large tree grown by entire transplanting & seed sowing
4.	*Artocarpus integrifolia* (Kathal)	Gardens & house compounds	Alluvial soils, medium black soil, red loamy soil	Timber, fruits, fodder	Grown by entire transplanting or direct sowing
5.	*Azadirachta indica*	Open lands, house compounds & along roads & paths	Alluvial soil, medium black soil	Timber, bark & seed medicinal, pesticidal, fertilizer, fodder	Large tree grown by entire transplanting & direct sowing
6.	*Cassia Siamea*	House compound, marginal land, santalum album forest (grown as host plant)	Red sandy soil, alluvial soil, medium black soil	Timber, fuel, ornamental	Medium tree grown by entire transplanting & sowing
7.	*Eucalyptus hybrida*	Marginal land, wood lots in private lands, shelter belt, road sides	Medium black soil, alluvial soil	Timber, pulp wood, fuel along	Large tree grown by entire transplanting
8.	*Leucaena leucocephala* (Subabul)	Along hedges, homesteads, marginal lands and village commons	Medium black soil	Timber & Fodder	-do-
9.	*Madhuca latifolia* (Mahua)	Open lands around village boundary & village commons	Medium black soil, alluvial soil	Timber, fuel, fruits, flowers, edible oil	Grown by direct sowing or transplanting
10.	*Tectona grandis* (Sagaun)	Field edges, marginal lands & village commons reforestation areas	Red loamy soil, medium black soil	Timber, railway carriages & wagons, cabinet, furniture etc.	Large tree grown by transplanting of root and shooculting

(Contd.)

1	2	3	4	5
(*iii*) Dry Areas of Rajasthan & Peninsular India (Dry tropical)				
1. *Acacia auriculiformis* 2. *Acacia nilotica* 3. *Ailanthus excelsa* 4. *Albizzia lebbeck* 5. *Azadirachta-indica* 6. *Cassia siamia* 7. *Eucalyptus hybrid* 8. *Leuceina leucocephala* 9. *Madhuca lalifolica* 10. *Prosopis Juliflora*		Trees suitable for afforestation in arid regions, grown by entire transplanting, other details mentioned earlier.		

QUESTIONS

1. Give brief accounts of soil classification and soil surveys.
2. Describe the main soil groups found in India and metion the distribution and properties of each group.
3. Discuss the distribution and properties of (*i*) arid soils, and (*ii*) scanty soils of hills and mountains.
4. What is soil survey? Discuss the methods through which soil is mapped.
5. Write shoot notes on :
   (a) Laterite Soil
   (b) Regur (Black cotton soil)
   (c) Aerial Photo-interpretation for Soil Surveys
   (d) Alkali Soil.

24

SOIL EROSION AND SOIL CONSERVATION

Soil is a store house for organic and inorganic plant nutrients and water. Some soils are rich in organic and humus contents and are more productive while others are less productive and have very poor percentage of organic contents. The soil is subjected to a continuous and simultaneous depletion or loss and addition of soil resources. The various soil components are being removed by living organisms and are returning to the soil by way of death and decay of organisms on it. If the rate of removal or loss of components is greater than the rate of addition, the soil will naturally become less fertile. The various factors which make the soils less fertile are :

(1) Leaching,

(2) Biological agencies, and

(3) Soil erosion.

Leaching is an important factor which makes the soil poor in its resources. In this process, minerals and organic substances are removed from the top layer of soil by rain water.

Biological agencies are also active in causing loss of resources from the soil. Cultivation of crops regularly year after year makes the soil less productive. In cultivation there are little chances for the compensation of lost nutrients of the soil by way of death and decay of the vegetation which grows on it. Leguminous plants, however, compensate the loss of nitrogenous compounds because bacteria inhabiting in their root nodules fix considerable amount of free atmospheric nitrogen into its compounds, such as nitrites, nitrates, ammonia and so on.

SOIL EROSION

The word 'erosion' literally means *to wearing away.* In soil erosion, fertile soil surfaces are detached and removed from their original places and are deposited at some other places. According to Fox (1950), "the term soil erosion covers a wide range of physical and chemical actions, such as removal of soluble matters, chemical changes, disintegration by frost or by rapid changes of temperature, attrition by dust charged wind, scouring by silt laden currents, alternate impact and succession by storm waves, landslides and so on". Thus, soil erosion is the removal of soil from its upper part.

There are two main types of erosions, namely (1) *normal erosion* and (2) *accelerated erosion*.

1. Normal Erosion

When the top soils are gradually removed under normal conditions of physical, biotic and hydrological equilibria it is called **normal erosion**. Sometimes, it is also called **geologic erosion**. It is very slow process in which complete equilibrium is maintained between soil removing and soil forming processes. The normal erosion tends to produce wavy or undulating land surface with alternating ridges and depressions. This is accomplished chiefly by means of slow migration of soil particles from soil surface in successive rains. In arid region, wind during the long dry season is an important factor for normal erosion.

2. Accelerated Soil Erosion

When the removal of soil does not keep harmony with the soil formation and it is much faster than the latter, it is called **accelerated soil erosion**.

AGENCIES CAUSING SOIL EROSION

Soil erosion is caused by the following two agencies :

(A) Climatic.

(B) Biotic.

A. Climatic Agencies Causing Erosion of Soil

These are water and wind.

1. **Water.** Water is an important factor in soil erosion. Snow and melting ice also remove the top soil to considerable extents. Soil is directly affected by heavy rainfall, rapidly running water and by wave action.

Erosion caused by water may be of the following types :

(*i*) **Sheet erosion.** Uniform removal of a thin layer of soil from large area is called sheet erosion. It is affected by run-off effect of rain water.

(*ii*) **Rill erosion.** In this type of soil erosion, heavy rainfall and rapidly running water produce finger-shaped grooves or rills over the entire field (Fig. 24.1).

(*iii*) **Gully erosion.** It is more prominent type of erosion in which heavy rainfall, rapidly running water and transporting water may result in deeper cavities or grooves called gullies.

Gullies may be 'V' shaped or 'U' shaped. Gullies cut the fields into small fragments and make them uncultivable (Fig. 24.2). Continuous flow of water through gullies further deepens the grooves and may ultimately result in ravines. Ravines are 15 to 30 m deep and with steep vertical sides.

(*iv*) **Landslides or slip erosion.** This type of soil erosion is caused by heavy rainfall and it occurs in slopy lands, such as mountains and hills. In this type of erosion when the running water percolates through the crevices of rocks great masses of soils and loose rocks lying on the steep slopes slip downward.

Fig. 24.1. Rill formation.

Fig. 24.2. Gullies.

(*v*) **Stream bank erosion.** On the banks of swollen rivers it is most active. During the rainy season when fast running water streams take turn in some other directions, they cut the soil and make caves in the banks. As a result of this, quite often large masses of soils become detached and washed away from the banks and are deposited at places in course of streams.

2. **Wind erosion.** Removal of soil by wind is called wind erosion. Stormy winds carry the soil particles to distant places and sometimes form sand-dunes. Wind currents usually remove the top soil which is fertile and full of humus and minerals. Wind causes the following three types of soil movements, viz., (*i*) saltation; (*ii*) suspension; and (*iii*) surface creep.

(*i*) **Saltation.** Under the influence of direct pressure of stormy wind small soil particles of 1 to 1.5 mm diameters move up from the soil surface, generally in vertical direction. Major part of wind carried soil is moved in a series of bounces, called saltation.

(*ii*) **Suspension.** In this, fine soil particles (diameter less than 1 mm) are suspended in air. These suspended particles are kicked up when particles of saltation strike on the soil. The soil particles are deposited at distant places.

(*iii*) **Surface creep.** In this, there are larger particles ranging from 5 to 10 mm in diameter. Because they are too heavy to move in saltation, they creep on surface of soil.

B. Biotic Agencies Causing Soil Erosion

Excessive grazing, deforestation, undesirable forest biota, and mechanical practices by man are important factors which cause soil erosion.

Deforestation is the commonest factor which is responsible for soil erosion. Ruthless felling has exposed soils to direct effects of rain, snow and drought and has set in soil deterioration of the gully and sheet types over extensive areas in Kashmir (J.S. Singh and M.K. Wali, 1961).

Grazing is yet another destructive biological factor for the soil erosion. Cattle and sheep during the summer graze the forest vegetation and make the soil bare. Whyte (1957) while commenting on the problem of soil erosion of Kashmir Himalayas, mentioned, "control of fluctuating grazing was made the responsibility of forest department in 1939 but this appears to have little effect and the problem is as acute as ever"

Some other Causes of Soil Erosion

1. Uneven distribution of rainfall.

2. **Shifting cultivations.** Shifting cultivations are usually noted in the mountains which are geographically young and degraded into soil easily and the whole of the land is covered with a thick mantle of tropical forest vegetation. The removal of the forest or bush cover by felling and burning for shifting cultivation with resulting exposure of the bare soil to rains and sun, causes enormous soil losses especially on hill slopes. Both surface layer of the soil and large quantity of plant nutrients are washed away under the influence of intense rainfall. Shifting cultivation is a major problem in the hilly areas of Assam, Manipur, Tripura, Arunachal Pradesh, Nagaland and Orissa. It is reported that about 207,267 hectares in Assam, 46,963 hectares in Tripura, 21,862 hectares in Manipur and 308,502 hectares in Orissa are under shifting cultivation. Shifting cultivation is practised sporadically in Andhra Pradesh, Madhya Pradesh, Maharashtra, Kerala,

Karnataka and Tamil Nadu also. The process of shifting the area of cultivation is called by various names : *Jhum* or *Jum* in Assam, *podu, dahi* or *kamana* in Orissa, *penda* in Madhya Pradesh and so on. In English it is described as slash, burn or *swidden* or simply as *shifting cultivation*.

3. Fields on steep slopes are cultivated and top soil is washed away by rains. The loss of soil is too much and the fields become uncultivable.

4. Forest fires are responsible for burning down forest trees on huge scale.

5. Faulty agricultural methods—Sometimes farmers do not care towards levelling and terracing of their upland fields. Rainfall washes away the top soil and results in erosion.

6. Over-grazing by cattle causes removal of vegetational cover of the soil.

Factors Affecting Soil Erosion

There are several factors which affect the soil erosion at a particular area. These factors are given below :

1. Nature of soil.
2. Distribution, nature and amount of precipitation.
3. General slope of the soil.
4. Vegetational cover.
5. Soil management.
6. Land use practices.

Consequences of Soil Erosion

There are several serious effects of soil erosion which are as follows :

1. Due to uprooting of trees shortage of timber and fuel results.
2. Loss of soil stability and fertility.
3. Shortage of fodder.
4. Destruction of land in plains.
5. Formation of sand dunes.
6. Greater frequency of floods and threat to communication channels.
7. Silting of river bed, lakes and dams.
8. Higher temperature and lower rainfall.

SOIL CONSERVATION

The main aims of soil conservation are as follows :

(1) To protect the soil from erosion.

(2) To maintain the productive capacity of the soil.

Soil erosion is a natural phenomenon by which soil is removed from rocks. Accelerated erosion due to misuse of resources of land, water and soil is today one of the most difficult and pressing problems before man. Both engineering and biological methods have been used to check the soil erosion but it is still without a plausible check. Vast tracts of fertile land are rendered useless on account of industrialisation and development. Erosion has posed a serious challenge in the United States, South and North Africa, Japan, Mesopotamia, North China, India, Pakistan and in a number of other countries. In India, we are aware of advancing deserts of Rajasthan and erosional losses, floods etc., in other parts of the country. The problem has received the attention of forest ecologists, soil scientists and engineers only recently.

Practical methods of soil conservation are broadly grouped as follows :

(A) Biological measures,

(B) Mechanical or Engineering methods.

A. Biological Measures

The following are the biological methods which are helpful in checking the soil erosion :

1. Agronomic practices;
2. Agrostological methods;
3. Dry farming practices.

1. **Agronomic practices.** The important agricultural practices which contribute to the conservation and productivity of cultivated lands are referred to as conservational farmings or advanced agronomical methods. These are listed as under :

(*i*) Contour farming :

(*ii*) Tillage and keeping the land fallow

(*iii*) Crop rotation, sowing of leguminous crops and mixed cropping

(*iv*) Mulching

(*v*) Strip cropping

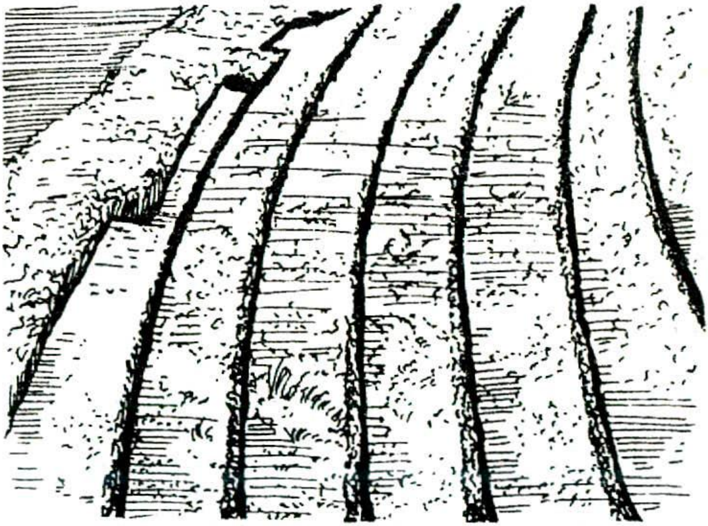


Fig. 24.3. Contour strip cropping for controlling soil erosion and strip cropping for controlling soil and moisture losses on uniform slopes.

(*i*) **Contour farming.** It is practised in the hilly regions or on the slopes. In such areas, the rain water is absorbed in very little amount because of its quick downward movement on the slopes. If these slopy areas are ploughed up and down the slope, the heavy rainfall may cause gully development. Taking into consideration this defect, the slopy areas are ploughed and seeded against the slope, *i.e.*, in circular furrows around the slopes. This process is termed as *contour farming*. The contours (circular or peripheral furrows) catch the downwardly moving water until it is absorbed in the soil. The ridges reduce the flow of water. The circular rows of plants across the slopes check the soil erosion. Thus, contour farming reduces run off, saves more water for crops, reduces soil erosion and increases the yield of crops (Fig. 24.3).

(*ii*) **Tillage operation and keeping the land fallow.** There are several diverse opinions as to whether deep ploughing gives good result or shallow ploughing. A number of researches support the view that in dry areas, shallow ploughing gives comparatively good crop yields. Shallow ploughing removes the weeds and enables the soil to absorb water. Deep ploughing often leads to soil erosion but in the areas where rainfall is sufficiently high, deep ploughing (upto 15—30 cm deep) is effective in removing weeds and increasing crops yields.

If the land is left uncultivated and sheep, goats and other cattle are allowed to graze and sit over it for some time, the soil becomes fertile. Though this practice is useful yet it is not possible in the countries like India where exists severe problem of cereals because of thick human population.

(*iii*) **Crop rotation sowing of legumes and mixed cropping.** When the same crop is grown in the field every year, the soil becomes depleted in certain minerals. The soil loses its fertility even after the use of fertilizers and ultimately erosion sets in. Rotation of crops is an important method for checking erosion and maintaining productivity of soil. After 2 years crop should be changed in the fields. A good rotation should include a cultivated row crop, densely planted small grasses and a spreading legume or a legume and grass mixture. Selection of crops for rotation should be made taking into consideration the climate, economic condition, soil types, soil texture, slopes, nature of erosion, etc. Deep-rooted crops should be rotated by shallow-rooted crops. Deep-rooted crops absorb nutrients from the deeper strata of the soil. Thus, the minerals of top soil remain stored for future use by shallow-rooted plants. When the deep rooted crops die, they add humus in the soil which is future storehouse of plant nutrients. Growing of *Phaseolus mungo* (Mung in Hindi) in Bihar, *P. radiatus* (Urad in Hindi) and *P. mungo* in U.P. in kharif season before wheat cropping improves soil fertility as well as yields of cereal crops.

In Vidarbha (Maharashtra), the rotation of cotton, jowar, and groundnut has been proved useful in maintaining the productivity of the soil.

Leguminous plants play very active part in increasing the nitrogenous contents in the soil because of the fact that bacteria inhabiting their root nodules fix the free nitrogen of atmosphere into nitrogenous compounds such as nitrates, nitrites, ammonium salts, amino acids and proteins. The nitrogenous compounds return to the soil by way of death and decay of underground nodulated roots of these legumes. Thus, growing of leguminous plants is one of the important methods for maintaining soil fertility.

The rotation of crop serves the following purposes :

(*a*) Enriches the soil,

(*b*) Improves the soil texture,

(*c*) Improves water holding capacity of the soil,

(*d*) Improves crop production,

(*e*) Controls the recurrence of weeds and diseases.

Mixed cropping is another important method for increasing productivity of the soil. In this practice, one main crop and one or two subsidiary crops are grown together on the same land, as for example, growing of Arhar, Urad, Til along with millet. This practice checks the soil erosion and avoids the risk of crop failure. If one crop fails due to diseases or any other factor, the others remain ensured.

(*iv*) **Mulching.** It means covering the soil surface by straw, leaves or grasses. Mulches of different kinds check soil erosion, increase soil fertility and also minimise moisture evaporation from the top soils. Various types of surface tillers and crop residues are helpful in obstructing the movement of soil particles.

(*v*) **Strip cropping.** It is an important method which employs all the advanced cultivation practices such as contour farming, proper tillage, crop rotation, mulching, cover cropping, etc. Strip cropping is very effective and practical means for controlling soil erosion. It is of the following types :

(*a*) Contour strip cropping,

(*b*) Field strip cropping,

(*c*) Wind strip cropping, and

(*d*) Permanent or temporary buffer strip cropping.

(*a*) ***Contour strip cropping.*** It is special type of contour farming in which soil exposing crops are grown on the strips across the slope on the level of contour and in the following season soil protecting crops are sown on the strips on which soil exposing crops were grown in the previous season and again in place of these soil protecting crops some soil exposing crops are sown. This practice is useful because it checks the fast flow of run off water, increases the infiltration of water in the soil and prevents soil erosion.

(*b*) ***Field strip cropping.*** It is a farming in more or less parallel strips across fairly uniform slopes but not on the exact contour.

(c) *Wind strip cropping.* In this method tall growing plants (*e.g.* Bajra, jowar, etc.) alternating with the short growing crops, such as 'arhar', 'urad' are sown in long straight strips right across the direction of wind regardless of contour.

(d) *Permanent or temporary buffer strip cropping.* This is a special type of contour strip cropping in which care is taken to check the soil erosion. In this, crop rotation practice is not applied and on the strip perennial legumes and grasses are planted on permanent or temporary basis.

2. **Agrostological methods.** The following are the important agrostological practices that check soil erosion :

(i) Cultivation of grasses (ley farming).
(ii) Retiring the land.
(iii) Afforestation and Reforestation.
(iv) Checking of overgrazing.

(i) **Cultivation of grasses (Ley farming).** This method consists in growing grasses in rotation with agricultural crops. This practice improves the fertility of soil and helps in binding of the soil, thus preventing the soil erosion. This practice is recommended for Nilgiri and similar places which are subjected to very severe soil erosion.

(ii) **Retiring the land.** Areas subjected to heavy soil erosion should necessarily be put under thick cover of grasses. Under favourable climatic conditions grazing should also be allowed for short periods. Researches conducted at Solapur in Maharashtra have shown that grasses have good soil binding capacity. In Nilgiri hills, Tamil Nadu doobgrass (*Cynodon dactylon*), *Dectylis glomerata, Eragrostic amabitis* and *E. cerbula* are proved most effective in binding the soil and in stabilizing the reserves of the bench terrace and sodding water channels.

(iii) **Afforestation and reforestation.** *Afforestation* means growing forests at places where there were no forests before owing to lack of seed trees or due to adverse factors such as unstable soil, aridity, or swampiness. *Reforestation* means replanting of forests at places where they have been destroyed by uncontrolled forest fires, excessive felling and lopping. Plantation of trees in short blocks is known as a *wind break* and extensive plantation of trees is called *shelter belts.* Wind break and shelter belt type of plantations are being done in some regions of Uttar Pradesh where desert is encroaching. The plantation is usually done in two or three belts. Small sized plants are planted on windward side and tall trees on leeward side. These reduce the wind velocity considerably and also check the transport of lifted sand and soil particles. Afforestation is the best means to check the soil erosion. Lutz and Chandler (1946) cited the following points in support of the vegetational check of erosion :

(a) Infiltration of water is favoured due to high porosity of soil under vegetation. Percolation of water helps in preserving the soil moisture which accelerates further growth of the vegetation.

(*b*) Surface accumulation of organic matter increases the water holding capacity of soil.

(*c*) Root systems of the vegetation hold the soil mechanically and provide stability to the soil.

(*d*) It gives protection to soil against wind. The forest vegetation shields the soil from direct effects of drought, snow and rain.

Destruction of vegetational cover usually results in accelerated erosion, flooding and silting. The past victims of soil erosion tell the story of drastic deforestation (destruction of forests). In our country deforestation has been recognised as the most potent and powerful cause of soil erosion and efforts are being made to check it.

State forest departments in India have already undertaken this practice, although in very restricted areas and have met with good success. Forest departments in Baramulla, Gulmarg, and Banihal in Kashmir afford good examples. In Baramulla region, mixed planting of *Pinus, Cedrus* and other species has been done. The plants are thriving well and have checked erosional losses of soil to a good degree. In the area where plantations have not been made the soil is actively eroding. Another example is afforded by Sankaracharya Hills in the vicinity of Srinagar which was heavily eroded in the past. It has now been improved by afforestation. Forest department took up the planting of conifer species like *Pinus wallichiana P. roxburghii, P. sylvestris, P. insignis, P. gerardiana, Cupressus arizonica, C. sempervirens, Juniperous* species, *Cedrus deodara,* and broad leaved species, like *Aesculus indica, Fraxinus, Juglans regia.* These plants check erosion to some extent.

The efforts are being made to check the spread of Rajasthan desert towards Uttar Pradesh and the plantation is being done in that region in two or three belts. Small-sized plants are planted on the windward side and tall trees on the leeward side. On the windward side *Leptadenia spartium, Cenchrus ciliaris, Balanites roxburghii, Calligonum polygonoides, Sachharum munja, Kochia indica,* etc. are commonly planted and on leeward side *Acacia senegal, A. leucophloea, Ricinus communis, Prosopis spicigera, P. juliflora, Parkinsonia,* etc. are being grown.

The problem of afforestation is the selection of suitable species for a given area. This can be accomplished by dividing the whole area into different catchment zones according to climate, soil and biota. Suitable species for each zone should be selected from those already growing there. Knowledge of successional trends of the vegetation will be of great help in afforestation practices. Lutz and Chandler (1946) have stated that climax vegetation in any region is most effective agent to prevent accelerated erosion. Afforestation also checks the erosion of unsuitable rocks probably by checking the leakage of water (Puri 1951).

Along with afforestation and reforestation, forest management practices should also be strictly enforced which require

(*a*) Control on forest fires,

(*b*) Extension of forest areas,

(*c*) Checking extensive felling and lopping,

(*d*) Restricted grazing in forest areas, and

(*e*) Formation of reserve forests.

(*iv*) **Checking of overgrazing.** Since grazing in all the areas subjected to soil erosion cannot be completely stopped, a system of restricted and rotational grazing may be helpful in checking soil erosion to some extent. The area open to grazing for sometimes should be closed for the following years to facilitate regeneration of forest and to maintain thick ground vegetation.

3. **Dry farming practices.** Dry farming is useful in those areas where rainfall is very low, uncertain and uneven in distribution. In such areas maximum conservation of water in the soil and reduction of soil erosion are the two main problems.

The improved dry farming practice developed as result of researches carried out in India is an integrated rational system of cultivation of purely rainfed and drought enduring crops in dry areas. This practice consists in bunding, both contour and compartmental, and all other advanced agricultural practices to conserve maximum amount of rain water in the soil so as to make it available for crops during their growth period. In this, usually early maturing crop varieties are selected for cultivation. Important dry farming regions of India are :

(1) Punjab,

(2) Rajasthan,

(3) South-west part of U.P., north-west part of M.P., and

(4) Some parts of peninsular India including dry tracts of Mumbai, Mysore, Andhra Pradesh and Tamil Nadu.

Dry farming methods and selection of crops vary in different regions as per requirement of local conditions.

B. Mechanical Methods

It is only in recent years that soil erosion problems have received attention of engineers. The mechanical practices of soil conservation include various engineering techniques and structures which are adopted to supplement the biological methods when the latter alone are not sufficiently effective. These practices aim at the following objectives :

1. To reduce the velocity of run-off water and to retain it for long period so as to allow maximum water to be absorbed and held in the soil.

2. To divide a long slope into several small parts so as to reduce the velocity of run-off water to the minimum, and

3. Protection against erosion by wind and water.

Mechanical methods for soil conservation are :

(*i*) Basin leaching,
(*ii*) Pan breaking,
(*iii*) Subsoiling,
(*iv*) Contour terracing,
(*v*) Contour trenching,
(*vi*) Terrace outlets,
(*vii*) Gully control,
(*viii*) Digging of ponds and reservoirs, and
(*ix*) Stream bank protection.

(*i*) **Basin leaching.** In this method, a number of small basins (water reservoirs) are made along the contour by means of an implement called basin blister. Basins collect and retain rain water for long period and also catch and stabilize downwardly moving soils of the slopes.

(*ii*) **Pan breaking.** In some areas, soils become impervious to water and are less productive because of formation of hard sheet of clay a few feet below the surface. Such areas can be made productive and water permeable by breaking hard clay pans by means of pan breaker on contour at a distance of about 5 feet. By pan breaking, drainage and percolation of rain water is improved and soil is saved from residual run-off and erosion.

(*iii*) **Sub-soiling.** In this method hard subsoil is broken deeply by means of an implement called subsoiler without involving the conservation of soil. This process promotes absorption of rain water in the soil and makes the soil more loose and fit to allow luxuriant growth of vegetation.

(*iv*) **Contour terracing.** Sometimes drainage channels or properly spaced ridges or soil mounds are formed along the contour to check soil erosion. These are called terraces. Terracing may be of the following four types :

(*a*) *Channel terracing.* This is concerned with making of wide but shallow channels on contours at suitable distance. In this process, the excavated soil is deposited along the lower edge of channel in the form of low ridge.

(*b*) *Narrow based ridge terracing.* This process is commonly called bunding. In this a number of narrow based ridges or bunds are constructed at distance of 1 m to 2 m across the slope along the contour.

(*c*) *Broad-based ridge terracing.* In this, wide but low bunds are made on contour by excavating soils from both the sides of ridge.

(*b*) *Bench terracing.* This method involves making of wide steplike platforms, the so called bench terraces, having suitable drops along contours (Fig. 24.4). Along the outer edges of bench terraces bunds of about one foot height are raised to check the downward flow of rain water and also

Fig. 24.4. Bench terraces on a steep slope.

soil erosion. The vertical drops may vary from 1 m to 2 m. Bench terracing is very costly process and so it should be applied in the area of land scarcity for growing money crops.

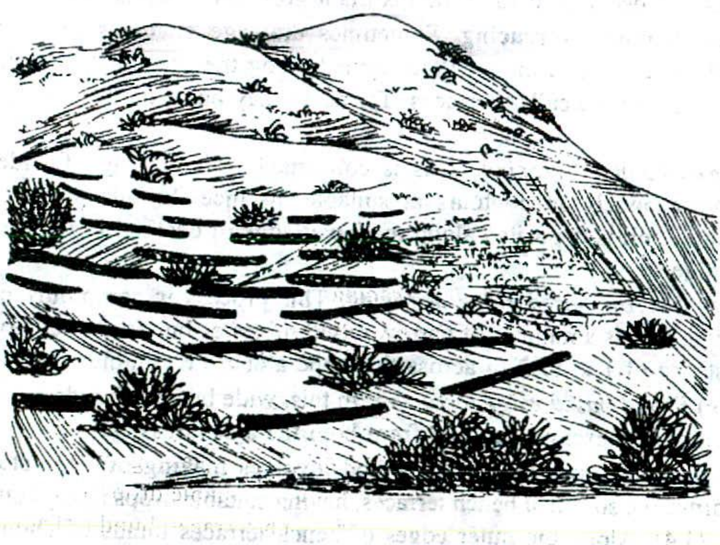


Fig. 24.5. Contour trenching on a slopy land.

(*v*) **Contour Trenching.** This method involves making a series of deep pits (2′ × 1′) or trenches across the slope at convenient distance (Fig. 24.5). The soil excavated from the trenches is deposited along the lower edge in the form of bund. On the ridges tree seeds are sown (Fig. 24.5).

(*vi*) **Terrace outlet.** In order to reduce soil erosion and to remove excess of rain water safely from the contour terraces pipe outlets are used or channels are made which are thickly covered by grasses.

(*vii*) **Gully and ravine control.** Gully formation can be checked by the following methods :

(*a*) By making perimeter bunds around gullies to check flow of water through it.

(*b*) By growing suitable soil-binding vegetation on the gullies to check soil erosion.

(*c*) Diversion trenches should be made around gullies.

(*viii*) **Ponds and reservoirs.** Small ponds and water reservoirs or dams (Fig. 24.6) should also be made at suitable places for irrigation and some other purposes. Various types of dams have been devised to arrest and plug gullies and thus to check soil erosion. These dams may be (*a*) brush dams (*b*) earth dams, (*c*) concrete dams or (*d*) woven wire dams.

(*ix*) **Stream bank protection.** Banks of ravines and rivers with high vertical drops are subjected to heavy soil erosion. The bank erosions can be checked by making the drop slopy and by growing vegetation on the slopes or by constructing stone or concrete pitch.

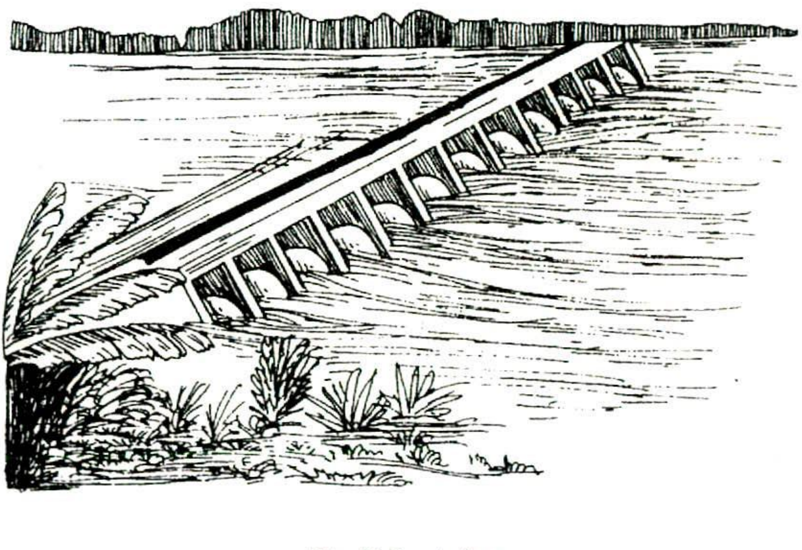


Fig. 24.6. A dam.

The problem is very complicated and is receiving attention of scientists and engineers. The erosion of Siwaliks has been studied by Glover and

Hamilton (1935) and Gorrie (1951) and various methods have been suggested for soil conservation. Recently Puri (1949, 1954) analysed the problems from different angles and suggested that soil should be kept under tree vegetation in order to check erosional losses and landslides. The Central Arid Zone Research Institute in collaboration with UNESCO is attempting to check erosional losses in Rajasthan. The Indian Council of Agricultural Research (ICAR), especially the Waste Land Reclamation Committee is giving attention to the problem in collaboration with some State forest and agriculture departments. Central Soil Conservation Board has established 9 research centres, one each at Dehradun, Kota, Ootacamund, Bellary, Vasad, Agra, Chandigarh, Jodhpur and Chhatra to organise, co-ordinate and initiate research on soil conservation to meet the paucity of trained personnels for manning soil conservation schemes and to assist States and River valley projects technically.

QUESTIONS

1. Comment upon the following statements :
   (*i*) Presence of micro-organisms in soils is harmful to soil fertility.
   (*ii*) Acid soils are better for plant growth than alkali soils.
   (*iii*) Base exchange causes soil erosion.
2. Define Soil erosion. Give an account of various factors causing erosion of soil.
3. What are the aims of soil conservation? Discuss in brief the various biological and mechanical methods of soil conservation.
4. Write short notes on :
   (*i*) Crop rotation.
   (*ii*) Afforestation and Reforestation.
   (*iii*) Contour farming.

25

SOIL FERTILITY—ITS MEANING, CAUSES AND MAINTENANCE

The soil is a natural medium for plant growth and it supplies nutrients to plants. Some soils are productive and they support luxuriant growth of plants with very little human effort whereas others may be unproductive which support almost no useful plant life regardless of every human effort. In order for soil to be productive, it must (*i*) be easily tillable and fertile, (*ii*) contain all essential elements in the forms readily available to plants in sufficient amount, and (*iii*) physically good to support plants and contain just the right amount of water and air for proper root growth. The soil must supply these essentials every day in the life of the plant.

Soil fertility and soil productivity appear to be synonymous but in soil science these two terms bear different meanings. Soil fertility may be defined as the ability of soil to provide all essential plant nutrients in available forms and in a suitable balance whereas soil productivity is the resultant of several factors such as soil fertility, good soil management practices, availability of water supply and suitable climate. A soil can be highly fertile, *i.e.*, it has ready supply of nutrients in available form, yet it may not be highly productive. Water-logged soils may be highly fertile but may not produce good crop because of the unfavourable physical conditions. A fertile soil may be highly saline or alkaline which may not be good for agriculture. Sandy soil may be poor in fertility but with the use of fertilizers and water it may be made productive. Soil fertility thus denotes the status of plant nutrients in the soil whereas the soil productivity is the resultant of various factors influencing crop production.

In fact, there is no standard for either fertility or productivity because both depend upon the crops to be grown. Soil that is productive for potatoes may not necessarily be productive for certain other crops.

PLANT NUTRIENTS

Of the 90 or so chemical elements forming the earth's crust, 16 are known to be essential for plant growth and reproduction. Seven elements needed in good quantity (*macro nutrients*) are : hydrogen, oxygen, nitrogen and carbon from air and water and phosphorus, potassium and calcium from mineral particles in the soil. The other 9 elements needed only in small amount (micronutrients) are : magnesium, sulphur, boron, copper, iron, manganese, zinc, molybdenum and chlorine.

Jacob and Uexkull have listed cobalt and sodium as essential elements for plant growth. With the exception of hydrogen, carbon, and oxygen all other inorganic plant requirements are obtained directly or indirectly from the soil minerals, hence these elements are called mineral nutrients. Strictly speaking, nitrogen is not a mineral element but it has been included in the list because it can also be obtained by plants from soil.

The mineral elements are taken by plants from soils mostly in the form of ions. Plants obtain nutrients from the following four devices :

(*i*) from the soil solutions through roots,

(*ii*) from exchangeable ions on the surface of clay and humus particles through roots,

(*iii*) from readily decomposable minerals, and

(*iv*) through the leaves.

The essentiality of an element is proved by the following criteria :

(*a*) The element may be considered essential if its exclusion from the nutrient medium inhibits or drastically reduces the growth and reproduction of plant.

(*b*) Acute deficiency of the element produces certain well defined disease symptoms which are not produced by the deficiency of any other element.

(*c*) Deficiency disease symptoms will disappear if the particular element is supplied before the living system has been damaged beyond repairs.

The capacity of soil to supply the essential elements is a fundamental edaphological problem. In natural habitat the plant matter is returned to ground through decay and unless there is extensive leaching and percolation the inorganic nutrients become available again for new growth. Many farm crops are removed from ground in *toto* and the supply of essential elements thereby becomes depleted. To replace these elements taken away from ground by crops, the manures or fertilizers are added. Unless it is done the crop will suffer from deficiencies in the essential elements. Deficiencies become reflected in the growth of plants in several ways; some may cause a reduction in yield as a result of poor plant growth and some may delay maturation of crop, a function that may be very vital to crop yield in the places where the growing season is short. The symptoms of mineral deficiencies may be dwarf, spotted, distorted, curled or wilted leaves or rotting of the centre of fruits. Different mineral nutrients have certain specific deficiency symptoms. The physiological roles or various mineral elements in the life of plants and deficiency symptoms caused by them can be found in any plant physiology book.

SOIL FERTILITY FACTORS

Several factors are know to govern the fertility of soil. Some of the important factors are discussed below :

1. As a result of cropping, a large amount of organic matter and soil minerals are removed and if the normal cycling of mineral elements is retarded, loss in soil fertility may result.

2. Besides cropping, soil erosion also causes tremendous loss of plant nutrients from the top soil.

3. Conversion of organic forms of nitrogen locked in humus into ammonia gas and nitrogen gas and leaching out of soluble nitrates and nitrites from surface soil greatly affect the fertility status of soil.

4. Abundance of certain nutrient elements in soluble form may be as unsatisfactory as ground that has deficiency and even the elements, say alkalies, essential for plant growth may be toxic if present in excess. Flowering plants do not grow in the soil containing more than 6 per cent NaCl and other salts. The elements are not equally toxic and the various species of plants differ in their susceptibility to different elements.

5. **Toxic chemicals and pesticides in soil.** Several agricultural chemicals being used for controlling various diseases and insect pests are highly toxic and their application adversely affects the soil microflora and fauna. Prolonged persistence of these pesticides in soil is bound to lower the soil fertility both directly and indirectly.

6. **Soil reaction.** The soils may be alkaline or neutral or acidic in their reaction. Some plants find acid soil unsuitable for growth and other plants find alkaline ground unfavourable. pH value of soil solution determines the availability of certain plant nutrients and thus it has bearing on soil fertility problem. Increase in the acidity of the soil makes mineral salts more soluble in soil solution and thus salts may become available in concentrations that may be highly toxic or may damage plants growing in such soils. Janick *et al.* (1969) have demonstrated that high concentration of both iron and aluminium may damage plants growing in acid soils.

MAINTENANCE OF SOIL FERTILITY

Soil fertility is the most important asset of a nation. Maintenance of soil fertility is an important aspect of agriculture. The soil fertility problem has been studied in many countries and scientists have brought to light several facts concerning soil fertility and its maintenance. Soil fertility is of two types;

(*a*) **Permanent fertility.** It is derived from the soil itself. It can be improved, maintained or corrected by soil management practices.

(*b*) **Temporary fertility.** It is acquired by suitable soil management but the response of built up soil fertility is highly dependent on the degree of permanent fertility which is already there.

Several methods are known for controlling the loss of soil fertility. Here only the important methods are discussed.

1. Application of Organic Manures and Chemical Fertilizers

A. Organic Manures

The organic content of the soil which is a good source of plant nutrients contributes most to the fertility of the soil. Organic manures improved soil fertility in the following ways :

(*i*) They modify the physical properties as increase of granulation of the soil and increase permeability and moisture holding capacity of soil.

(*ii*) They provide food for soil microbes and thus enhance microbial activities.

(*iii*) Decomposition products of organic manures help to bring mineral constituents of soil into solution.

(*iv*) They improve physico-chemical properties of soil, such as cation exchange and buffering action.

Organic manures are of several kinds some of which are discussed below :

(*i*) **Farmyard manures.** Solid and liquid excreta as dung and urine of all farm animals are termed farmyard manures. They are ready made manures and contain nitrogen, phosphorus and potassium. The farmyard manures of different animals vary greatly in their composition but they are good for all types of soils and all the crops. Farmyard manure when collected in field in exposed condition for several months shows considerable loss of fertilizing value as upon decomposition a considerable amount of ammonia is lost by volatilization. Therefore, it is important to keep manure protected from weather and manure preparation should be carried out in trenches of about a metre depth. When the trenches are filled the top surface is covered with a cowdung-earth slurry. In about 3 months the manure is ready for use.

(*ii*) **Compost.** Compost manure can be prepared from a variety of refuse materials, such as straw, sugar cane refuse, rice hulls, forest, litter, weeds, leaves, kitchen wastes. It is prepared in pits usually 6—8 m long, 1½ to 2 m wide and one metre deep. In the pits, 30 cm thick layer of plant residues moistened with dung, urine and water is formed and then a second layer of about 30 cm thickness of mixed refuse is spread over it and moistened with slurry. The operation is repeated until the heap rises to a height of about 50 cm above the ground level. The top is then covered with a thin layer of moist earth. After three months of decomposition the material is well mixed and again covered. After a couple of months the manure is ready for use. There are two types of composts :

(*a*) *Farmyard compost* which is obtained from animal excreta and plant residues.

(*b*) *Town compost* which is obtained by decomposition of kitchen wastes and garbage of towns and cities.

Compost manures are rich in all plant nutrients.

(*iii*) **Green manures.** Green manuring is the practice of growing, ploughing and mixing of green crops with soil to improve soil fertility and productivity. Its effects on soils are similar to those of farmyard manures. It is cheap and the best method to increase soil fertility as it can supplement farmyard and other organic manures without involving much cost. Green manures add nitrogen and organic matter to the soil for the improvement of crop yield. Through green manuring mobilization of minerals, reduction of organic nutrient losses due to erosion, leaching and percolation, and improvement in physical, chemical and biological activities of the soil can be achieved. Green manuring also improves soil aeration and drainage conditions. For green manuring both leguminous and non-leguminous crops are used. In India, leguminous crops such as sannhemp **(sanai),** dhaincha, berseem, clover, *Phaseolus mungo,* cowpea, are generally used for green manuring.

(*iv*) **Sawdust.** Sawdust can be used as bedding material to conserve animal urine or for making compost. It is a low fertilizing material but it is definitely richer than wheat straw in calcium.

(*v*) **Sewage.** In modern system of sanitation, water is used for removal of human excreta and other wastes. Sewage consists of two components :

(*a*) the solid part, called *sludge* and (*b*) the liquid part, called *effluent or sewage water.* Sewage is quite rich in several plant nutrients and can be used for fertilizing the crop by irrigating the soil directly with sewage water but there is a danger for the spread of several human diseases.

B. Chemical Fertilizers

Of the elements known to be essential for plant growth, nitrogen (N), phosphorus (P) and potassium (K) are required by plants in pretty large amounts, and are therefore, designated as *major* or *primary nutrients* while calcium, magnesium and sulphur are secondary nutrients. For acid soils, use of Ca and Mg is necessary. Seven elements iron, manganese, boron, molybdenum, copper, zinc and chlorine are required in trace amount and hence called *micro-nutrients.* Under continuous cultivation our soils are losing organic matter and mineral nutrients faster than they can be replaced. Regular loss of nutrients from the soil results in compact soil, shallow roots, increased drought, claddy and poorly productive soil. So, for the maintenance of soil fertility quick replacement of the organic matter and mineral nutrients removed from the soils is necessary (Table 25.1).

Nitrogen (N), phosphorus (P) and potassium (K), the primary plant nutrients are commonly applied to soils in the form of commercial fertilizers and hence they are often referred to as *fertilizer elements.*

Chemical fertilizers are classified into the following three groups on the basis of materials supplied : (*i*) Nitrogenous fertilizers, (*ii*) Phosphorus

Table 25.1. Fertilizers and their composition

	Fertilizer	*Composition*	*Source*	*Nitrogen %*
1.	Ammonium sulphate	$(NH_4)_2SO_4$	By-produce from coke and also as synthetic	26.6
2.	Ammonium nitrate	NH_4NO_3	Synthetic	33
3.	Ammonium chloride	NH_4Cl	Synthetic	25
4.	Ammonia liquor	Dilute NH_4OH	Synthetic	20—25
5.	Ammonium phosphate (DAP)	$NH_4H_2PO_4$	Synthetic	11% N and 48% P_2O_5
6.	Diammonium phosphate	$(NH_4)_2HPO_4$	Synthetic	21% N and 53% P_2O_5
7.	Sodium nitrate	$NaNO_3$	Chile saltpetre and synthetic	16
8.	Calcium ammonium nitrate	NH_4NO_3 and Dolomite	Synthetic	20.5
9.	Calcium cyanamide	$CaCN_2$	Synthetic	21
10.	Calcium nitrate	$Ca(NO_3)_2$	Synthetic	15
11.	Urea	$CO(NH_2)_2$	Synthetic	45

fertilizers, and (*iii*) Potassium fertilizers. Classification is not so simple as this grouping would imply, however, several such fertilizer materials carry two of these elements, as for example, potassium nitrate and ammonium phosphate.

(*i*) **Nitrogenous fertilizers.** Crops usually take nitrogen from the soil in the form of nitrate (NO_3^-) and ammonium ions (NH_4^+). Nitrogen fertilizers may be divided for convenience into two groups : (*a*) Organic nitrogen fertilizers, and (*b*) Inorganic nitrogen fertilizers.

(*a*) **Organic nitrogen fertilizers.** Organic materials such as cotton seed meal, guano and fish tankage are nitrogen carriers but because they supply less than 2% of total nitrogen added on commercial fertilizers, their use is costly and hence they are not used extensively. Nitrogen of organic fertilizers is released slowly by microbial action. They are used as special fertilizers for gardens, lawns and potted plants.

(*b*) **Inorganic nitrogen fertilizers.** Several inorganic chemicals are used to supply nitrogen to plants. The most important of these are presented in the table on previous page.

(*ii*) **Phosphorus fertilizers.** Phosphorus has rightly been called 'master key' to agriculture as low crop production is due to more often to lack of phosphate than to the deficiency of any other element except nitrogen. In phosphorus fertilizers this element is present in the form of phosphate or superphosphate salts and it is available to the plants when it is combined with organic matter or with calcium and magnesium. Phosphorus is also found in combination with iron and aluminium and is present in certain rock minerals as apatite. Plants take up phosphorus chiefly as phosphate $(PO_4)^{--}$, HPO_4^{--} and $H_2PO_4^-$ ions and availability of these ions depends chiefly upon the acidity of the ground. They become nearly insoluble in strongly acid or strongly alkaline soils. Release of phosphorus from phosphate rocks is slow. The breakdown of phosphate fertilizers produces phosphoric acid (P_2O_5) in soluble form that is absorbed by plants. Use of phosphate fertilizers on alkaline soils is not suitable. Phosphorus fertilizers are classified into (*i*) water soluble, (*ii*) citrate soluble, and (*iii*) insoluble. When the term P_2O_5 is used, it means water soluble plus citrate soluble P_2O_5. The following are the important phosphate fertilizers being used in all parts of the world including tropical Asia (Table 25.2).

Table 25.2. Phosphate fertilizers

Fertilizer with chemical composition	*P_2O_5 available percentage*
(*a*) **Fertilizers containing water soluble phosphorus :**	
(*i*) Superphosphate $Ca(H_2PO_4)_2$ and (ordinary grade) $CaHPO_4$	16—20
(*ii*) Superphosphate $Ca(H_2PO_4)_2$ and $CaHPO_4$ (concentrated)	40—45
(*iii*) Ammonium phosphate $NH_4H_2PO_4$	48 (11% N)

Fertilizer with chemical composition	*P_2O_5 available percentage*
(*iv*) Diammonium phosphate $(NH_4)_2HPO_4$	46—53 (4% N)
(*b*) **Citrate soluble phosphorus fertilizers :**	
(*i*) Dicalcium phosphate	35—40
(*ii*) Basic slag (Indian) $(CaO)_5P_2O_5 . SiO_2$	3—5
(*c*) **Insoluble phosphorus fertilizers :**	
(*i*) Rock phosphate Fluor and chloraphatite	20—30
(*ii*) Bone Meal $Ca_3(PO_4)_2$	18—20

Superphosphate. It is water soluble fertilizer. It does not affect the soil adversely. It contains monocalcium phosphate, dicalcium phosphate and tricalcium phosphate, gypsum, silica, iron, aluminium sulphate and calcium fluoride and water.

Ammonium phosphate. It is a fertilizer containing both nitrogen and phosphorus. It is rich in phosphoric acid content but comparatively low in nitrogen content.

Ammonium superphosphate $(NH_4H_2PO_4)$. $Ca_3\ (PO_4)_2\ (NH_4)_2\ SO_4$. It is the cheapest fertilizer and is a mixture of nitrogen and phosphorus fertilizers. It contains nitrogen 3 to 4 per cent and phosphorus pentaoxide (P_2O_5) 16 to 18%.

Nitrophosphate. It is highly hygroscopic. It contains nitrogen 13—18 per cent and phosphorus 20 per cent. It is suitable for acid soils.

Bone meal. It is derived from bone. Bone ash and bone char are the bone products. It is suitable for acidic soils.

Basic slag. Basic slag, a by-product in the manufacture of steel, is one of the cheapest sources of phosphorus. It is a double compound of silicate and phosphate of lime. It is dark brown in colour and alkaline in reaction.

Rock phosphate. It occurs in natural deposits. It is light grey in colour. It is a very cheap fertilizer suitable for acid soils.

(*iii*) **Potassium fertilizers.** These fertilizers are soluble in water which means that potassium is readily available to plants. Total potassium of potassium fertilizers is usually expressed in terms of water soluble potassium (K) or potash (K_2O). Soils of arid and semiarid areas are generally well supplied with potassium. Acid soils usually need potassium fertilizers more than neutral or alkaline soils because acid soils develop in the areas of high rainfall that leaches out available potassium. All potassium fertilizers are physiologically neutral in reaction. The following are some common potassium fertilizers.

(*i*) **Potassium chloride.** It is also called muriate of potash. It contains 48—62% K_2O. It is also cheap and neutral in reaction.

(*ii*) **Potassium sulphate.** It contains about 50% potash (K_2O). It is expensive fertilizer.

(*iii*) **Kainite.** It is natural potassium mineral which contains 14—20% potassium. It is suitable for alkaline soils.

(*iv*) **Wood ashes.** It is used in the form of ash as a manure. Potassium occurs in the form of potassium carbonate and the percentage of potash is from 2 to 6.5. It is suitable for alkaline soils.

Application of Micronutrients

In order to correct the deficiency of micronutrients, especially if it is very necessary, micronutrients should be added only after ascertaining the amount required. Copper, manganese, iron, zinc are supplied generally as their sulphate and boron is applied as borax. Molybdenum is supplied as sodium molybdate. In recent years there has been an increase in use of chelates to supply iron, zinc, manganese and copper.

Soils vary in their ability to supply available nutrients. Some soils may be deficient in nitrogen, some may be deficient in nitrogen and phosphorus, and still some others may be deficient in nitrogen, phosphorus and potassium. To suit the variable requirements of different soils and crops, *fertilizer mixtures* are prepared. Fertilizer mixtures or mixed fertilizers contain two or more fertilizer materials. If the ingredients and their amounts are known, the formula is referred to as **open** and if they are not disclosed the formula is termed **closed** one.

The kinds and amounts of fertilizers to be applied to soil are determined considering the following points :

(*a*) Kinds of crop to be grown—particularly its economic value, nutrient removal and absorbing ability.

(*b*) Chemical condition of soil in respect of total nutrients and available nutrients.

(*c*) Physical state of the soil, especially its moisture content and aeration. For recommending the kind and amount of fertilizers or soil amendments, the analysis of soil is essential.

2. Application of Soil Conservation Practices

Loss of plant nutrients and water from the soils due to soil erosion can be checked effectively and the fertility of soil can be maintained by application of various biological and engineering methods of soil conservation. A detailed account of these methods has already been given in soil conservation topic.

3. Water Supply and Drainage

Water supply is critical factor in crop production in most areas of the world. Soil moisture greatly affects the availability of mineral nutrients in the soil. It has been proved beyond doubt that fertilizer response is much higher with adequate irrigation.

Drainage and moisture control influence micronutrient availability in soils. Improving the drainage of acid soils encourages the formation of less toxic oxidized forms of iron and manganese.

4. Prevention and Elimination of Inorganic Chemical Contamination of Soil

Loss of soil fertility due to application of toxic chemicals as pesticides can be eliminated if (*i*) application of toxic chemicals to soil is reduced and (*ii*) the soil and crop are so managed as to prevent cycling of toxic chemicals.

5. Stabilization of Soil pH

The stabilization of pH through application of soil amendments and buffering seems to be an effective guard against the problems of non-availability of certain plant nutrients and radical changes in microbial activities arising due to change in soil pH. Several methods are discussed for correction of acidity and alkalinity of soils in the chapter on "Properties of Soil".

QUESTIONS

1. What do you mean by soil fertility? How does it differ from soil productivity? Discuss in brief various factors affecting loss of soil fertility.
2. Define soil fertility and describe the methods of checking loss of soil fertility.
3. Write brief notes on :
   (*a*) Productivity
   (*b*) Biological fertilizers
   (*c*) Green manuring.

26

SOIL DEGRADATION AND WASTELAND

Soil degradation has been defined as a process that leads to decline in the fertility or future productive capacity of soil as a result of human activity (United Nations Environment Programme, 1993). Degraded soils which result in poor or no production are also called *problem soils*.

Waste lands are those which for one or the other reason have poor the life sustaining property. Out of 100 per cent potentially active lands only 44 per cent are available for cultivation and 56 per cent of land are non-available for cultivation.

The wasteland can be made useful by increasing productivity of land by using some useful methods as afforestation or by using biofertilizers.

Soil degradation is a complex phenomenon derived by interaction between natural and socio economic factors. The degradation or deterioration of soil may be caused by the following factors :

1. *Physical factors, e.g.* loss of fertile top soil due to water or wind erosion.
2. *Chemical factors e.g.* depletion of nutrients or toxicity due to acidity or alkalinity (salinization) or water logging.
3. *Biological factors* which affect the microflora and reduce the microbial activity of the soil. These factors reduce the yield.

Some other factors as deforestation, extensive cultivation on marginal land, improper cultivation practices like monocropping, poor manuring, misuse of fertilizers or excess use of fertilizers, excessive irrigation, over-grazing, fragility of soil, adverse weather and mining may accelerate the process of soil degradation.

During last decade nutrients deficiency has been considered as the main cause of poor productivity and crop failure. A study of the current trends in agronomic practices has suggested that the nutrients deficiency is further aggravated by continued use of high yielding crop varieties, intensive cropping pattern and relatively poor fertilizers.

Among the major causes of degradation, water erosion is considered to be the most severe one which covers almost 87% of the affected area. The main cause of water erosion is removal of vegetation, over exploitation of vegetation, over grazing and improper agricultural practices. The latest data revealed that erosion has rendered 200 million hectares or 36% of the total area of the country barren (Table 26.1).

Soil degradation is a global phenomenon. Of the world's total land area of 13.5 billion hectares, only 3.03 billion hectares (22 per cent) is actually cultivable and about 2 billion hectares is degraded. The annual loss of land is expected to go up to 10 million hectares by 2000 A.D. (Yadava, 1996). In India alone, about 188 million hectares, or almost 57% of total land area, is degraded (Sehgel and Abrol, 1994).

Table 26.1. Soil degradation (in million ha) in India

Causes of degradation	*National commission on Agriculture (1976)*	*Sehgal and Abrol 1994*	*1997*
Erosion	150.0	162.4	167
Saline & alkali soils	7.0	10.1	11
Water logging	6.0	11.6	13
Shifting cultivation	—	—	9
Decline in soil Fertility	—	3.7	2
Total	163.0	187.0	202

The severity of soil degradation can be measured by the quantity of soil lost every year from each hectare of soil (Tables 26.2. & 26.3).

Table 26.2. Severity of soil degradation
(Slight, 5-10 tonnes; moderate, 11-20 tonnes; high, 21-40 tonnes; and severe, more than 40 tonnes)

	Severity of Degradation				*Total area*
Degradation	*Slight*	*Moderate*	*High*	*Severe*	*(Million ha)*
Water erosion	5.0	24.3	107.2	12.7	148.9
Wind erosion	0.0	0.0	10.8	2.7	13.5
Loss of nutrients	0.0	0.0	3.7	0.0	3.7
Salinization	2.8	2.0	5.3	0.0	10.1
Water-logging	6.4	5.2	0.0	0.0	11.6
Total	14.2	31.5	127.0	15.1	187.7

Table 26.3. Estimated annual costs of soil degradation
(billion Rupees)

Degradation	*Annual costs in billion Rs.*	*Share of Total estimated cost (Per cent)*
Erosion	61	69
Salinity	19	21
Water-logging	8	9
Depletion of nutrients	1	1
Total	89	100

Overall damage of some important crops due to soil degradation is given in Table 26.4.

Table 26.4. Losses in some important crops due to soil degradation
(According to Brandon and Hommann (1995)

Crops	*Loss Percentage*	*Losses in billion Rs.*
Paddy	9.7	29.2
Wheat	10.8	26.4
Barley	9.1	0.4
Groundnut	8.1	5.8
Rape seed	8.3	3.9
Cotton	10.2	2.2
Maize	8.0	2.4
Sugar cane	12.1	11.7
Total	100	88.7

Causes of Soil Degradation

The main reasons for unproductiveness or degradation of soils are as follows :

1. Nutrient disorder
2. Water-logging
3. Salinity
4. Erosion
5. Biological degradation
6. Other causes

Nutrient disorder. Most of the Indian soils are deficient in nutrients and organic matter. Organic matter is rapidly decomposed and leached or eroded by heavy rains. In addition to these causes, intensive cultivation using high-yielding short-duration and fertilizer-responsive cultivars of crops has further accelerated the loss of plant nutrients which is much greater than what is supplemented through fertilizers. According to an estimate of 1992, every year 20.2 million tonnes of NPK is removed by growing crops. The data published by National Bureau of Soil Survey and Land Use Planning (Sehgal and Abrol, 1994) show that about 3.7 million ha land suffers from nutrient loss or depletion of organic matter. The problem is more severe in the cultivated areas of the subtropical belt. Out of 20.2 million tonnes NPK removed by the plants, only 2.66 million tonnes comes from fertilizers and 3 million tonnes from organic sources. If the loss of nutrients due to soil erosion is included, the loss of nutrients from top soil is 43 million tonnes.

Water-logging. Soils become water-logged when the water balance of an area is disturbed because of excess recharge. Important sources of water are heavy rains, overland flows towards basin, seepage from canals and distribution system and tidal flooding. Natural basins without outlet for water, low permeability of subsurface horizons, internal drainage, low intake rate of surface soils and obstructions to natural flow of rain water etc. are conditions cause water-logging. In highly productive areas, canal irrigation is responsible for a rapid rise in water table. Expansion of canal irrigation is also directly concerned with widespread water-logging and salinity problems in arid and semiarid areas. Disturbances in the hydrologic cycle due to inefficient use of surface irrigation water, poor land development, seepage and poor drainage have resulted in higher water tables. Most of the canal areas in arid and semiarid regions are rich in soluble salts. In irrigation these salts are dissolved in soil water and rise to the surface through capillary action. When the water dries up, the salts are left on the upper surface as a crust or layer. According to National Commission on Agriculture (1976), about 6 million ha area is under water-logged condition. Data of World Bank Survey (1995) reveal that India loses 1.2 to 6 million tonnes of food grains production every year due to water-logging. The water-logging and salinity cause a loss of Rs. 12 billion to 27 billion annually.

Salinity (Saline and alkali soils). Salinity directly affects the productivity by making the soil unsuitable for crop growth. Indirectly it lowers productivity through its adverse effects on the availability of nutrients. The adverse effect of alkalinity on availability of nutrients is due to deflocculation effect of sodium ions. An area of about 21.7 million hectares of soil is rendered unproductive due to salinity and water-logging. The saline degradation is due to natural causes and poor irrigation practices which disturb the water cycle in areas. Most of the crops in India are affected due to salinity. Productivity loss of some crops is given in Table 26.5. The detail account of saline, alkaline soils and acidic soils are given in 'Soil Property' Chapter of this book.

Table 26.5. Loss (in million tonnes) of production of some crops due to salinity

Crops	*FAO (1993) estimate*	*Indian (1986) estimate*
Paddy	0.54	1.31
Wheat	0.68	0.95
Barley	0.03	0.03
Groundnut	0.08	0.08
Gram	0.12	0.09
Cotton	0.28	0.18
Maize	0.11	0.13
Sugar cane	3.76	6.49
Total	6.2	9.65

Erosion. Soil erosion is the major cause of soil degradation. In the soil erosion uppermost fertile layer of soil which contains essential mineral elements is lost. Thus soil becomes deficient in essential minerals and this results in productivity loss. Deforestation or destruction of forests accompanied by reduced frequency of rainfall leads to soil erosion and causes damage to agriculture property. Deforestation causes fast degradation when the soil is steep slopy or easily erodible. Destruction of natural vegetation cover is a major factor responsible for erosion of soils by water and wind. According to Global Assessment of Soil Degradation (GLASOD), deforestation is the main cause of soil erosion by wind in about 98% of the area. Overgrazing, cutting of timber trees, collection of fuel wood, shifting cultivation and encroachment of forest areas are some of the important factors responsible for the loss of vegetation cover on the soil which ultimately causes soil erosion. The latest data provided by Sehgal and Abrol (1994) show that the total degraded land in India is 187.8 million ha, of which 162.4 million ha is degraded due to erosion alone (Table 26.6). Table 26.6 presents the area under different types of soil degradation in different years :

Table 26.6. Area under different types of soil degradation in different years (in million ha)

	Different types of degradation			
	Salinity	*Water-logging*	*Erosion*	*Total*
1980	8.0	6.0	150.0	168.4
1985	9.4	8.5	141.5	166.3
1990	9.8	10.1	152.8	180.6
1994	10.1	11.6	162.4	191.8

Biological degradation. The factors which affect soil microflora and fauna also reduce the biological or microbial activity of soil adversely.

These factors reduce the yield. It is well known that monocropping (growing the same crop on the same land year after year) often leads to increasing attack of pests and diseases. The fatal nematodes threaten potato cultivation in the Nilgiris and, if not controlled they may pose threat to potato cultivation in that area. Excess use of pesticide reduces microbial activity and biomass. Applications of some pesticide chemicals (*e.g.*, amitrole, atrazine, bromacil, picloram, etc.) inhibit nitrification. The nodulation and growth of some leguminous crops and nitrogen fixation are inhibited by different pesticides. Disposal of oil shales, heavy metal contamination of soil and spillage of crude oils adversely affect soil microflora which ultimately affect soil productivity and cause soil degradation.

Other Causes of Soil Degradation

Extension of cultivation to marginal land. Due to tremendous population increase the use of land is increasing day by day. Marginal lands though sustainable for farming are less fertile and more prone to degradation. Examples of marginal lands are : steep slopy lands, shallow or sandy soils and the lands in dry and semi-dry areas.

Improper crop rotation. Due to shortage of land, increase of population and economic pressure, the farmers have adopted intensive cropping patterns of commercial crops in place of more balanced cereal-legume rotations. During last two decades the area under food crops decreased and that under non-food crops increased. Intensive cultivation leads to removal of large quantities of nutrients from the soil which results to in loss of soil fertility.

Fertilizer misuse. Soil fertility is reduced due to prolonged intensive cultivation. The farmers maintain productivity of soil by applying chemical fertilizers but make less use of organic manures. Although the yield can be maintained by using fertilizers that provide deficient minerals yet their use often results in deficiencies of other nutrients.

Overgrazing. In India pasture land area is decreasing day by day due to expansion of agricultural land. Recent satellite data show that the area under pasture land is severely degraded. This poor condition of pasture lands is due to excessive grazing. The unchecked and indiscriminate grazing on forest land also leads to degradation of forest soils. Overgrazing directly leads to disappearance of vegetation which is one of the important causes of wind and water erosion in dry lands.

Mining. Mining disturbs the physical, chemical and biological features of the soil. The impact of mining on soil depends on the physical, chemical properties of the waste generated. The soil profile is verted, the top soil is burnt deep inside the dumps. The erodible material is almost devoid of organic matter and lacks in mineral plant nutrients. According to an estimate, about 0.8 million ha soil is degraded to mining activity.

Impact of Soil Degradation

The following are the impacts of soil degradation :

1. Degradation leads to reduction in crop yield in the affected lands and a possible decline in cropping intensity.
2. In extreme cases, soil becomes unfit for cultivation.
3. Siltation of drainage, canals, rivers and reservoirs results in increased floods and droughts.
4. In some cases farmers use more fertilizer inputs to compensate reduced soil productivity while in other cases, they use excess fertilizers.
5. The rate of siltation in many water reservoirs are significantly high. According to Central Water Commission (1991), nearly 11 per cent of the total capacity of water reservoirs has been silted.
6. Soil degradation has several adverse impacts on the environment. It affects global climate through alterations in water cycle and energy balances and disruptions of carbon, nitrogen and sulphur cycles.

The estimated annual loss of different crops due to soil degradation rangs from Rs. 89 billion to 232 billion which represent a loss of 11 to 26 per cent yield (Table 26.6).

NATIONAL WASTELAND DEVELOPMENT BOARD

For wasteland and its management a separate board was established in 1985 which deals with the land degradation, reclamation of ravines, usar lands and arid tracts and deforestation which is called National Wasteland Development Board (NWDB).

The main objectives of National Development Board is to check land degradation, to convert wastelands which is for sustainable use, to increase biomass and to restore ecological balance. At present in 146 districts of India wastelands have been identified. The NWDB has converted 2.7 million hectares of wasteland for afforestation in 1989-90 costs Rs. 700 crores. Now which this department has been merged under Ministry of Rural Development. There are several regional centres of NWDB. These centres assist the central and state governments in evaluation and formulation of projects to provide training and reorientation programmes. These centres are :

North India	—	Dr. Y.S. Parmar University of Horticulture & Forestry Solon (H.P.).
South India	—	PME of Social Forestry Programme UAS, GKVK Campus, Bangalore (Karnataka).
West India	(*i*)	Indian Institute of Management, Vastrapur, Ahmedabad (Gujarat).
	(*ii*)	Agriculture Finance Consultants Ltd. Chhatrapati Shivaji Maharaj Marg, Mumbai (Maharashtra).
East India	—	Jadavpur University Calcutta (West Bengal).

Central India — Indian Institute of Forest Management, Nehru Nagar, Bhopal (MP).

North-Eastern India — North-Eastern Hill University (NEHU) Shillong (Meghalaya).

QUESTIONS

1. Define wasteland or problem soil. What are the corrective measures for problem soils?
2. Discuss the various causes of soil degradation.
3. Write short notes on :
   (*i*) Impacts of soil degradation on agriculture.
   (*ii*) National Wasteland Development Board (NWDB).
   (*iii*) Biological degradation