Soil Sciences

Conservation and Management of Soil and Water resources

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Soils of India and their Distribution

Physiographic region and climate

India, situated between the latitudes of 08°04' and 37°06'N and longitudes of 68°07' to 97°25'E, has a geographical area of 329 Mha. Physiographically it can be divided into the three broad regions, viz. Peninsular Plateau in the Deccan and south of Vindhyas, Mmountain region of the Himalayas, the Indo-Gangetic Plain.

The Mountain region of Himalayas shows the development of marine sediments of all ages, especially in the north. The major rock formations are tertiary-old sedimentary (sandstone, limestone etc.) and igneous (granites) (at places metamorphosed to gneisses and schists). In this region soils of the order (as per USDA classification) Inceptisols, Alfisols, Entisols, Mollisols predominate. In the northeastern region, Ultisols and Oxisols are also found.

The vast Indo-Gangetic and other plains of Pleistocene origin are composed of alluvium of the great river systems flowing in this region. These are the alluvial soils. However, depending on age of alluvium and degree of development, they can be classified in the orders, Inceptisols, Entisols or Alfisols in Soil Taxonomy.

Geologically, a great part of the Peninsula is occupied by Archean rocks comprising gneiss, schists and other rocks of diverse nature. Red soils (Alfisol) generally predominate in this region. Next in order of age are Cuddapah and Vindhyan rocks, followed by the coal bearing Gondowana formations supporting rocks of Mesozoic and Tertiary groups. These are mainly distributed over the north-central and NE-central parts where Red soils (Alfisols, Inceptisols and Entisols) have developed. The western and central parts are covered by lava flows of the Deccan trap where basaltic rocks predominate. Black cotton soils of different thickness (Vertisols, Inceptisols) predominate. In the central India, while Ultisols dominate the southern India. There are also pockets of Oxisols are also found.

The climate of India is of monsoon type, there being two distinct periods of rainfall in a year, viz., the south-west monsoon during the months of June to September and the north-east monsoon during the winter months. The climate is also influenced by the Himalayan Mountains as well as the Indian Ocean, the Arabian Sea and the Bay of Bengal. The Himalayas obstruct the path of entry of cold winds from north, giving a continental type of climate. The seas produce a hot monsoonic type of tropical climate. The temperature is equally variable like rainfall. Usually the temperature rises continually during the summer months (March to June). The air temperature may rise to about 45°C in the north and north–western plains. The mean annual temperature in the Indo-Gangetic alluavial plains is around 24°C. The climate thus varies from extreme aridity to high humidity and from scanty to torrential rainfall.

India with a great variety of landforms, geologic formations and climatic conditions, exhibits a large variety of soils; the variety is so diverse that barring a few soil orders (Andisols, Spodosols), India represents all the major soils of the world.

Soils of India

The major soils of India, according to the Genetic approach, can be classified into a few soil groups, viz. alluvial, black, red, forest and desert soils (Fig. 1).

Alluvial Soils: Alluvial soils are one of the most important soil groups in India. From agricultural point of view, these soils are the most important and fertile among all the soils of India. They are extensively distributed in the states of Punjab, Haryana, Uttar Pradesh, Uttaranchal, Bihar, West Bengal, Assam, coastal regions of India and occupy an estimated area of 75 Mha in the Indo-Gangetic plains and Brahmaputra valley alone. These soils have been formed on the parent materials transported and deposited by the rivers, Jamuna, Ganga and Brhmaputra and their tributaries. The soils are very deep, the solum sometimes extending over a few hundred metres. Pan formation (compact soil layer) is a common feature of many of the soils, which have been cultivated for long periods. These soils are deficient in nitrogen, phosphorus and humus but not in potash and lime. They produce a wide variety of crops including rice, wheat, sugarcane, jute and potato.

Deltaic alluvial soils are formed from sediments carried out by Ganga, Bhramaputra, Mahanadi, Godavari, Krishna and Cauvery, Narmada and deposited in the mouths of river joining the sea. These soils occur in Orissa, West Bengal, Gujrat, Tamil Nadu, Andhra Pradesh and Gujrat. Rice is the major crop in deltaic alluvial soils. In West Bengal jute is also grown on such soils.

Black soils: This is a well-known group of soils (Vertisols), characterized by dark grey to black colour, high clay content, neutral to slightly alkaline reaction, and deep cracks during summer. The black colour may be due to clay-humus complexes and or presence of titaniferous magnetite minerals. These soils are dominantly distributed in the central, western and southern states of India. According to a recent study these soils occupy an estimated area of 74 Mha. The depth of soil varies from less than a mmeter to several meters and in many cases it overlies decomposed rocks known as *murrum*. Black soils are mainly developed from Deccan basalt trap either in situ or on the transported parent material. At some places the black soils are also developed on granite and gneiss containing lime and feldspar and are basic in character. Semi-arid to sub humid tropical to subtropical monsoon type climate with alternate dry and wet periods and calcification are favouravble to the formation of black soils. The cracks which are 0.5 to 1 cm and sometimes up to 6 cm wide are formed by shrinkage of soil during summer. During monsoon, the cracks form easy passage of rain water, carrying therewith a lot of soil material from the surface and filling up the cracks. Thus there is a mixing of surface soil along the entire solum. These soils have poor drainage, poor moisture and are poor in nitrogen, phosphorus, sulphur and organic matter. Irrigation availability is low and in a larger part of these soils grows cotton, sorghum, millet, soybean, pigeon pea etc under rainfed conditions. Under irrigated conditions, a variety of other crops such as sugarcane, wheat etc. can be grown. There are also citrus plantations in these soils.

Red Soils: The name Red is given to soils rich in sesquioxides (Fe, Mn and Al oxides) that have developed on rocks of Archean origins (granite, gneiss) and on well drained, stable and higher land forms under hot, semi-arid to humid subtropical climatic conditions. These soils occur predominantly in the southern and eastern parts India comprising the states of Andhra Pradesh, Tamil Nadu, Karnataka, Maharastra, Orissa, Goa and in NE states. In Andhra Pradesh, the Red and Black soils occur under similar bioclimatic conditions, but on different parent material and land forms. The main features of red soils are lighter texture, friable structure, absence of lime concretions and free calcium carbonate, and low contents of soluble salts. They vary from shallow and poor gravelly in the uplands to very deep, fertile in the plains and valleys. These soils are generally deficient in nitrogen, phosphorus, potassium and organic matter. However, under good management practices, these soils can be profitably used for a variety of agricultural, horticultural and plantation crops such as millets, rice, groundnut, soybean, pigeonpea, green gram, jute, tea, cocoa, grapes, banana, papaya, and mango.

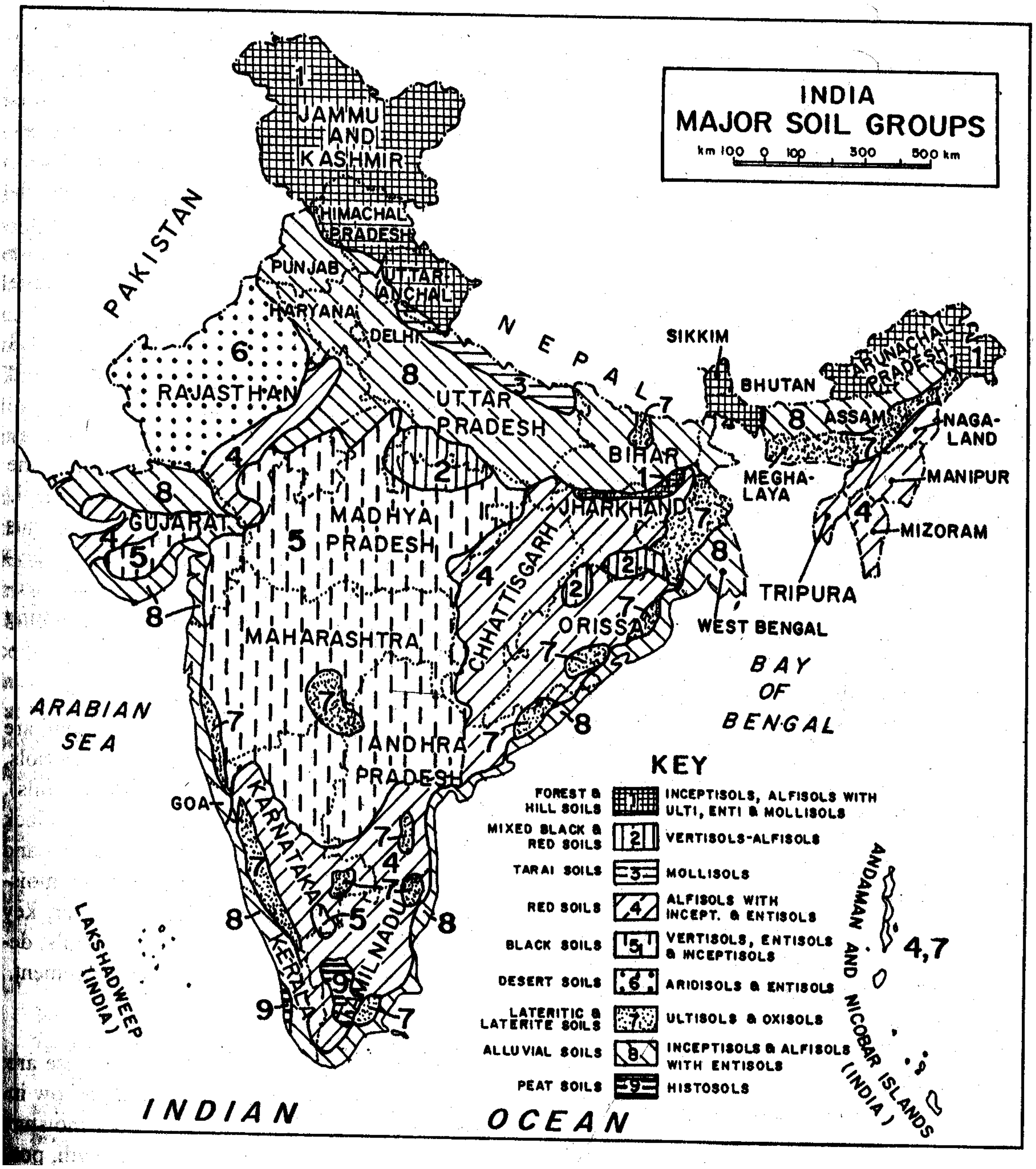


Fig. 1. Major soil groups of India and soil orders that occur in these soil groups

Laterite and Lateritic soils: The term 'Laterite" was originally used by Buchanan in 1807 for the highly ferruginous, vesicular and unstratified material observed in Malabar Hills of South India. The lateritic soils are those in which laterisation is the dominant soil forming process, i.e. eluviation of silica and enrichment with oxides of iron and aluminium. Under high rainfall (more than 100 cm) conditions, silica is released and leached downwards and the upper horizons of the soils become rich in oxides of iron and aluminium. They are generally observed on hill-tops and plateau landforms of Orissa, Andhra Pradesh, Maharastra, West Bengal, Kerala, and Tamilnadu etc.

Latiriric soils are formed under almost comparable climatic conditions as described for red and black soils above, but do not require alternate wet and dry conditions and ground water level may not be very near to surface. Lateritic soils are usually characterized by a compact to vesicular structure in the subsoil horizon composed essentially of a mixture of hydrated oxides of iron and aluminium. This is often referred to as a honey-comb structure.

The major limitations posed by these soils are deficiency of P, K, Ca, Zn, B etc. and high acidity and toxicity of aluminium and manganese. The laerites of lower topographic positions are used for growing rice, banana, coconut and arecanut, while those of higher topographic positions are used for growing cocoa, cashew, tea, coffee, rubber, etc.

Desert Soils: The name Desert is given to the soils supporting negligible vegetation, except xerophytes, unless irrigated. Such soils may occur in cold and hot temperature regime. A large tract of hot arid region, with a growing period of <60 days in a year is situated in the north-west India (Rajasthan, Gujarat, Punjab and Haryana). It covers approximately 29 Mha. The major characteristics of the these soils are: sandy to loamy fine sand in texture, poor in N, P, K, S and Zn and having low water holding capacity.

The major constraint of these soils is of water deficiency which restricts their use for agricultural purposes. The desert soils are useful for raising perennial deep rooted horticultural crops like *Ber, Amla, and Kinnow* etc.

Forest and Hill Soils: The name is implied for soils developed under forest cover. In India, the total area under various forest species (tropical, deciduous, coniferous, tropical evergreen) is estimated to be 75 Mha occur mainly in the states of Himachal Pradesh, Jammu and Kashmir, Uttar Pradesh, Uttaranchal, Chattasihgarh, Madhya Pradesh, Maharastra, Kerala and north-east region. The major soils observed in different forest areas are: Brown Forest and Podsolic (in Northern Himalayas) and Red and Leritic (in Deccan Pleatue), Podzols. These soils are used for growing a variety of crops, especially rice, maize, soybean, etc. on terraces and tea and other fruit plants on slopes. Brown forest soils have great potential for growing agricultural crops such as rice, maize and fruit plants, such as apple, almond, pear, apricot, etc.

Salt Affected Soils: The salt affected soils are spread in arid and semi-arid parts of India and such soils occupy an area of 10 Mha of which a major part (say 7Mha) is sodic and occurs in Indo-Gangetic alluvial plain (parts of Punjab, Haryana, Rajasthan) followed by the Deccan (Peninsula) plateau supporting black soils; the rest (about 20%), in arid and coastal regions is saline. The major limitations of these soils is the presence of salts, high pH, and presence of high sodium in clay exchange complex, poor physical conditions and low availability of water, multinutrient deficiencies. Despite many limitations, the sodic soils, once ameliorated using gypsum, are used successfully for growing rice followed by wheat.

Water Resources of India and their Utilization in Crops

Water is the most important key input not only for ensuring food security and sustainable socio-economic development but also for impacting the basic existence of life per se, and will continue to play crucial role in enhancing agricultural production in future as well. Even the most fertile lands will fail to realize the productivity potential of the high yielding cultivars without adequate availability of water.

Rainfall

Source of all water is precipitation. On an average over space and time, average annual rainfall over the Indian sub-continent has been estimated at 400 million hectare-meter (M ha-m). About 300 M ha-m of this resource is generated during June to September, while another 100 M ha-m is during the rest of the year. About 20 M ha-m of runoff is brought from outside India, thus making a total of 420 M ha-m of water resource for exploitation and use.

Snow

About one tenth of the depth of snow is added to the depth of rainfall in the Himalayan region to obtain the precipitation. Many of the perennial rivers in north India are fed by snow melt from the Himalayan range in the summer season. It is estimated that about 10 M ha-m of water received in the rivers is from snow melt out of a total of 115 Mha-m which makes about 10% of the runoff received from rainfall.

Surface water

India has been divided into 12 major river basins each having a catchment area exceeding 20, 000 km^2. The total water potential of these basins is estimated at 188 M ha-m. The largest potential of water is available in Ganga/Brahmaputra/Barak and others making a total of 117 Mha-m followed by Godavari and by west flowing rivers from Tapti to Tadri each having an average annual potential of more than 10 M ha-m.

Ground water

Replenishable groundwater resource is mostly derived from precipitation. Out of 400 Mha-m, 215 Mha-m of rain water percolates into the ground, out of which only 50 Mha-m is available for exploitation. The total ground water potential is estimated at 43.1 M ha-m. The Ganga basin has the maximum ground water potential (38%) followed by Godavari basin (9.4%). After deducting the provision for domestic and industrial purposes, the potential available for irrigation is 36.03 M ha-m.

Water is a limiting factor for crop production and its efficient use is a major problem for sustainable agriculture both for irrigated and rainfed areas. It is possible to increase felt that irrigation water use from present level of 40% to 60% with adoption of water use efficiency technologies. Using sprinkler and drip irrigation technologies, water use efficiency (WUE) of 85 to 95% can be obtained. Crops like rice and sugarcane are biggest claimants of irrigation water. Unless steps are taken to regionalize cropping system and water management practices and changes for the water use on volume basis are adopted, the increase in WUE and equitable distribution can not be ensured.

Tilth Requirement of Different Crops

Tillage is the physical modification of soil properties for the purpose of promoting crop production. Different crops require different tilth conditions for optimum growth and development. The tilth requirements of few important field crops are discussed below.

Rice

Low-land rice is grown under submerged conditions. Puddling is done in lowland rice. Puddling should begin about two weeks ahead of transplanting of rice. An earthen bund, about 30 cm high is made around the field to allow the water to stand. After two days of flooding, the field is puddle by three to four runs of a puddler in standing water. Different types of bullock and tractor drawn puddlers are used for this purpose. The maintenance of continuous standing water in rice field is really not essential. Water use efficiency in rice can be largely increased by irrigating the fields to flooding after the recedes to saturated soil conditions.

Wheat

Wheat requires a well-pulverised but compact seed-bed for good and uniform germination. After the harvest of preceding crop, the field is ploughed with disc or mouldboard plough. Where tractor is available one deep ploughing followed by two or three harrowing with disc or tines and 2-3 planking is done to prepare a well pulverized seed bed. In rain-fed area field preparation should be done with great care as conservation of moisture is dependent on it. Fields are usually prepared by giving one deep ploughing followed by two or three ploughings with a *desi* plough and planking.

Maize, Sorghum and Soybean

Maize kernels need a seedbed which is friable, well aerated, moist and weed free to provide better contact between the seed and the soil. There is no need to prepare extremely fine seedbed. The first ploughing should be done with soil inverting plough so that atleast 20-25 cm deep soil may become loose. It should be followed by two or three harrowing or three to four cross-ploughings with a *desi* plough. Planking is to be done after each ploughing. A properly leveled field is required for good water management.

Bajra

Bajra requires a fine seedbed free from clods as the seeds are of very small in size. A deep ploughing (atleast 15 cm deep) with soil-inverting plough followed by two or three harrowing is considered to be optimum. While leveling the field, care should be taken to ensure that rainwater does not stagnate.

Gram

Gram is highly sensitive to soil aeration. It requires loose and well aerated seedbed. This imposes a restriction for its cultivation on heavy soils and calls for special care in seedbed preparation. A rough seedbed is required for gram. Very fine and compact seedbed is not good for gram.

Mustard

A clean and well pulverized seedbed of good tilth is needed for better germination. The land should be well prepared first by ploughing deep with a soil inverting plough, followed by two cross harrowing. Each ploughing/harrowing should be followed by planking so that the soil is well pulverized and leveled.

Groundnut

Although groundnut is a deep-rooted crop but looking to its underground pod forming habit, deep ploughing should be avoided. One ploughing with soil turning plough followed by two harrowing is sufficient to achieve a good surface tilth up to 12-18 cm depth.

Potato

A well pulverized seedbed is required for good tuber formation of potato crop. The field should be ploughed once 20-25 cm deep with a soil turning plough. Thereafter, two to three cross harrowing or four to five ploughings with a *desi* plough should be done. One or two planking are needed to make the surface smooth and well leveled.

Sugarcane

Sugarcane requires a very thorough and clean preparation of land. In north India, where sugarcane is mostly grown on alluvial loam soils, one ploughing with a soil turning plough followed by two cross harrowing or five to six ploughings with a *desi* plough is enough. Planking should be done to make the field smooth and clod-free. At least one or two deep ploughings and one cross ploughings with a moldboard plough are essential in heavy textured soils of Peninsular India. It should be followed by two or three harrowing to bring the seedbed into fine tilth.

Fig. 2. Zero-tillage seeding

Soil Impedance Layer and their Improvement

In many soils, a compacted layer is commonly found at the bottom of the zone of ploughing. This layer is termed as "plough sole. Use of heavy machines such as tractors intensify problem of surface and sub-surface compaction in soils. These hard compact layers often restrict root penetration and growth and also reduces the nutrient uptake by roots. Shallow root system makes the plant drought prone. In high rainfall areas, the presence of such layers at shallow depth reduces the water storage capacity of the soil with the result that runoff starts even after a short spell rain. Soil compaction changes soil moisture and thermal regimes and mechanical resistance in soils. For enhancing crop growth, the management practices are needed to break the hard compacted layer through chiseling or profile modification of the dry soil up to 40-45 cm depth and to prevent its formation. On the other hand, in highly coarse-textured sandy, loamy sand soils, and in rice fields compaction is beneficial for water retention which reduces percolation loss of water and nutrients.

Soil Water Energy State and Availability in Plants

The retention and movement of water in soils, its uptake and translocation in plants and potential evapotranspiration etc. are related to energy. By using the term 'free energy' status of water can be characterized to indicate the strength with which water is held by the soil particles. The term soil water potential is defined as the work required to be done to move water from its present state (held by soil particles) to a pool of water with zero free energy (the reference state). The movement of water in soil takes place from a high free energy to a lower free energy level. The more tightly the water is adsorbed, the more negative is soil moisture potential. The soil water potential (ψ_w) is a combination of the effect of the surface tension at soil particles and termed as matric potential (ψ_m), the effect of attraction of ions and other solutes for water known as osmotic potential (ψ_s), the atmospheric pressure effects, the pressure potential ((ψ_p) and the elevation effect or the position of water compared to reference level called as the gravitational potential (ψ_g). The total water potential (ψ_t) can be written as follows:

$$\psi_t = \psi_m + \psi_s + \psi_p + \psi_g$$

In saturated soil the pressure potential is usually considered zero. Also in bulk soil situation the osmotic potential is generally zero.

Total soil water potential (ψt) is thus generally the matric potential (ψ_m) and gravitational water potential (ψ_g).

$$\psi_t = \psi_m + \psi_g$$

Soil water potential can be measured in two units at varying energy levels in soil.

pF scale

The free energy is measured in terms of the height of a column of water required to produce necessary suction or water potential at a particular soil moisture level. So the pF may be defined as the logarithm of centimeter height of a water column to give the necessary suction. Here 'p' indicates logarithmic value and 'F' indicates free energy e.g., pF = 4 indicates 10,000 centimeters height of a water column (logarithm of 10,000 = 4).

Relationships between bar, atmosphere and Pascal

Atmosphere or Bar is the average air pressure at sea level. A popular unit bar is equated to a number of other units as follows:

1 bar = 0.9869 atmospheres

The unit used in the original CGS metric system for pressure was the bar. Many of the classical Soil Physics parameters, such as field capacity and permanent wilting point, are still commonly expressed in bars. Therefore, it is useful to know how to convert between bars and SI units. Its relationship with the approved pascal unit of the SI is a decimal one, for 1 bar equals 100,000 pascal.

The following list of identities is also useful in converting between the many units used to describe water potential:

- 1 bar = 100 J/kg
- 1 bar = 100,000 Pa = 0.1 MPa
- 1 bar = 1020 cm
- 1 J/kg = 1000 Pa = 1 kPa

Classification of soil water

Gravitational water: Gravitational water may be defined as the water that is held at a potential greater than -1/3 bar (-0.33 atm or -0.033 MPa).

Capillary water: Capillary water is held in the micropores of soils (capillary pores). This may be defined as the water that is retained in the soil between the water potential -1/3 rd bar (-0.33 atm or -0.033 MPa) to -31 bar (-30.6 atm or -0.031 MPa).

Hygroscopic water: Hygroscopic water is defined as the water that is held by the soil particles at a suction more than -31 bars (-30.6 atm or -0.031 MPa).

Soil moisture constants

Soil moisture constants and their approximate equivalents in bars of water potential as they affect the relative availability of water to plants are shown in Fig.3.

Saturation water content: The saturation water content refers to the water content at which all the pore spaces, including the expanding space of clay minerals, are filled with water and matric potential is zero.

Non-capillary water: It refers to the volume of water that is drained from a saturated soil subjected to a suction of 60 cm bar. The water remaining in soil is called as capillary water.

Drainable pore volume: It is the volume of water that is drained when a saturated soil is subjected to a suction of 100 cm.

Field capacity: It is defined as the amount of water retained in the soil after the downward water movement from a pre-saturated soil has 'materially' ceased. Generally it is taken as -1/3 bar. It could be 0.1 to -0.03 bar depending upon soil texture.

Wilting point: It refers to the soil moisture content at which plant roots cannot extract water at a rate sufficient to meet the transpiration needs. At this moisture content, plant loose cell turgidity and show symptoms of wilting. The matric potential corresponding to this moisture content is -15 bar.

Plant available water: The water retained in soil between field capacity and wilting point is known as plant available water.

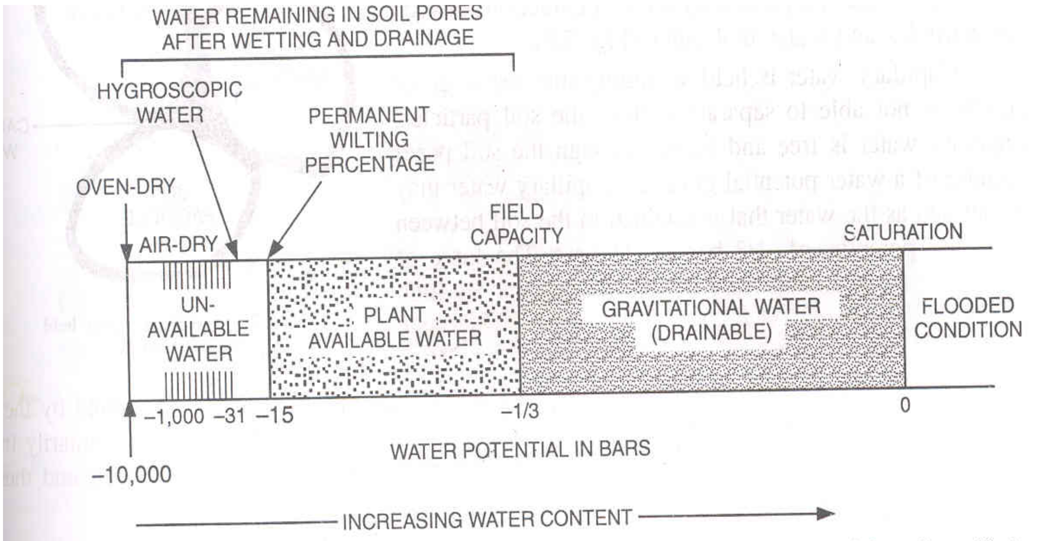


Fig. 3. Soil water constants and their approximate equivalents in bars of water

Water Harvesting Techniques

Many water harvesting structures and water conveyance systems specific to the eco-regions and cultures have been developed. Rainwater harvesting, its conservation and efficient utilization can solve problem of water scarcity to the great extent. Half moon terraces or *demi-lunes* are semi-circular beds of appropriate diameter with the shape resembling a half moon (Fig. 4.). These terraces are recommended for fruit trees or other plantation crops on steep slopes. Rainwater harvesting in small ponds (*nadis*), underground tanks (*tankas*), *khadins* (low lying areas) etc. is an age-old tradition in arid zone of Rajasthan (Fig. 5). *Nadi* is a dugout pond used for storing runoff water from adjoining catchments during rainy season. Rainwater harvesting for groundwater recharge percolation tanks with infiltration galleries, sand filled dam, *anicuts* across the stream, sub-surface barriers etc. are used.

Fig. 4. Half moons or *demi-lunes*

Appropriate harvesting of rainwater from roof top and open and can alleviate the problem of contaminants like fluoride, arsenic, selenium contamination. Farm ponds are water bodies made by constructing an embankment across a water course or excavating a pit or by combining both. The dug-out ponds are recommended for areas with flat topography whereas the impounding type farm ponds are developed on water courses in the regions with rolling topography. Among different shapes, cylindrical ponds offer geometrical advantage of maximum storage per unit perimeter. Low earthen dams are commonly used in the areas with preponderance of water streams. They are constructed on the basis of engineering principles across water courses for creating a water reservoir.

Fig. 5. *Khadins or dhora* are popular in Rajasthan

In addition there are special water harvesting structures traditionally in use in the Himalayan region which are described below:

Zings: *Zings* are water harvesting structures found in Ladakh and Spiti valley (Fig. 6). The are small tanks in which melted glacier water is collected. Essential to the system is the network of guiding channels that brings the water from glacier to the tank.

Fig. 6. *Zings* are used to collect snow melted water

Naula: *Naula* is a surface-water method typical to the hill areas of Uttarakhand and Himachal Pradesh. These are small wells or ponds in which water is collected by making a stone wall across a stream.

Khatri: *Khatris* are structures, about 10 × 12 feet in size and six feet deep carved out in the hard mountain rock.

Kuhl: *Kuhls* are surface channels diverting water from natural flowing streams or from glaciers to villages. The flow of course is from upper regions to lower regions and movement is due to gravity.

Apatani: *Apatani* is wet-rice cultivation cum fish farming system practiced by Atapani tribes in Arunachal Pradesh. In Apatani system, valleys are terraced into plots separated by 0.6 m high earthen dams supported by bamboo frames. The inlet of low-lying plot functions as an outlet of the high lying plot.

Zabo: The rain falls on a patch of protected forest on the hill top as the water runs off along the slope, it passes through various terraces. The water is collected in pond-like structures in the middle of the terraces. Towards the foot of the hill are paddy fields, where the run-off ultimately meanders into.

Bamboo drip irrigation

About 19-20 liters of water entering the bamboo pipe system per minute gets transported over several hundred miters and finally gets reduced to 20-80 drops per minute at the site of the plant (Fig. 7).

Fig. 7. Bamboo drip irrigation

Effect of Water Quality on Soils and Plants

The suitability of waters for crop production is judged from the long term effects on the soil productivity. Irrigation with poor quality water deteriorates the soil properties and creates conditions unfavourable for economic growth of crops. The most common problems resulting from irrigation with poor quality water can be due to salinity, sodicity and toxicity hazards.

Salinity hazard

The most important criterion for evaluating a given water is its total salt concentration. The quantity of salts dissolved in irrigation water is usually expressed in terms of electrical conductivity (EC), mg/L or meq/L.

Mostly cations like Na^+, Ca^{2+}, and Mg^{2+} and anions like Cl^-, SO_4^{2-}, HCO_3^- and CO_3^{2-} are the major salt constituents contained in saline water. Plant growth is adversely affected with saline irrigation primarily through the effects of excessive salts on osmotic pressure of the soil solution, though excessive concentration and absorption of individual ions e.g., Na, Cl, B etc. may prove toxic to plants and /or retard the absorption of other essential plant nutrients.

The reduced water availability at high salinity thus causes water deficits for plants and plant growth gets inhibited when soil solution concentration reaches critical threshold salinity. High salinity in irrigation water causes poor germination of seeds. High salinity in soil interferes with the availability of essential plant nutrients.

Table 1: US Salinity laboratory's grouping of irrigation water

Classification of water		Electrical conductivity in mhos/cm at 25 oC (EC)	Salt concentration in g/L (aaproximate)
C1	*Low salinity water* can be used for irrigation with most crops on most soils, with little likelihood that a salinity problem will develop. Some leaching is required , but this occurs under normal irrigation practices, except in soils of extremely low permeability	0<EC≤250 (0.25 ds/m)	<0.2
C2	*Medium salinity water* can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most instances without special practices for salinity control.	250<EC≤750 (0.25 ds/m)	0.2-1.5
C3	*High salinity water* can not be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.	750<EC≤2250 (0.75-2.5 ds/m)	0.5-1.5
C4	*Very high salinity* water is not suitable for irrigation under ordinary conditions but may be used occasionally under very special circumstances. The soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching and very salt tolerant crops should be selected.	2250<EC≤5000 (2.5-5.0 ds/m)	1.5-3.0

Sodicity hazard

Another important measurement of water quality is the relative amount of sodium (sodicity) of the water. Irrigation waters with high sodium content tend to produce soils with high exchangeable sodium levels. Such soils frequently crust badly and swell or disperse, greatly decreasing the hydraulic conductivity or intensities of permeability. Decreased permeability can interfere with the drainage required for normal salinity control and with the normal water supply and aeration required for plant growth.

Several methods were proposed for expressing the sodium hazard. Previously waster quality was defined on the basis its sodium percentage alone. The soluble sodium percentage (SSP) may be calculated by the formula:

SSP = [soluble sodium concentration (me l-1)/total solub;e cation concentration (meq/l)] × 100

Workers at the U.S. Salinity Laboratory proposed the sodium adsorption ratio (SAR) to characterize the relative sodium status of irrigation waters and soil solution:

$SAR = [Na^+]/[[Ca^{2+} + Mg^{2+}]/2]^{1/2}$

The ionic concentration are expressed in meq/l. As indicated in Fig.8, an empirical relation has been drawn up between SAR and ESP. in meq/lit.

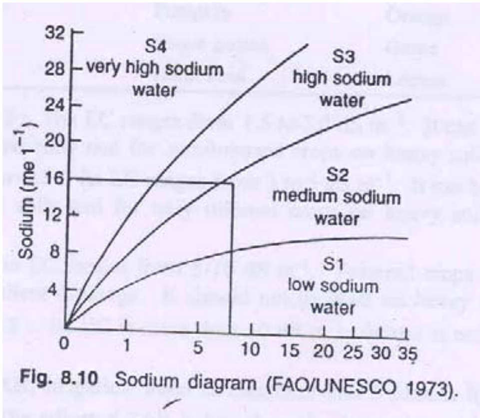


Fig. 8. Sodium diagram (FAO/UNESCO, 1973)

The classification of water according to the SAR is also related to the water's electrical conductivity. Four groups are indicated: low, medium, high and very high electrical conductivity. For EC = 100 micromhos/cm, the dividing points are at the SAR values, 6, 10 and 18 (Fig. 3).

Residual sodium carbonate is another empirical approach used to assess sodicity hazard of carbonate and bicarbonate rich waters. Presence of such anions in irrigation waters results in precipitation of calcium and magnesium of the soil and thus increases sodicity hazard of waters. The RSC is expressed as:

$$RSC = (CO_3^{2-} + HCO_3^{2-}) - (Ca^{2+} + Mg^{2+})$$

where all concentrations are in meq/lit.

Boron toxicity hazard

Irrigation water also contains potentially toxic ions such as boron, fluoride, lithium, sodium, and chloride. High accumulation of boron in plants causes necrosis and may sometimes reduce leaf size to the extent of significantly reducing photosynthesis. Relative tolerance of crops to boron is given in Table 1. The crops at the top of the column semi-tolerant would be injured more severely. Probably all the crops listed in the first column could be irrigated with water containing 2.0 ppm boron without serious injury. Sprinkling water high in sodium or chloride on the leaves of horticultural plants and vegetables, fruits, and berry crops can cause plant damage.

Table 2: Limits of boron in irrigation water for crops of different degrees of boron tolerance

Tolerant (2-4 ppm)	Semitolerant (1-2 ppm)	Sensitive (0.3-1.0 ppm)
Date palm	Sunflower	Walnut
Sugar beet	Potato	Plum
Alfaalfa	Cotton	Pear
Onion	Tomato	Apple
Turnip	Radish	Grape
Cabbage	Barley	Cherry
Lettuce	Wheat	Peach
Carrot	Pumpkin	Orange
	Sweet potato	Grape
	Lima bean	Lemon

Soil Aeration Problems and Management

A well aerated soil must have generally 20-30% air space for ready movement of essential gases into and out of soil pore spaces. When a soil is subjected excess to excess moisture so that gases in most of the pore spaces are replaced by water, the soil becomes sick. Excessive wetness degrades soil physically and chemically. Loss of soil strength encourages soil erosion, facilitates soil compaction, and impedes trafficability. Chemical and biological reduction under anaerobic soil conditions diminishes the availability of many essential plant nutrients, especially nitrogen, and solubilizes some other to potentially toxic levels. The major effects of excessive soil water on crop yield are caused by reduced exchange of air between the atmosphere and the root zone. Wet soil conditions may result in a deficiency of oxygen required for root respiration, an increase in carbon dioxide and the formation of toxic compound in the soil. Root respiration is essential for absorbing nutrients from the soil. The inadequate interchange of gases between the soil and the free atmosphere depends on two factors: (i) the rate of biochemical reactions influencing the soil gases, and (ii) the actual rate at which each gas is moving into or out of the soil. The cultural practices that encourage air filled pore spaces and the gaseous exchange improve soil aeration.

Improving soil structure

The practices that help in the maintenance of stable soil aggregates such as use of animal manure, green manure, plant residue manure and growing of legume crops, will in turn encourage better soil aeration.

Drainage

The soils get filled with water due to continuous seepage from canals, presence of perched or high water tables, and after heavy rains or irrigation. The drainage of such fields is essential for the supply of sufficient oxygen.

Cultivation

A light cultivation of soil or intercultural operation does not only control weeds but also helps in the exchange of gases, especially in heavy-textured poorly drained soils. Bed furrow sowing minimizes the risk of waterlogging.

Plant adaptations

Plant roots, in general, are adapted to aerobic respiration. However, some of the plant species develop mechanisms such as increase in the air space of roots (root porosity) or internal aeration through leaves and cortex cells and thereby can grow even in oxygen-deficient soils. The selection of crop species, therefore, is important for growing crops in waterlogged or poorly drained soils. For examples, rice thrives well in submerged soil conditions. Also, soybean crop can tolerate temporarily waterlogged soil conditions better than maize, pigeonpea and other deep rooted crops. Appropriate time of sowing/planting could avoid period of waterlogging at critical growth stages.

Soil Thermal Regimes in Relation to Crops and their Optimization

In nature, soil temperature varies continuously in response to the ever changing meteorological regime acting on the soil-atmosphere interface. That regime is governed by a regular periodic succession of days and nights and of summers and winters. Yet the regular diurnal and annual cycles are perturbed by irregular episodes such as cloudiness, cold waves, warm waves, rainstorms or snowstorms, and period of drought. When sun rays strike the ground, the energy it carries is partly absorbed by the soil, thereby surface soil gets heated and a difference of temperature between the surface soil (hotter) and the subsurface soil (cooler) is created. This difference of temperature causes the heat to flow downward. The difference between maximum and minimum temperature is the highest at the soil surface and decreases with depth and becomes small beyond 0.25 m. The temperature maxima at still lower depths occur during night when the upper part of the profile starts cooling rapidly.

Soil temperature influences the plant growth only indirectly, by affecting the physical, chemical and biological processes in soils and plants. Seeds of the most crop species germinate within a reasonable time between 10 and 35 ^{o}C. Unfavourable temperatures prevent the emergence of many tender seedlings. The temperature optima for root growth of most crop species are between 20 and 25 ^{o}C. The optimum temperature for the activity of most of the microorganisms is between 25 and 35 ^{o}C. A low temperature produces toxic substances which are injurious to plants, whereas a high decomposition rate at optimum temperature usually results into the products which are beneficial to plants.

Management of soil temperature

The primary source of heat energy to soil being sun, practices encouraging the heat absorption and the flow in soil and those discouraging heat loss to the atmosphere would help in heat storage and temperature rise. The soil temperature under field conditions can thus be altered by mulching and vegetation, tillage, compaction, irrigation and drainage.

***Mulching*:** Straw mulches intercept both incoming and outgoing radiations from soil and therefore reduces the soil temperature fluctuations. On the other hand mulching with polyethylene sheets raises the soil temperature during the day time.

***Tillage*:** Tillage of any kind affects the pore distribution and wetness and consequently the soil temperature. Rapid changes in soil temperature are observed in ridges, whereas furrows are generally cooler. A tilled-surface soil is generally warmer during the day time because of its higher porosity and low thermal conductivity than a compacted-untilled soil.

Soil compaction: Compaction in soil brings its particles closer and regulates temperature in the root zone. The abrupt changes in soil temperature, observed in surface layers of loose soil, do not occur in a compact soil due to its high thermal conductivity.
Irrigation and drainage: The soil water controls absorption of solar radiation, loss of heat energy to the atmosphere, and movement of heat in soil. Water resists changes in soil temperature because of its high specific heat and high heat of vaporization. A wet soil conducts heat faster than dry soil and therefore, temperature fluctuations in the surface layers are rapid and approach extreme values easily in drier soils than in wetter soils. The raising of soil temperature by draining of waterlogged fields and stabilizing soil temperature by irrigating dry fields are the common practices used by farmers. The irrigation in summer causes large evaporative cooling of the surface soil.

Recycling of Agricultural and Industrial Organic Wastes

Modern agriculture the world over depends upon the external application of plant nutrients to meet crop needs. The main reason for human intervention in the natural nutrients supply systems is that soil reserves or natural recycling can not provide large amounts of nutrients needed year after year to harvest the quantum of crop produce required for human consumption and as industrial inputs. It is now abundantly clear that no single source of plant nutrients can meet the total nutrient needs of modern agriculture, which is expected to take care of increasing human needs. In India for example, the harvested crops removing 9-10 million tonnes more N + P_2O_5 + K_2O each year than the total additions through fertilizers. Recycling of wastes in agriculture brings in the much needed organic and mineral matter to the soils. Since most recyclable wastes are organic, they directly add organic matter and the plant nutrients contained in it. While the nutrient input improves soil fertility, the organic input has a profound and vital role to play in improving soil physical properties such as its tilth, water holding capacity and providing a more favourable environment for root growth. Thus waste recycling leads to an improvement of soil productivity, of which soil fertility is the key component. The agricultural wastes include crop residues, oil seed cakes, sugarcane trash, vegetable wastes, dung and urine, human excreta etc. The major industrial wastes having potential in agricultural use include press-mud generated by sugar factories, effluents from paper mills and phosphogypsum generated as a by-product from phosphoric acid industry.

Crop residues are the remnants of crop plants left after the harvested crops are threshed for removal of economic components such as grain and fiber. Being easily accessible to the farmers for use on his land, crop residues can play an important role in maintaining soil productivity. With the production of increased quantities of food grains, the production of crop residues has also proportionately increased. The estimates for India are at about 174 million tones annually. The nutrient potential in terms of N + P_2O_5 + K_2O of these crop residues is 2.47 million tonnes. It is assumed that only one third of the total crop residues generated can be available for soil incorporation two thirds of crop residues in India are used as animal feed and as fuel in rural homes.

A large variety of oilseeds are produced in India. Besides yielding edible oils, a variety of oilseeds obtained from certain trees and shrubs provide non-edible oils. Oilcakes are generally referred to as concentrated organic manures because of their higher nutrient content than conventional bulky organic manures such as FYM and compost. Annual production of non-edible oilseed cakes is the order of 3.8 million tones. On an average this quantity can furnish 87, 25, 57 thousand tones of N, P_2O_5, and K_2O, respectively. Having almost similar content of organic carbon but variable levels of N, P and K, oilseed cakes mineralize easily when added to soil. Notwithstanding the alternative use of edible oilseed cakes as animal feed, both types of materials have been extensively used as organic fertilizers, either alone or in combination with fertilizers.

Composting emerges as the most widely applicable process for handling diverse wastes. A very wide variety of crop residues and nutrient-depleted wastes can be composted as also human wastes, animal wastes, press mud and agro-industrial wastes. Composting takes care of most of the pathogens present in the substrates (Fig. 9.). It also offers a proven avenue for the utilization of low-grade phosphate rocks which can be incorporated into the compost either during composting or at a later stage. Cellulolytic microorganisms such as *Trichoderma* sp., *Celumonas* sp. which hasten the process of composting and occupy a special place in making recycling particularly attractive, as do earthworms. The compost produced with the help of earthworm is known as vermicompost.

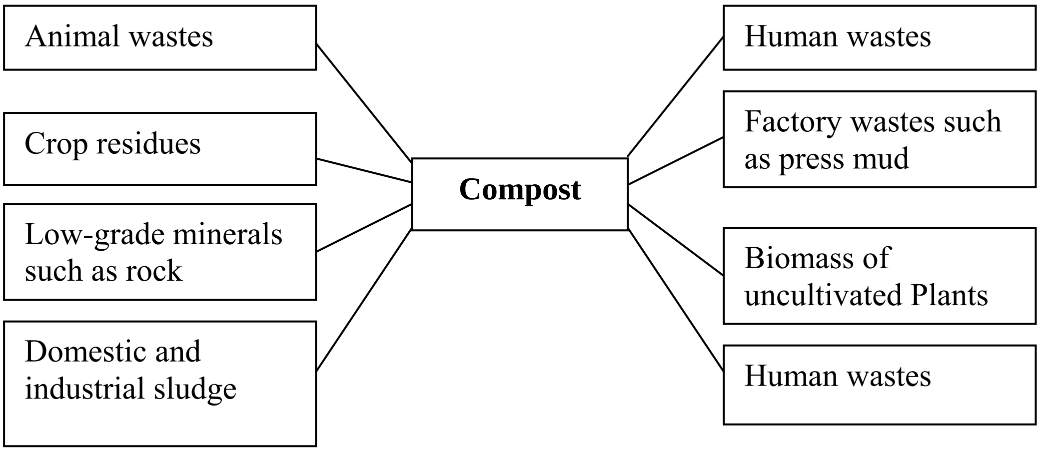


Fig. 9. Compost prepared from various organic and inorganic waste materials

Green manure refers to fresh plant matter which is added to the soil largely for supplying nutrients contained in its biomass. Such biomass can either be grown *in situ* and incorporated or grown elsewhere and brought in for incorporation in the field to be manured. Green manures of special importance are grain legumes such as pigeon pea, green gram, cowpea, soybean, or groundnut. Potential woody multipurpose legumes include *Leucaena leucocephala* (subabul), *Gliricidia sepium*, *Cassia siamea* while non-grain legumes include *Crotolaria*, *Sesbania*, *Centrosema*, *Stylosanthes* and *Desmodium*. Leguminous plants are largely used as green manures due to fixing of atmospheric N and supplying N to crops easily during decomposition. Green manuring is widely practiced in lowland rice. Green manuring has also residual effect in successive crops grown after rice.

There is a large potential for the exploitation of manurial value of biological and industrial wastes in India. The major sources are crop residues, animal excreta, rural compost, domestic and industrial waste water, forest litter, and city refuse, sewage sludge, press mud, biogas slurry, phosphogypsum, basic slag etc. However, extra precautions should be followed while using sewage sludge and city refuse for probable contamination of food chain through soil-plant continuum and from the viewpoint of heavy metal (Pb, Cd, Hg etc.) content.

Biofertilisers have also an important role to play in improving the nutrient supplies. Nitrogen fixing bioinoculants, blue green algae, azolla, azotobacter and azospirillum are important in supplying N to plants. Other bioinoculants like phosphate solubilising microorganism (PSM) and vesicular arbuscular microorganism (VAM) are important for improving phosphorus nutrition of crop plants.

Wastelands and their Management

The dictionary meaning of waste land is that a land which is desolate, barren, or ravaged. As per the Report of the Technical Task Group constituted by the Planning Commission, 1987, the wastelands are the degraded lands which can be brought under vegetative cover with reasonable efforts and which are currently underutilized and the land which is deteriorating for lack of appropriate water and soil management or on account of natural causes. In India, out of 328.8 Mha of geographical area approximately 175 Mha are waste land, producing less than 20% of its capacity (Fig. 10). Approximately 60-80 Mha of cultivated land and 30-40 Mha of forest land are degraded in India. Maximum area under wasteland occurs in Rajasthan (37 Mha) followed by Madhya Pradesh (20 Mha) and more than 10 Mha in each Maharastra, Andhra Pradesh, Karnataka and Gujarat. Many other states also posses wasteland, though in lesser extent. According to the estimates, out of 329 Mha of total geographical land, 23% are the wastelands which fall under the following category:

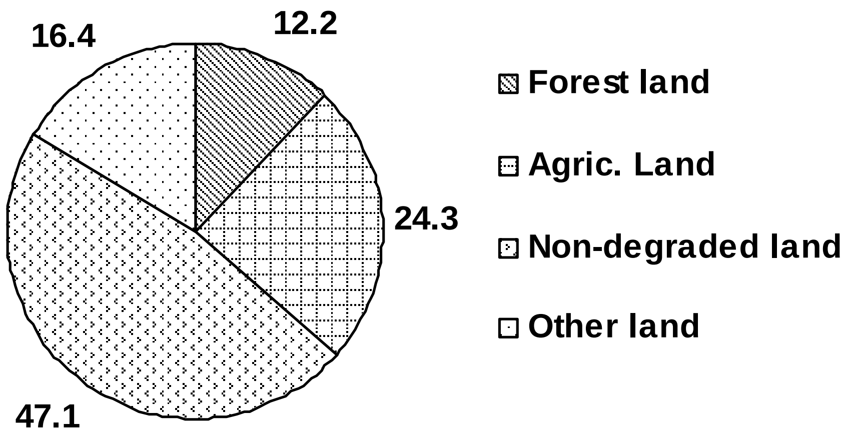


Fig. 10. Per cent distribution of different land uses of total geographical area in India

Non-forest land has the maximum area under wasteland. The waste land is a very broad term which includes any land which is unfit for cultivation. Therefore in a broader perspective it includes eroded land, waterlogged land, desert land, nutrient depleted land, salt affected land, acidic land, polluted land, biologically degraded land. The land engaged in periurban agriculture is also prone to chemical and biological degradation due to use of untreated sewage and effluents emanated from industry as well as domestic fronts. Natural as well as anthropogenic factors are responsible for the formation of wasteland. Natural factors include climate, geology and anthropogenic factors include unwise land use, indiscriminate deforestation, heavy population pressure and ineffective land policies.

Different types of wasteland require different options of management practices. Water erosion can be controlled by various agronomic practices like mixed cropping, intercropping, contour farming, and land practices like contour bunding, bench terracing, gully plugging etc. Wind erosion can be controlled by providing windbreaks, shelterbelts, conservation tillage practices, growing cover crops etc. Wind erosion is the main cause for desertification and can be controlled by the above measures. Sodic soils are managed by ameliorating it with gypsum application followed by irrigation. Provision of adequate drainage to lower the water table and leach out the soluble salts is imperative for amelioration of saline soils. Soil acidity could be reclaimed by adding liming material. Decline in soil fertility could be checked by judicious application of inorganic, organic and bio-fertilizers. Inclusion of legumes in the cropping system is also advantageous. Indiscriminate use of irrigation water causes the rise in water table responsible for waterlogging and secondary salinization. Waterlogging also takes place in the depressions, back swamps of rivers and streams, tidal flats of estuaries, deltas and coastal regions. Sometimes presence of gypsiferrous hard layer in profile accentuates the problem. Proper irrigation, engineering and land use management is required for waterlogged soils.

Reclamation and Management of Acidic, Saline and Sodic Soils

Soil acidity may be defined as the soil system's proton (H^+) donating capacity during its transition from a given state to a reference state. Soil acidity involves intensity and quantity aspects. The intensity aspect is universally characterized by the measurement of H^+ ion activity, expressed as pH. The quantity aspect is characterized directly or indirectly by the quantity of alkali required to titrate soil to some arbitrarily established end point.

Sources of soil acidity

Leaching due to heavy rainfall: Leaching of bases is the prerequisite for the formation of acid soil. Soils become rich in insoluble compounds of Al and Fe. The nature of these compounds is acidic. Therefore acid soils are found in high rainfall regions. The clay exchange complex is dominated with exchangeable H^+ ions.

Acidic parent material: Some soils have developed from parent materials which are acid, such as granite.

Acid forming fertilizer: Nitrogen in any form (amide, ammonium or nitrate), sulphur and chloride in fertilizers lead to the formation of nitric, sulphuric and hydrochloric acid which are responsible for leaching of Ca and other bases. This leads to the development of acidity. Lime required to neutralize acidity caused by 100g of different fertilizer is given below:

Table 3: Lime requirement of various nitrogenous fertilizers

Fertilizer	Lime required kg/100 g fertilizer
Ammonium sulphate	110
Urea	84
Anhydrous ammonia	148
Calcium ammonium nitrate	0
Diammonium phosphate (DAP)	55
Single superphosphate	0
Potassium sulphate or potassium chloride	0

Humus and other organic acids: Humus in soils occur in soil as a result of microbiological decomposition. It has different functional groups like carboxylic (−COOH), phenolic (−OH) etc. which can protonate (H^+) to casue soil acidity. Carbon dioxide is the end product of soil respiration and decomposition of organic matter and produces carbonic acid (H_2CO_3).

Aluminosilicate minerals: At low pH values most of the aluminium ion is present as hydrated aluminum ions which undergoes hydrolysis and release hydrogen ions in the soil solution.

$$Al^{3+} + H_2O = Al(OH)^{2+} + H^+$$

$$Al(OH)^{2+} + H_2O = Al(OH)_2^+ + H^+$$

$$Al(OH)_2^+ + H_2O = Al(OH)_3 + H^+$$

$$Al(OH)_3 + H_2O = Al(OH)_4^- + H^+$$

It is also possible that structural OH^- ions at corners and edges of clay minerals may dissociate H^+ ions and develop acidity.

Distribution

Out of 157 Mha of cultivated land in India, 49 Mha are acidic, of which 26 Mha of land have soil pH less than 5.6 and the rest 23 Mha have a pH range 5.6 to 6.5. Due to wide variation in climatic conditions, there is occurrence of acid soils of widely divergent nature. Acid soils of India may be laterites, lateritic red, mixed red, black and yellow, ferruginous red, podsolic brown forest and peat soils.

Characteristics

Low pH, high proportion of exchangeable H^+ and Al^{3+} are the main characteristics of acid soils. Kaolinitic and illitic type of clays are dominant in these soils. Halloysite has been detected in few cases. These soils have low CECs and low base saturation.

The adverse effect of acid soils on plant growth is mainly related to the presence of aluminium, manganese and iron in toxic concentration, deficiency of calcium and magnesium, nutrient imbalance and reduced microbial activities. The aluminium has multiple effects, of which the inhibition of root growth is perhaps the most important. Manganese toxicity may show up in soils having pH below 5.0. The acid soils are generally low in available phosphorus and have high phosphate fixation capacity. Soil acidity retards biological N fixation. The population of bacteria and actinomycetes are lower, and those of fungi higher in acid soils than in neutral soils.

Management

Acid soils can be managed either by growing crops suitable for a particular soil pH or by ameliorating the soils through the application of lime. Liming raises the soil pH. The reaction that takes place by lime application is given below:

$$CaCO_3 + H_2O + CO_2 \rightarrow Ca(HCO_3)_2$$

$$Ca(HCO_3)_2 \rightarrow Ca^{2+} + 2HCO_3$$

$$H\text{–}Soil + Ca^{2+} \rightarrow Ca\text{–}Soil + 2H^+$$

$$H^+ + HCO_3 \rightarrow H_2CO_3 \leftrightarrow H_2O + CO_2$$

The higher the soil moisture, the more is the rate of reaction. The H^+ ions react to form weakly dissociated water and the calcium ions undergo exchange reactions to replace further exchangeable H^+, thus producing acidity.

The *lime requirement* of a soil is the amount of liming material that must be added to raise the soil pH to some prescribed value, usually in the range of 6.0 to 7.0. SMP buffer method (Shoemaker et al.,1961) is used for the determination of lime requirement of an acid soil.

‘Lime factor’ may be defined as the factor by which the actual amount of lime can be calculated from the estimated theoretical amount of lime. This factor varies from 1 to 3, depending on rate of limestone solution, plant uptake and leaching during the reaction period.

Application of liming material in combination with NPK fertilizers has shown increase in yield of wheat, maize, jower and jute. On the basis of experiments carried out in Bihar and differential responses of crop to liming, upland crops were grouped as (1) high response group (pigeon pea, soybean, cotton), (2) medium response group (gram, lentil, peas, groundnut, maize, sorghum), (3) low or no response group (small millets, rice, potato etc.).

Salt-affected Soils

Some amounts of salts are always present in soil. When the concentration of these salts is low, they are not harmful for the growth of plants. But with the increase in salt content of the soil to high levels, plant growth is adversely affected which in turn, decreases the productivity of agricultural crops. Salt-affected soils are classified into two main categories viz., saline soils and sodic or alkali soils. Sodic soils are again subdivided into saline sodic soils and non-saline sodic soils.

Distribution

Both kinds of salt-affected soils (saline and sodic) occur in different parts of India. Table 1 shows the distribution of such soils based on the existing information. Sodic soils tend to occur in a geographical zone distinct from the zone where saline soils tend to occur.

Table 4: Geographical distribution of salt-affected soils of India

No.	Type	Approximate area (M ha)	States in which the soils occur
1.	Coastal salt-affected soils		
	(a) Coastal salt-affected soils of arid regions	0.7	Gujatrat, West Bengal
	(b) Deltaic salt-affected soils of the humid regions	1.4	Orrisa, Andhra Pradesh, Tamil Nadu, Karnataka
2.	Salt-affected soils o the black soil region	1.3	Madhya Pradesh, Andhra Pradesh, Maharastra, Rajasthan
3.	Salt-affected soils of the arid and semi-arid regions	1.0	Rajasthan, Punjab, Haryana, U.P.
4.	Salt-affected soils of the Indo-Gangetic alluvial plains	2.5	U.P., Bihar, Rajasthan, M.P.
	Total	6.9	

Source: Review of Soil Research in India (1982), 2, 636.

Saline soils

The major salts which lead to the formation of saline soils include chlorides, sulphates, and carbonates of calcium, magnesium and potassium. The contents of potassium salts are generally low. Under dry arid conditions, large amounts of salts of boron, nitrates, and fluorides can also accumulate. Soil salinization is a problem in arid and semi-arid areas where annual rainfall is less than 55 cm. Primary minerals, ground water, sea water, irrigation water, salts blown by wind and excessive use of basic fertilizers (sodium nitrate and basic slag) can be a source of salts.

Characterization: These soils contain excess of neutral soluble salts dominated by chlorides and sulphates which affect plant growth. These soils have pH of saturation paste (pH_s) less than 8.5, exchangeable sodium percentage (ESP) less than 15, and electrical conductivity (EC) more than 4 ds/m at 25 oC. However, based on Indian experience saline soils have been defined as those having pH_s less than 8.2, the EC_e more than 4 dS/m and predominance of chlorides and sulphates of sodium, calcium and magnesium. The ratio of $[Na]/([Cl + SO_4])$ in soil solution is less than 1.0.

Excessive salts in the soil solution increase the osmotic pressure of soil solution in comparison to cell sap of plant roots that grow in soil. This osmotic potential decreases free energy of water and makes it difficult for plant roots/microorganisms to extract water. During a dry period, salt in solutions may be so concentrated as to kill the plants/microbes by dehydration by pulling water from them through ex-osmosis. When the concentration of soluble salts increases to a high level then it produces toxic effect directly to plants such as root injury, inhibition of seed germination etc. High pH in saline soils causes the deficiency of micronutrient (Fe, Mn, Zn, Cu) and adversely affects the microbial activity in soils.

Reclamation: Removal of excessive salt to a desired level in the rooting zone is the basic principle of reclamation of saline soils. Leaching with water of good quality and drainage are the two essential components of any permanent solution of the salinity problem. The leaching requirement has been defined as that fraction of water that must be leached through the root zone to control soil salinity at a specified level. This is simply the ratio of equivalent depth of the drainage water to the depth of the applied water and may be expressed as fraction or percentage.

$LR = EC_{iw}/EC_{dw}$, where LR is leaching requirement, EC_{iw} and EC_{dw} indicate electrical conductivity of applied water and drainage water, respectively. Ponding of water is the most commonly used method for leaching excessive salts from saline soils.

Management: Water management and cropping system are very important for crop production on saline soils. Proper water management for raising crops is also essential to control further development of soil salinity. For optimum crop production in saline areas, selection of crops and crop varieties, adoption of best suited cultural and fertilizer practices are essential. Rice is considered a satisfactory crop during the initial years of reclamation. The practice of ponding of water for growing rice dilutes salt concentration in soil and causes leaching of salts under saturated condition. Cultivation of high salt tolerant crops like sesbania, rice, sugarcane, oats, lucerne, fenugreek, barley etc. could be an alternate option for managing saline soils.

Sodic soils

The distinguishing characteristics of a sodic soil are: pH > 8.5, ESP > 15% and ECe < 4 dS/m. Out of the estimated 2.8 million hectares of sodic soils, about 2.5 million hectares occur in the Indo-Gangetic plains of Uttar Pradesh, Haryana, and the Punjab. Sodic soils occur in the states of Bihar, Gujarat, Karnataka, Madhya Pradesh, Maharastra, Rajasthan, and Tamil Nadu.

Saline-sodic soils

Soils containing both high soluble salt and high exchangeable sodium levels are called saline-sodic soils. These soils are formed as a result of salinisation and alkalization processes.

Characterization:These soils are characterized by ECe more than 4 ds/m, pHs typically less than 8.5 and ESP more than 15. Such soils generally limit plant growth by their high soluble salt levels. The main hazard occurs on leaching these soils for removal of soluble salts. Leaching removes soluble salts more rapidly than it removes exchangeable sodium, causing their conversion to sodic soils. The presence of excessive salts as well as high ESP adversely affects the plant growth. Because of high sodium these soils exhibit poor physical condition (low permeability).

Reclamation: Application of gypsum followed by leaching excess salts is the main reclamation measure used.

Non-saline sodic soils

These soils have sufficient sodium saturation and alkalinity to adversely affect plant growth and crop productivity. In some parts of India, they are called '*Usar*" , while in others they are called '*Kallar*'.

Characterization: Non-saline sodic soils are characterized by pH_s more than 8.5, ESP more than 15 and EC_e less than 4 ds/m at 25^o C. Due to high ESP, the soils are are dispersed and deflocculated. Impeded drainage condition, low infiltration and low hydraulic conductivity are the most significant physical properties. High pH of the soils lowers the availability of the plant nutrients except molybdenum and phosphorus. In the field, sodic soils are reported to give an appearance of grayish white efflorescence.

Reclamation: Reclamation of sodic soils requires neutralization of sodicity and replacement of most of the sodium ions from the soil-exchange complex by the more favourable calcium ions, as given by the expression.

$$2Na\text{-}X + Ca^{2+} \text{(solution)} = Ca\text{-}X + 2Na \text{ (solution)}$$

where 'X; is soil–exchange complex. After application of amendments it is essential to leach the replaced sodium from the soil solution with good quality irrigation water.

This can be accomplished by gypsum ($CaSO_4.2H_2O$), calcite ($CaCO_3$) and acids or acid formers (elemental sulphur, sulphuric acid, sulphates of iron and aluminium, pyrites, lime-sulphur). For reasonable crop production on a sodic soil, the lowering of the ESP to the level of 10 is considered sufficient. The amount of gypsum required to be added to a sodic soil to lower the ESP to a desired value is known as *gypsum requirement*. Pyrites produce sulphuric acid which reacts with calcium carbonate to form calcium sulphates. The reactions are as follows.

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

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

Management: Proper choice of crops, adoption of best suited cultural and crop management practices are essential for management of sodic soils. Growing of crops tolerant to high exchangeable sodium can ensure reasonable returns during the initial years of reclamation. Different types of grasses like karnal grass, Rhodes grass, para grass, Bermuda grass, rice and sugar beet are very tolerant to high sodicity in soil. Cropping practices should include a green manure crop and/or a legume is common.

Soil Erosion

"Erosion" means wearing away. Uneven land surfaces are being continually eroded by running water, wind, ice, or other geological agents. The eroded materials are then deposited in valleys and alluvial plains. Soil erosion is defined as the detachment and transportation of soil mass from one place to another through the action of wind, water in motion or by the beating action of rain drops (Fig. 11). Erosion extensively occurs in poorly aggregated soils (low humus) and in soils having a higher percentage of silt and very fine sand. Only two major types of erosion, water and wind erosion will be discussed.

Water erosion

It is the removal of soil from the land surface by water, including runoff from melted snow and ice and is one of the major causes of soil degradation. Based on the nature of deformation of land surface, water erosion may be of four types, splash, sheet, rill and gully.

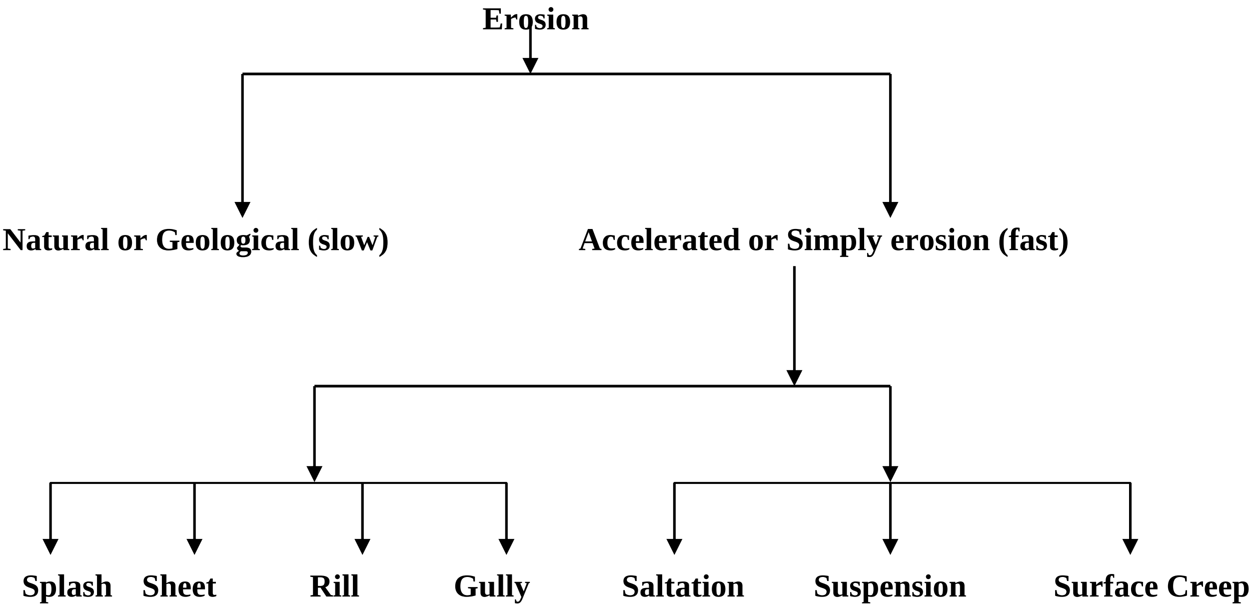


Fig. 11. Classification of soil erosion

Splash erosion: Splash erosion is the scattering of detached soil particles by the impact of raindrops. A raindrop produces three important effects: (a) its beating action that breaks down the soil aggregates, (b) it detaches soil particle, (3) its splash after touching the ground causes displacement of soil. The continued impact of raindrops compacts the soil and further seals the surface, so that water can not penetrate the soil and as a result causes more surface run off. On sloppy land, splash may cause considerable soil movement. Under low intensity and low rainfall conditions if the dispersed material is not removed by the run off, it forms a hard crust after drying. Such conditions adversely affect germination and growth of crops.

Sheet erosion: Sheet erosion is the removal of a fairly uniform layer of surface soil by the action of rainfall and runoff water. This type of erosion, though extremely harmful to the land, usually goes unnoticed. This is very common on gently sloppy land. Muddy runoff from the field is an indication of sheet erosion. Soils subjected to sheet erosion are either lighter in colour than their normal neighbours or else manifest concretions on the surface. The most serious sheet erosion occurs in red and black soils, occupying 69 and 67 Mha of land, respectively in the country.

Rill erosion: Rill erosion is the formation of a few centimeters deep small channels all over the field along the water course. It generally develops on bare and unprotected land where soil conservation measures are not adopted. In advanced stage, it may take the shape of gullies. The rill erosion is the intermediate stage between sheet and gully erosion. The rills can be removed by normal tillage operations during cultivation .

Gully erosion: Gully erosion is the removal of soil by running water, with the formation of channels that can not be smoothened out completely by normal agricultural operation or cultivation. It is the advanced stage of rill erosion. Rills with more than 30 cm depth are generally called gullies. An intricate network of severe gully erosion forms ravines. These may be seen in roughly triangular areas formed by joining gullies in the Chambal, Jamuna, Betwa, Dhasan and Manas river basins.

Factors affecting water erosion

The major factors affecting water erosion are climate, topography, vegetation and soil. The relationship can be written as:

$$E_w = f(c, t, v, s)$$

where E_w is the erosion due to water, c is the climate, t is the topography, v is the vegetation and s is the type of soils.

This equation comprises two types of variables- controllable and uncontrollable. Climate, topography and some physical characteristics of soils can not be directly controlled.

Climate: The major climatic factors influencing runoff and erosion are rainfall, temperature and wind, of which rainfall is the most important. Wind also influences the angle and impact of raindrops. The amount, intensity, frequency and duration of rainfall influence the runoff. The intensity of rainfall is important since a heavy rainfall with low intensity causes less erosion as compared to low rainfall with high intensity.

Topography: The land slope, its degree and length is important in determining the extent of soil erosion. Higher the degree of slope and more its length, more is the soil erosion due to increased velocity of water running down the slope. Erosive power increases four times and carrying capacity 64 times. Similarly the velocity of winds and storms also affects soil erosion in arid regions. Large sand dunes are transported from one place to another within no time due to action of high wind velocity.

Vegetation: A good vegetative cover like thick growth of grass or a dense forest canopy of vegetation nullify the effects of climate, topography and soil on erosion. The thick canopy of vegetation intercepts the rain water and the rooting system improves the binding capacity of the soil particles as well as infiltration. It also reduces the velocity of runoff water and increases time for runoff water and increases time for run off water to infiltrate into soil. A good vegetative cover also protects the soil from wind erosion by reducing the velocity of wind and maintaining good soil aggregation.

Soil: Erodibility of the soil is influenced by its physical and chemical properties. It is influenced by the soil texture, structure, organic matter, nature of clay and the amounts and kinds of salts present. Soil texture and structure influences the soil erosion indirectly through the influence of infiltration and permeability. A coarse textured soil (sandy) has very high rate of infiltration of water and permits very little runoff. On the other hand, a fine textured soil (clay) containing a large number of micropores which results in low infiltration rate and thus accelerates soil erosion through surface run off. During the dry part of the season when the soil water is low, wind erosion is significant. Soil water decreases soil erodibility by wind. The cohesive force of water film even at the stage of permanent wilting point resists wind erosion. Soils that are not aggregated due to low content of clay and organic matter are susceptible to wind erosion.

Effects of erosion

Erosion causes (i) loss of top fertile soil, (ii) accumulation of sand or other unproductive coarse soil materials on other productive lands, (iii) silting of lakes and other reservoirs, (iv) silting of drainage and other water channels, (v) decreases water table and (vi) fragmentation of land

Estimation of water erosion

Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1978) for predicting soil loss under water erosion as given below.

$$A = R \times K \times L \times S \times C \times P$$

where,

A = Computed soil loss from per unit area

R = Rainfall factor

K = soil erodibility factor

L = slope length factor

C = crop management factor

P = erosion control practice factor

Soil conservation techniques to control water erosion

Soil and water conservation is a combination of all management and land use practices which protect the soil against depletion or deterioration by natural or man-induced factors and improves the productivity of the natural resources on sustained basis. The following soil conservation measures can be adopted for the controlling the soil erosion.

Mechanical measures

Contour bunds: contour bunds are mechanical barriers built across the slope for safe diversion of excess runoff and retaining eroded soil. The land area in between the two bunds gets leveled in due course of time. Due to deposition of eroded soil along the bund, the latter takes the shape of a riser. These risers should be planted with grasses to check their erosion.

Graded bunds: The graded bund is a small earthen bund with slight grade constructed across the slope for safe disposal of runoff. Graded bunds are recommended up to 10% slope for areas where annual rainfall exceeds 800 mm, particularly on clayey and black soils with poor drainage. The purpose of graded bunds is to reduce the velocity of runoff water.

Bench terraces: Bench terracing consists of a series of flat beds having suitable vertical drops along the contour or on suitably graded lines across the general slope of the land. The material excavated from the upper part of the terrace is used to fill the lower part, and a small bund is also raised along the outer edge of the terrace. Bench terraces may be sloping outward, inward or just plane like a tabletop, depending on the rainfall. Suitable drainage provisions are made for diverting excess runoff water.

Half moon terraces: Half moon terraces are semi-circular beds of appropriate diameter with the shape resembling a half moon. These terraces are recommended for fruit trees or other plantation crops on steep slopes.

Grassed water ways: Grasses are well known for their soil binding properties. Planting of grasses on the water ways can reduce the run off of top fertile soil and nutrients and water ponds are constructed en route at appropriate locations to catch the soils.

Gully plugging: The eroding and deepening of gullies can be prevented by gully plugging with live hedges, earth, sand bags, boulders and brick missionary. Smaller gullies can be reclaimed by clearing, minor leveling, disposal of excess runoff through grassed waterways.

Contour trenches: Contour trenches are dug out, piling up the dig-out earth on lower side of the trench, for trapping sediment and runoff at early stage of their movement. These trenches also improve soil moisture and favours quick growth of trees and grasses

Water harvesting ponds: Water harvesting ponds can be dug out to receive excess runoff water constructed down the slope. The water thus collected can be stored and used for irrigation during dry periods.

Agronomic practices

For preventing soil erosion on cultivated lands, proper choice of crops and cropping patterns is necessary, particularly on hill slopes. The protection through vegetative shield, forest cover, grasses, crops and mulches, etc. are some important measures to prevent soil erosion. The following crop management practices can be useful to control water erosion.

Cropping systems: Crops with the ability to develop canopy quickly provide an early protection of the soil. Inter-planting with erosion-resistant crops like cowpea, soybean, etc. is useful. Strip cropping with erosion-resistant legumes along with cereals can conserve rain water and reduce the velocity of runoff.

Crop geometry: It is essential to manipulate the crop layout in the field in a manner which may prevent soil erosion. A closer spacing of rows across the slope can help in this regard.

Contour cultivation: Contour cultivation reduces the runoff to a large extent, thereby reducing the soil and nutrient losses. Contour cultivation as well as furrows and ridges have been found useful.

Contour strip cropping: It is the practice of growing erosion resistant and erosion permitting crops in alternate strips of suitable width along the contour and across the slope which can reduce soil erosion considerably.

Tillage: Low intensity tillage favours consolidation of soil through better structure, infiltration and pore distribution. This imparts erosion resistance. The adoption of zero-tillage or no-tillage has been found effective in reducing soil erosion substantially.

Agroforestry: Growing of multipurpose agroforestry tree species along with agricultural crops is beneficial to reduce soil erosion as well as generating income of the farmers.

Grasses and legumes: Grasses and legumes, by virtue of their canopy over the surface and highly branched root system, play a very important role in soil conservation, by improving biological activity and stabilizing surfaces of waterways.

Wind erosion

Wind erosion is the movement and loss of soil by action of wind. Wind generally operates as a tangential force while transferring soil particles. For soil erosion, the wind force during the dry period is most significant. In northern plains and the desert, the wind speed reaches its maximum during early June and is responsible for wind erosion. Wind erosion in India is probably the highest in and around Rajasthan and the adjoining parts of Punjab, Haryana, Malwa and Gujarat. This type of land destruction occurs wherever land is either unprotected or partially so by vegetation.

Wind erodes the soil in three steps. Initiation of movement, transport either in the air are along the surface and deposition of soil in a new site. Each step is influenced by the condition of air, ground surface and the soil. The soil particles are carried by the wind in three types namely saltation, suspension and surface creep.

Saltation: The bouncing or jumping of soil particles in the size range of 0.05 to 0.5 mm in diameter is termed as saltation. This is the dominant type of soil movement in the process of wind erosion. Saltation movement is caused by the pressure of the wind on the soil particle and collision of soil particles among themselves. The particles are transported horizontally in the direction of the wind. The finer the soil particle the more are they liable to erosion and carried aloft to a considerable distance. The height of the jumps varies with the size and density of the soil particles, the roughness of the soil surface, and the velocity of the wind.

Suspension: The floating of small sized particles in air and their movement by the impact of the soil particles in saltation is called suspension. Once they enter the turbulent air layers, they can be carried away many kilometers. Very fine sand, clay and much of the soil organic matter moves by this process.

Surface creep:Surface creep is the rolling or sliding of large soil particles (0.5 to 2 mm) along the land surface. They are too heavy to be lifted by the wind and are moved primarily by the impact of the particles in saltation rather than by direct force of the wind. Threshold velocity is the minimum wind velocity required to initiate the movement of soil particles.

Factors affecting wind erosion

Some factors that influence the wind erosion are listed below:

(i) Characteristics of wind viz., speed, direction, structure, temperature, humidity and burden carried etc.

(ii) Characters of surface viz., roughness, vegetative cover, obstructions and temperature.

(iii) Topography viz., flat, undulating and broken soil.

(iv) Nature and properties of soil viz., texture, structure, organic matter and moisture content.

In addition to these factors, soil cloddiness, surface roughness and crop residues are also the most important factors which contribute 75 per cent of the variability in the amount of wind erosion.

Estimation of wind erosion

Similar to Universal Soil Loss Equation, wind erosion can be estimated by using the following equation provided by Chepil and Woodruff (1963), which predicts the relationship between annual soil loss by wind erosion from a given field and the five factors influencing wind erosion:

$$E = f\,(I \times K \times C \times L \times V)$$

0where, E = average annual soil loss in tonnes/acre,

I = soil erodibility index indicated by soil aggregates greater than 0.84 mm in diameter and percentage of land slope,

C = climatic factor indicated by wind velocity and surface soil moisture,

K = soil surface roughness

L = unsheltered field width measured along the direction of the prevailing wind, and

V = vegetation cover

The above equation is useful to determine potential wind erosion on any field under existing conditions, of surface roughness, soil cloddiness, vegetative cover, sheltering or width and orientation of field necessary to reduce wind erosion to tolerable level. The vegetative factors that affect wind erosion are: kind of vegetation, height, density etc. Living plant roots and tops are more effective in retarding wind erosion.

Control of wind erosion

The most important control measures are basically meant to reduce wind speed and the reduction in soil erodibility. This can be achieved through vegetation or cultural practices. The control measures include:

(i) Creation of permanent grass strips across the prevailing wind direction.

(ii) Roughening of the soil surface to trap some of the moving particles

(iii) Provision of stubble mulch

(iv) Tillage to provide cloddy surface condition which is at right angles to the wind direction

(v) Strip cropping which can prove useful in reducing the effect of wind

(vi) Wind-breaks with trees which are effective in reducing wind velocity for short distances

Watershed Management

Watershed is the area of land that catches rain and snow and drains or seeps into a marsh, stream, river, lake or groundwater. The terms watershed, drainage basin, river basin, catchments or contributing area are used synonymously. This area is also characterized by an up slope region which contributes flow to a given location. A typical watershed has a boundary, stream net work, sub-basin and outlets (Fig. 12). Stream network is the rill or gullies through which water flows and all these join into a main stream. The outlet is the point at which water flows out of an area. This is the lowest point along the boundary of the drainage basin and is also known as pour point. If a basin is the total area flowing to an outlet, a sub-basin area flowing to an outlet as overland flow.

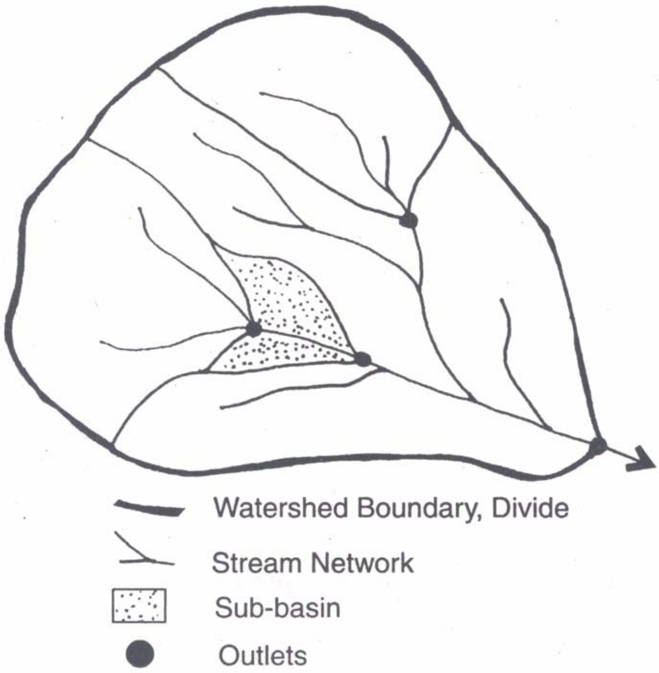
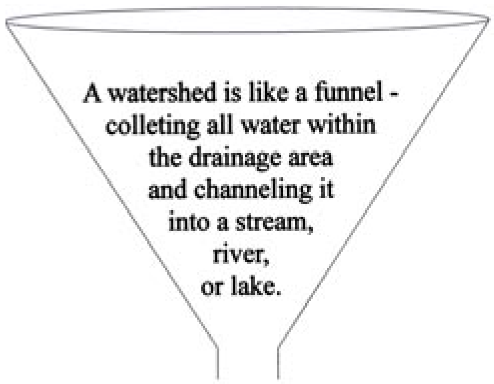


Fig.12. Diagram of a typical watershed

Watershed management is an integration of technologies within the natural boundaries of drainage areas for optimum development of land, water and plant resources to meet the basic minimum needs of the people in that watershed in a sustained manner. It entails protection against all forms of land deterioration and loss of productivity, sediment control, mitigation of flood hazards and suitable land use for a higher production on sustainable. In the abstract, the term is very nearly synonymous with soil and water conservation with the emphasis on water production and control rather than on crop production.



The principal factors which affect the operation of the individual watershed and which must be studied before any management programme can be developed are as follows:

(i) shape of the watershed,
(ii) topography and slope,
(iii) soil and geology
(iv) precipitation history
(v) land use
(vi) vegetative cover plants & (vii) size

Rainwater conservation techniques

Rainwater management in a watershed for improved crop production in a watershed is the major issue. Different types of rainwater harvesting structures like *Nadi*, *Tanka*, *Khadin*, *Anicut*, etc. are constructed for storing water available from adjoining natural catchments during the rainy seasons. *Nadi* is the oldest method of storing water through construction of reservoir. *Tanka* is a small circular or square underground *tanka* constructed with lime mortar or cement plaster. It is constructed normally on fallow ground where surface runoff can be diverted to the tank by creating a clean catchment all around. *Khadin* is a unique practice of water harvesting and moisture conservation in suitable deep soil plots by some sort of natural catchment zone. In this system, runoff from uplands and rocky surfaces is collected in the adjoining lower valley segments. *Anicut* is a structure constructed across a stream. It is an earth fill section with a spillway and is designed to hold sufficient water to submerge a substantial upstream area during rainy season. The retained water sinks into soil profile and then seeps down to replenish adjacent wells. In ravines or heavily gullied lands, small earthen dams with drop inlet spillways are often constructed. These create a small storage to increase ground water recharge, promote better vegetative growth and provide water for irrigation during monsoon as well as winter season.

Soil conservation techniques

The main problem in a watershed is the soil erosion by rainfall. Thus, the overall objectives of all watershed management programmes are: (i) to increase infiltration of rainwater into the soil, (ii) to control damage by runoff, and (iii) to manage and utilize runoff for useful purposes or simply soil conservation measures. Engineering management in agricultural watershed are: contour trenching, terracing, check dams, gully control structures, diversion channels, contour furrowing, contour bunding, percolation tank and various runoff storage structures. Contour terracing consists of excavating trenches and forming bunds at trenches along a uniform level or a particular contour across the slope of uncultivated wasteland in steep slopes. Terracing consists of construction of step like fields by half cutting and half filling. Watershed runoff generally from its maximum generation point, is required to be diverted to other locations in the watershed, this is realized by constructing channels across the slope. Contour furrowing is suitable for soil and water conservation in range/pasture lands. The furrows can also be used for planting trees in this system. Contour bunding is done along the contour line and across slope to receive rainwater and its storing. Percolation tank is provided to help in the reaching of aquifers from diverted runoff.

Agronomic practices

The protection through vegetative shield, forest cover, grasses, crops and mulches, etc. are some important measures to prevent soil erosion. The following crop management practices can be useful to control water erosion. Proper cropping system with crop geometry is essential to control soil erosion. Contour cultivation and contour strip cropping is very useful to reduce soil loss through runoff. The alternate land use systems like agro-forestry, agro-silvo, agro-pastoral, agro-horti, horti-pastoral alley/strip cropping etc. are sustainable especially in arid and semi-arid regions of India. The land uses besides reducing soil erosion are beneficial to increase the income of the farmers.

Application of Remote Sensing for Assessment of Soil and Water Resources

Remote sensing is an art or science by which information about an object can be gathered from a distance without being in physical contact of it. There are two aspects of remote sensing: (i) air borne remote sensing and (ii) space borne remote sensing. In air borne remote sensing, photographs are taken by a camera board on an aeroplane. The aerial photographs due to synoptic view and stereo view are of great help in the study of a terrain. In space borne remote sensing, object is sensed from space by a satellite through various types of sensors. It is concerned with the measurement of solar energy which is reflected, emitted and/or absorbed by objects receiving and returning the solar energy in the form of electromagnetic radiations.

Remote sensing has proven applications in various fields like, land use/land cover, land degradation, geology, soil conservation planning, water resources, forest and natural vegetation, agriculture outcrops, human settlement etc.

Land degradation

For reclamation and sustainable use of degraded lands (salt affected soils, waterlogging, wins and water erosion, shifting cultivation, desertification of cultivated lands), information on the nature, extent, intensity and subsequent monitoring of these degradations is essential. Remote sensing provides a viable tool for this purpose. Salt affected soils can be detected by change in spectral signature in the standard FCC images. Remote sensing data has been used to monitor the effects of reclamation measures carried out for salt affected areas. Similarly, the waterlogged areas are easy to detect due to the sensitiveness of NIR and SWIR bands to water content. Shifting cultivation or *jhum* is an age old practice of tribal, which consists of slash and burning of forests and then cultivation of these areas, until soil productivity declines and then moving over to new sites. Remote sensing data is successfully used to create baseline maps of current and abandoned jhum areas.

Hydrology

Hydrology is the study of water on the Earth's surface flowing above ground, frozen in ice or snow, or retained by soil. It is the major environmental concern of the world today. Most hydrological processes are dynamic, not only between years, but also within and between seasons, and, therefore, require frequent observations. Remote sensing offers a synoptic view of the spatial distribution and dynamics of hydrological phenomena, often unattainable by traditional ground surveys. Radar has brought a new dimension to hydrological studies with its sensing capabilities allowing the time window of image acquisition to include inclement weather conditions or seasonal or diurnal darkness. Clearly, the most widespread application to date of remote sensors operating from space platforms have been to image water – either in oceans, lakes, and streams or in the air as water vapour – in its main functions in the earth system.

The major hydrological applications include:

(i) wetland mapping and monitoring

(ii) soil moisture status

(iii) snow peak: delineation of extent, thickness and monitoring

(iv) glacier dynamics monitoring

(v) river/delta change detection

(vi) flood mapping and monitoring

(vii) drainage basin mapping and watershed modeling, and

(viii) irrigation canal leakage detection.

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