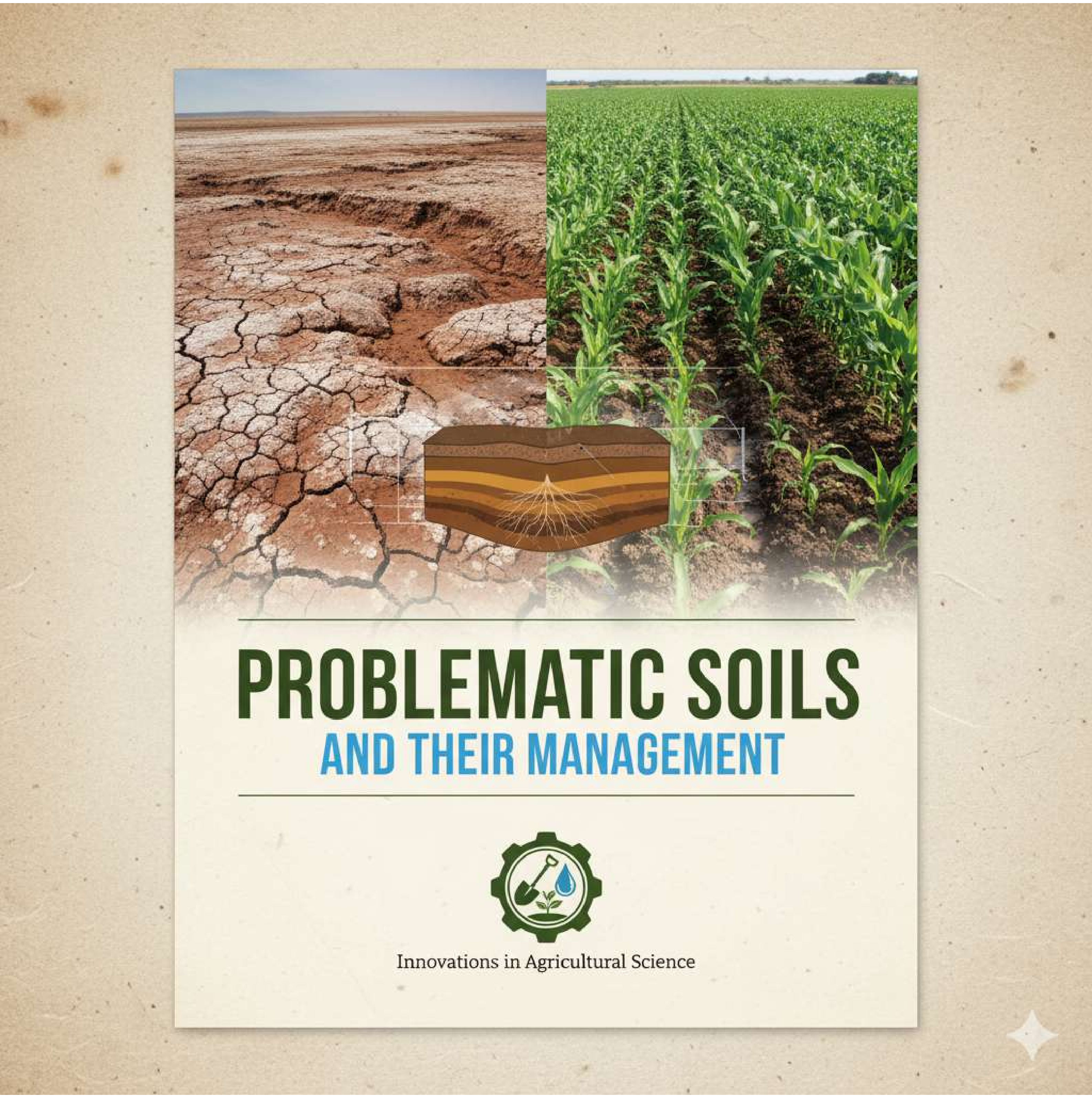
PROBLEMATIC SOILS
AND THEIR MANAGEMENT
Innovations in Agricultural Science

PROBLEMATIC SOILS AND THEIR MANAGEMENT

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

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Chapter 1

INTRODUCTION

"The multiple roles of soils often go unnoticed. Soils don‘t have a voice, and few people speak out for them. They are our silent ally in food production."

Jose Graziano da Silva, FAO Director-General

Soil is a natural finite resource base which sustains life on earth. It is a three phase dynamic system that performs many functions and ecosystem services and highly heterogeneous. Soil biota is the biological universe which helps the soil in carrying out its functions. Often soil health is considered independently without referring to interlinked soil functions and also based on soil test for few parameters. Physical condition of soil and biological fertility are overlooked in soil health management which needs revisiting of soil users. Recognising the importance of soil health in all dimensions, 2015 has been declared as the International Year of Soils by the 68th UN General Assembly. Food and Agriculture organisation of the United Nations has formed Global soil partnership with various countries to promote healthy soils for a healthy life and world without hunger. India, the second most populous country in the world faces severe problems in agriculture. It is estimated that out of the 328.8 m ha of the total geographical area in India, 173.65 m ha are degraded, producing less than 20% of its potential yield (Govt. of India, 1990).

Soil heterogeneity is the reasons for the diverse nature of cropping and production pattern. Soil heterogeneity is the case where soil in a relatively small area varies greatly in texture, fertility, topography, moisture content, drainage etc. If it exists in large scale due to the parent material or manmade activities, then the problem of soil suitability to agriculture arises.

Soil consists of a solid phase (minerals and organic matter) as well as a porous phase that holds gases and water. Accordingly, soils are often treated as a three-state system.

The soils which possess characteristics that make them uneconomical for the cultivation of crops without adopting proper reclamation measures are known as problem soils.

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Chapter 2

SOIL HEALTH AND QUALITY

Soil health is the capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health. Anthropogenic reductions in soil health, and of individual components of soil quality, are a pressing ecological concern. A conference entitled ‗Soil Health: Managing the Biological Component of Soil Quality' was held was held in the USA in November 1998 to help increase awareness of the importance and utility of soil organisms as indicators of soil quality and determinants of soil health. To evaluate sustainability of agricultural practices, assessment of soil health using various indicators of soil quality is needed. Soil organism and biotic parameters (e.g. abundance, diversity, food web structure, or community stability) meet most of the five criteria for useful indicators of soil quality. Soil organisms respond sensitively to land management practices and climate. They are well correlated with beneficial soil and ecosystem functions including water storage, decomposition and nutrient cycling, detoxification of toxicants, and suppression of noxious and pathogenic organisms. Soil organisms also illustrate the chain of cause and effect that links land management decisions to ultimate productivity and health of plants and animals. Indicators must be comprehensible and useful to land managers, who are the ultimate stewards of soil quality and soil health. Visible organisms such as earthworms, insects, and molds have historically met this criterion. Finally, indicators must be easy and inexpensive to measure, but the need for knowledge of taxonomy complicates the measurement of soil organisms. Several farmer-participatory programs for managing soil quality and health have incorporated abiotic and simple biotic indicators. The challenge for the future is to develop sustainable management systems which are the vanguard of soil health; soil quality indicators are merely a means towards this end.

Introduction: Interest in evaluating the quality and health of our soil resources has been stimulated by increasing awareness that soil is a critically important component of the earth's biosphere, functioning not only in the production of food and fibre but also in the maintenance of local, regional, and global environmental quality. Soil is also the basis of agricultural and of natural plant communities. Thus, the thin layer of soil covering the surface of the earth represents the difference between survival and extinction for most land-based life. However, inventories of soil productive capacity indicate human-induced degradation on nearly 40% of the world's agricultural land as a result of soil erosion, atmospheric pollution, and extensive soil cultivation, over-grazing, land clearing, salinization, and desertification. Indeed, degradation and loss of productive agricultural land is one of our most pressing ecological concerns, rivalled only by human caused environmental problems like global climate change, depletion of the protective ozone layer, and serious declines in biodiversity.

Food and Agricultural organization (FAO) has defined soil health as under:

"*Soil health is the capacity of soil to function as a living system, with ecosystem and land use boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health. Healthy soils maintain a diverse community of soil organisms that help to control plant disease, insect and weed pests, form beneficial symbiotic associations with plant roots; recycle essential plant nutrients; improve soil structure with positive repercussions for soil water and nutrient holding capacity, and ultimately improve crop production*". However, soil quality has been defined by the Soil Science Society of America Ad Hoc Committee on soil quality (S-581) as ‗*the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation*‘. *The term ‗soil health*‘ is preferred by some because it portrays soil as a living, dynamic system whose functions are mediated by a diversity of living organisms that require management and conservation. Soil health, biodiversity, and soil resilience are severely limited in extreme environments and are more sensitive to anthropogenic disturbance. However use of the term soil quality will generally be associated with a soils‘ fitness for a specific use and the term soil health used in a broader sense to indicate the capacity of soil to function as a vital living system to sustain biological productivity, promote environmental quality, and maintain plant and animal health. In this sense soil health is synonymous with sustainability. The soil health approach is better applied when specific goals are defined for a desired outcome from a set of decisions. Therefore we can think of the soil health soil quality as an evaluation process which consists of a series of actions:-

□ Selection of soil health indicators
□ Determination of a minimum data set (MDS)
□ Development of an interpretation scheme of indices
□ On-farm assessment and validation

The quality of a soil includes an inherent component, determined by the soil‘s physical and chemical properties within the constraints set by climate and ecosystem. In addition, soil quality includes a component affected by management and land-use decisions. Unfortunately, past management of agriculture and other ecosystems has substantially degraded and reduced the quality of many soils throughout the world. In particular, mechanical cultivation and the continuous production of row crops has resulted in physical loss of soil, displacement through erosion, and large decreases in soil organic matter content with a concomitant release of CO_2 to the atmosphere. Further, the projected doubling of the human population in the next century threatens accelerated degradation of soils and other natural resources. Thus, to preserve agriculture for future generations, we must develop production systems that conserve and enhance soil quality.

As a small step towards this end, a conference entitled _Soil Health: Managing the Biological Component of Soil Quality' was held as part of the joint annual meeting of the Entomological Society of America (ESA) and the American Phytopathology Society (APS) which convened in Las Vegas, Nevada in November 1998. The goals of the conference were to increase awareness within the ESA and APS of the utility of soil organisms as indicators of soil quality, and to permit researchers from diverse disciplines to integrate results from multiple taxa of soil organisms. The overarching objective was to help _translate science into practice' by providing a forum for researchers and extension workers to discuss farmer-participatory programs for managing soil quality.

Soil quality: indicator of sustainable land management

Developing sustainable land management systems is complicated by the need to consider their utility to humans, their efficiency of resource use, and their ability to maintain a balance with the environment that is favourable both to humans and most other species. In particular, it is challenged to develop agricultural management systems that balance the needs for production of food and fibre with those for maintenance of the environment. In short, the assessment of soil quality or health, and direction of change with time, is the primary indicator of sustainable land management.

Although soil's contribution to plant productivity is widely recognized, soil condition also impacts water and air quality. The quality of surface and sub-surface water has been jeopardized in many parts of the world by intensive land management practices and the consequent imbalance of C, N, and water cycling in soil. Agriculture is considered the most widespread contributor to nonpoint source water pollution in the USA (National Research Council, 1993). The major water contaminant in North America and Europe is nitrate nitrogen, the principal sources of which are conversion of unmanaged land to intensive agriculture, animal manures, atmospheric deposition, and commercial fertilizers. Human alterations of the nitrogen cycle have almost doubled the rate of nitrogen input to terrestrial ecosystems over the past 30 years resulting in large increases in the transfer of nitrogen from land to the atmosphere and to rivers, estuaries, and coastal oceans. Soil management practices such as tillage, cropping patterns, and pesticide and fertilizer use influence water quality. In addition, these management practices can influence atmospheric quality through changes in the soil's capacity to produce or consume important atmospheric gases such as carbon dioxide, nitrous oxide, and methane. The present threat of global climate change and ozone depletion, through elevated levels of greenhouse gases and altered hydrological cycles, necessitates a better understanding of the influence of land management on soil processes. In summary, the quality and health of soil determine agricultural sustainability, environmental quality, and as a consequence of both, plant, animal, and human health. Scientists make a significant contribution to sustainable land management by translating scientific knowledge and information on soil function into practical tools and approaches by which land managers can assess the sustainability of their management practices. Specifically, assessment of soil quality/health is needed to identify problem production areas, make realistic estimates of food production, monitor changes in sustainability and environmental quality as related to agricultural management, and to assist government agencies in formulating and evaluating sustainable agricultural and land-use policies.

Use of one given approach for assessing or indexing soil quality is fraught with complexity and precludes its practical or meaningful use by land managers or policy makers. However, the use of simple indicators of soil quality and health which have meaning to farmers and other land managers will likely be the most fruitful means of linking science with practice in assessing the sustainability of management practices.

Soil Health Indicators: Minimum dataset required to be documented in soil health must be sufficient to indicate about health of the soil, to decide best suited crop/(s) for the field and to prescribe manure and or fertilizers for highest or targeted yields of crops. But, it is surprising that most of the soil testing laboratories incorporate only the dataset related to nutrient status, pH, electrical conductivity and organic carbon content of the supplied soil sample in respective soil health card. In the opinion of authors, this data set is incomplete and required to be modified. For example, dose and scheduling of nitrogenous fertilizer depends greatly on textural classes of soil and data set related to this parameter is not supplied with health card. Doran et al (1996) have proposed the minimum data set of physical, chemical and biological indicators for determining the quality or health of the soil in their literature published in Advances in Agronomy are as under:

Physical indicators:

- Texture
- Depth of soil and rooting
- Infiltration and soil bulk density
- Water holding capacity

Chemical Indicators:

- Total soil organic matter
- Active organic matter
- pH
- Electrical conductivity
- Extractable N, P and K

Biological Indicator:

- Microbial biomass C and N
- Potentially mineralizable N
- Specific respiration
- Macro organism numbers

However, Johnson et al. (1997) defined soil quality as _a measure of the condition of soil relative to the requirements of one or more biological species and/or to any human purpose‘.

Chapter 3

DISTRIBUTION OF WASTE LAND AND PROBLEM SOILS IN INDIA

Wasteland: The National Wasteland Development Board (NWBD) has defined wasteland as ―degraded land which can be brought under vegetative cover with reasonable effort and which is currently underutilized and land which is deteriorating for lack of appropriate water and soil management or on account of natural causes‖

Categories of Wasteland in India

- Gullies and/or ravines
- Upland with or without scrub
- Waterlogged and marshy land
- Land affected by salinity/alkalinity in coastal and inland areas
- Land under shifting cultivation
- Underutilized/ degraded notified forest land
- Degraded pasture/grazing land
- Degraded land under plantation crops
- Shifting sands-inland/coastal
- Mining/industrial wasteland
- Barren rocky/stony waste/sheet rock areas
- Steep sloping area
- Snow covered and/or glacial area

Table: India - State-wise distribution of Wastelands

				Area in Sq km
Sl. No.	**STATE NAME**	**TGA**	**Total WL**	**% to TGA**
1	Andhra Pradesh	275068	38788.22	14.10
2	Arunachal Pradesh	83743	5743.84	6.86
3	Assam	78438	8778.02	11.19
4	Bihar	94171	6841.09	7.26
5	Chattisgarh	135194	11817.82	8.74
6	Delhi	1483	83.34	5.62
7	Goa	3702	496.27	13.41
8	Gujarat	196024	21350.38	10.89
9	Haryana	44212	2347.05	5.31
10	Himachal Pradesh	55673	22470.05	40.36
11	Jammu & Kashmir *	101387	73754.38	72.75
12	Jharkhand	79706	11670.14	14.64
13	Karnataka	191791	14438.12	7.53
14	Kerala	38863	2458.69	6.33
15	Madhya Pradesh	308252	40042.98	12.99
16	Maharashtra	307690	38262.81	12.44
17	Manipur	22327	7027.47	31.48
18	Meghalaya	22429	3865.76	17.24
19	Mizoram	21081	6021.14	28.56
20	Nagaland	16579	4815.18	29.04
21	Orissa	155707	16648.27	10.69
22	Punjab	50362	1019.50	2.02
23	Rajasthan	342239	93689.47	27.38
24	Sikkim	7096	3280.88	46.24
25	Tamilnadu	130058	9125.56	7.02
26	Tripura	10486	1315.17	12.54
27	Uttarakhand	53483	12790.06	23.91
28	UttarPradesh	240928	10988.59	4.56
29	West Bengal	88752	1994.41	2.25
30	Union Territory	9490	337.30	3.55
	Total	**3166414**	**472261.95**	**14.91**
* Unsurveyed areas (J&K) : 120849.00			Total geographical area : 3287263.00	

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Table: India - Category-wise distribution of Wastelands in India

Area in Sq km

Sl.No.	**Category**	**Total WL**	**% to TGA**
1	Gullied and/or ravinous land-Medium	6999.03	0.22
2	Gullied and/or ravinous land-Deep/very deep ravine	1714.83	0.05
3	Land with dense scrub	93389.55	2.95

4	Land with open scrub	91633.00	2.89
5	Waterlogged and Marshy land-Permanent	2532.46	0.08
6	Waterlogged and Marshy land-Seasonal	2990.84	0.09
7	Land affected by salinity/alkalinity-Moderate	5429.83	0.17
8	Land affected by salinity/alkalinity-Strong	1737.81	0.05
9	Shifting cultivation area-Current Jhum	5625.07	0.18
10	Shifting cultivation area-Abandoned Jhum	4608.45	0.15
11	Under utilised/degraded forest-Scrub dominated	85809.54	2.71
12	Agricultural land inside notified forest land	16386.08	0.52
13	Degraded pastures/grazing land	7196.44	0.23
14	Degraded land under plantation crops	316.22	0.01
15	Sands- Riverine	2439.85	0.08
16	Sands- Coastal sand	719.00	0.02
17	Sands- Desert Sand	5280.07	0.17
18	Sands- Semi-stabilized to stabilized (>40m) dune	11188.21	0.35
19	Sands- Semi-stabilized to stabilized moderately high (15- 40m) dune	15627.63	0.49
20	Mining Wastelands	505.35	0.02
21	Industrial wastelands	63.99	0.00
22	Barren rocky area	69373.92	2.19
23	Snow cover and/or glacial area	40694.80	1.29
	Total	**472261.95**	**14.91**

Wasteland Reclamation: Reclamation of wasteland means re-claiming it or to use it for productive purpose. Wasteland reclamation is the process of turning barren, sterile wasteland into something that is fertile and suitable for habitation and cultivation.

Need for wasteland reclamation:

- It provides a source of income for the rural poor.
- It ensures a constant supply of fuel, fodder and timber for local use.
- It makes the soil fertile by preventing soil erosion and conserving moisture.
- The programme helps maintain an ecological balance in the area.
- The increasing forest cover helps in maintaining local climatic conditions.

Problem Soils: The soils which possess characteristics that make them uneconomical for the cultivation of crops without adopting proper reclamation measures are known as problem soils.

India, the second most populous country in the world faces severe problems in agriculture. It is estimated that out of the 328.8 m ha of the total geographical area in India, 173.65 m ha are degraded, producing less than 20% of its potential yield.

Types of problem soils

1. Physical problem soils
2. Chemical Problem soils
3. Biological Problem soils
4. Nutritional problem soils as a result of above constraints

1. Physical problem soils

- ✓ ***Slow permeable soils/Impermeable soils*** - the capillary porosity is high it leads to impeded drainage, poor aeration and reduced conditions.
- ✓ Soil surface crusting - Surface crusting is due to the presence of colloidal oxides of iron and aluminium in soils which binds the soil particles under wet regimes. On drying it forms a hard mass on the surface.
- ✓ ***Sub soil hard pan*** - The reasons for the formation of sub surface hard pan in red soils is due to the illuviation of clay to the sub soil horizons coupled with cementing action of oxides of iron, aluminium and calcium carbonate.
- ✓ ***Shallow soils*** - Shallow soils are formed due to the presence of parent rocks immediately below the soil surface (15-20 cm depth).
- ✓ ***Highly permeable soils*** - Sandy soils containing more than 70 per cent sand fractions occur in coastal areas, river delta and in the desert belts. Excessive permeability of the sandy soils results in poor water retention capacity, very high hydraulic conductivity and infiltration rates. These soils being devoid of finer particles and organic matter, the aggregates are weakly formed, the non-capillary pores dominating with very poor soil structure. So whatever the nutrients and water added to these soils are not utilized by the crops and subjected to loss of nutrients and water. In addition, it is not providing anchorage to the crops grown.
- ✓ ***Heavy clay soils*** - Clay soils are referred as heavy soils. To be classified as clay soil, it should be made up of about 40% clay particles, the finest particles found in soil.

This is also slowly permeable soils. Heavy have very hard consistence when dry and very plastic and sticky (heavy) when wet. They are imperfectly to poorly drained, leaching of soluble weathering products is limited. Flooding can be a major problem in areas with higher rainfall.

2. Chemical Problem soils

- ✓ ***Salt affected soils*** - The salt-affected soils occur in the arid and semiarid regions where evapo-transpiration greatly exceeds precipitation. The accumulated ions causing salinity or alkalinity include sodium, potassium, magnesium, calcium, chlorides, carbonates and bicarbonates. The salt affected soils can be primarily classified as saline soil and sodic soil. The state-wise distribution of salt affected soils in India is presented in the following table

State	**Water logged area**	**Salt affected area**
Andhra Pradesh	339	813
Bihar	363	400
Gujarat	484	1214
Haryana	275	455
Karnataka	36	404
Kerala	12	26
Madhya Pradesh	57	242
Maharashtra & Goa	111	534
Odhisa	196	400
Punjab	199	519
Rajasthan	348	1122
TN	128	340
UP	1980	1295
WB	NA	800
Total	4528	8565

- ✓ ***Saline soils***- Saline soils defined as soils having a conductivity of the saturation extract greater than 4 dS m^{-1} and an exchangeable sodium percentage less than 15 Saline soils defined as soils having a conductivity of the saturation extract greater than 4 dS m^{-1} and an exchangeable sodium percentage less than 15. The pH is usually less than 8.5. Formerly these soils were called white alkali soils because of surface crust of white salts.

- ✓ ***Alkali / Sodic soils*** **-** Alkali or sodic soil is defined as a soil having a conductivity of the saturation extract less than 4 dS m^{-1} and an exchangeable sodium percentage greater than 15. The pH is usually between 8.5 – 10.0. Most alkali soils, particularly in the arid and semi-arid regions, contain $CaCO_3$ in the profile in some form and constant hydrolysis of $CaCO_3$ sustains the release of OH ions in soil solution. The OH ions so released result in the maintenance of higher pH in calcareous alkali soils than that in non – calcareous alkali soils.
- ✓ ***Saline-alkali/ sodic soils*** **-** Saline-alkali / sodic soil is defined as a soil having a conductivity of the saturation extract greater than 4 dS m^{-1} and an exchangeable sodium percentage greater than 15. The pH is variable and usually above 8.5 depending on the relative amounts of exchangeable sodium and soluble salts. When soils dominated by exchangeable sodium, the pH will be more than 8.5 and when soils dominated by soluble salts, the pH will be less than 8.5.
- ✓ ***Acid soils*** **-** Soil acidity refers to presence of higher concentration of H^+ in soil solution and at exchange sites. They are characterized by low soil pH and with low base saturation. The ranges in soil pH and associated degree of acidity are as follows:

pH range	***Nature of acidity***
3-4	Very strong
4-5	Strong
5-6	Moderate
6-7	Slight

In acid soil regions (ASR) precipitation exceeds the evapo-transpiration and hence leaching is predominant causing loss of bases from the soil. When the process of weathering is drastic, the subsoil and in many cases, the whole profile becomes acidic.

Acid soils occupy approximately 60% of the earth land area and are arise under humid climate conditions from carbonaceous less soil forming rocks in all thermal belts of the earth.

- World wide – 800 M ha

• India - 100 M ha

95% of soils of Assam and 30% of geographical area of Jammu and Kashmir are acidic. In West Bengal, 2.2 M ha, in Himachal Pradesh, 0.33 M ha, in Bihar, 2 Mha and all hill soils of erstwhile Uttar Pradesh come under acid soils. About 80% of soils in Orissa, 88% in Kerala, 45% in Karnataka and 20% in Maharastra are acidic. The laterite zone in Tamil Nadu is covered with acid soil and about 40,000 ha are acidic in Andhra Pradesh

- ✓ ***Acid Sulphate soils***- Acid sulphate are drained coastal wetland soils that have become acid (pH<4) due to oxidation of the pyritic minerals in the soil. Undrained soils containing pyrites need not be acid and they are called potential acid sulphate soils. Soil with sufficient sulphides (FeS_2 and others) to become strongly acidic when drained are termed acid sulphate soils or as the Dutch refer to those soils cat clays. Generally acid sulphate soils are found in coastal areas where the land is inundated by salt water. In India, acid sulphate soil is, mostly found in Kerala, Orissa, Andhra Pradesh, Tamil Nadu and West Bengal.
- ✓ ***Calcareous soil*** - Calcareous soil that contains enough free calcium carbonate ($CaCO_3$) and give effervescence visibly releasing CO_2 gas when treated with dilute 0.1 N hydrochloric acid. The pH of calcareous soil is > 8.5 and it is also regarded as an alkaline (Basic) soil.
- ✓ Man made polluted soils - Soil contamination is the presence of man-made chemicals or other alteration of the natural soil environment. This type of contamination typically arises from the rupture of underground storage tanks, application of pesticides, percolation of contaminated surface water to subsurface strata, leaching of wastes from landfills or direct discharge of industrial wastes to the soil. The most common chemicals involved are petroleum hydrocarbons, solvents, pesticides, lead and other heavy metals. This occurrence of this phenomenon is correlated with the degree of industrialization and intensity of chemical usage. The concern over soil contamination stems primarily from health risks, both of direct contact and from secondary contamination of water supplies.

3. Biological problems in soils

- ✓ ***SOC and microbial population***- Biological problems often results from management practices and anthropogenic influence. Soil organic carbon (SOC) is the main source of energy for soil microorganisms and a trigger for nutrient availability through mineralization. Humus participates in aggregate stability, and nutrient and water holding capacity. Organic acids (e.g., oxalic acid), commonly released from decomposing organic residues and manures, prevents phosphorus fixation by clay minerals and improve its plant availability, especially in subtropical and tropical soils. An increase in SOM, and therefore total C, leads to greater biological diversity in the soil.

- ✓ ***Soil Respiration*** - Soil respiration reflects the capacity of soil to support soil life including crops, soil animals, and microorganisms. In the laboratory, soil respiration can be used to estimate soil microbial biomass and make some inference about nutrient cycling in the soil. Soil respiration also provides an indication of the soil's ability to sustain plant growth.
- ✓ ***Soil Enzymes*** - Absence or suppression of soil enzymes prevents or reduces processes that can affect plant nutrition. Poor enzyme activity (e.g., pesticide degrading enzymes) can result in an accumulation of chemicals that are harmful to the environment; some of these chemicals may further inhibit soil enzyme activity
- ✓ ***Eroded soils***- 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. Erosion extensively occurs in poorly aggregated soils (low humus) and in a higher percentage of silt and very fine sand. Erosion increases when soil remains bare or without vegetation. In India about 86.9% soil erosion is caused by water and 17.7% soil erosion is caused by wind. Out of the total 173.6 Mha of total degraded land in India, soil erosion by wind and water accounts for 144.1 Mha. The surface soil is taken away by the runoff causing loss of valuable topsoil along with nutrients, both native and applied. In India about 5334 million tones (16.35 tonnes/ha/year) of soil is being eroded annually due to agriculture and associated activities and 29% of the eroded materials are permanently lost into the sea.

Chapter 4

RECLAMATION AND MANAGEMENT OF SALINE AND SODIC SOILS

The most widely accepted definition of salt-affected soils is as defined by the United States Department of Agriculture, USDA (Richards, 1954).In canal irrigated areas, due to seepage of water from the canal or in low lying areas with frequent flooding, water logging occurs which mainly led to increase in salinity/alkalinity.

Alkali Soils: In these soils, the Exchangeable Sodium Percentage (ESP) is greater than 15, pH is more than 8.2 and Electric Conductivity (EC) is below 4 ds/m.

Saline Soils: Saline soils have excessive concentration of natural soluble salts, mainly chlorides, sulphates and carbonates of calcium, magnesium and sodium. In such soil Electrical Conductivity (EC) of saturated soil extract is more than 4 ds/m, Exchangeable Sodium Percentage (ESP) is less than 15 and pH is also less than 8.2. Such soils are called

―saline soils‖ or ―white alkali‖ or ―solonchack‖ soils.

Management of Soil Salinity and Alkalinity problems:

Keeping in view the fact that plant growth can be restricted or entirely prevented by increased levels of salinity and alkalinity in the soil, these soils have to be reclaimed so that they become productive. The processes of accumulation of salts and build up of ESP have to be reversed. To achieve these objectives provision of adequate drainage, replacement of Na^+ ions form the soil – exchange complex and leaching out of soluble salts below root zone have to be ensured. Without adequate drainage and leaching of salts, proper reclamation cannot be achieved on a long- term basis. In addition to decreasing the salts and ESP levels in the root zone and maintaining them below the permissible limits (which depend upon salt and Na^+ ions tolerance of crops), soil management practices must ensure prevention form reverting the salinity and ESP to the original condition. Following general principle has to be considered for properly understanding and implementing the reclamation measures:

- The total soluble salt concentration in the root zone has to be decreased to control osmotic effect on plant growth. Maintenance of total soil moisture tension (osmotic pressure plus soil moisture tension) must be ensured at optimum level so that plant roots can absorb adequate amount of water.
- Since soluble salts in the soil are transported by water, the quality of water used for dissolving the salts, determines the efficiency of leaching and drainage processes. Therefore, availability of good quality water is of paramount important for the success of reclamation work.
- Salt concentration in soil solution, upward movement of salts and their accumulation

increase with increase in the evaporation and transpiration form the surface of the soil and the vegetation, especially when ground water-table is shallow.

- Increase or decrease of salts in the root zone depends upon whether the salt inputs are higher or lower than the salt outputs.
- The cations in the soil solution and those adsorbed on the exchange complex are in equilibrium with each other. The dispersion and flocculation of clay particles and the effectiveness of amendments are controlled by this principle. Systematic planning for reclamation work requires characterization of the problem (e.g extent and kind of salinity or alkalinity/sodicity) as the first step. Thereafter, for each specific problem, specific systems of management have to be followed.
- The physical, hydro technical, chemical and biological methods (Kovda et al., 1973) used for the amelioration of salt- affected soils are discussed below.

Physical amelioration

The commonly followed physical methods for amelioration of salt-affected soils include deep ploughing, sub-soiling, sanding, profile inversion and scrapping. The first two methods break the impermeable layer, hard pan or cemented sub-soil layer existing at various depths in the soil profile to improve the internal drainage of the soil and facilitate the transportation of salts dissolved in water to deeper layers. Incorporation of sand in salt –affected soil is done to bring about permanent change in texture, increase soil permeability and improve air-water relations in the root zone. In sodic soils having large amount of clay, application of inadequate quantity of sand may, however, create problems because of the cementing effect. Therefore, large quantities of send have to be applied to cheek this cementing effect,

Profile inversion can be adopted only under conditions where surface soil is good but the soil below some depth is sodic, saline or has undesirable characteristics. The objective is to retain the good soil of the surface while inverting the saline /sodic sub-soil down. Since this is a very cumbersome method, it is generally not followed by the farmers.

Many farmers often resort to scrapping of surface by a few centimetres of salt/salty soil and dump it at some other place. This is only a temporary measure for improving the plant growth. Reclamation by this method cannot be achieved on a permanent basis, particularly under shallow water- table condition where salts can again rise and accumulate at the surface due to evapotranspiration.

Hydro-technical Amelioration

The reclamation of salt-affected soils by this method involves basically the removal of salts form the saline soil or displacement of sodium ions form the exchange complex of alkali soils through the processes of leaching with water and drainage. This requires that sufficient water must pass through the soil to decrease salt concentration in the soil below the permissible limits and, in turn, maintain proper salt and water balance in the soil to be reclaimed. The leaching of the salt-affected soils leads to highly saline drainage water. Therefore, suitable measures for its disposal should be taken before initiating the leaching processes, particularly in areas having high water table the success of leaching of salts and reclamation, therefore, depends upon the efficiency with which salts can be removed from the soil. It is important to check the re-salinisation or re-alkalisation of the soils. Therefore, provision of adequate drainage system is a pre-requisite for any reclamation process.

The extent of leaching required depends upon : (a) soil properties (soil texture, soil structure, soil pore geometry, cracking phenomenon and clay mineralogy), (b)Initial salinity and chemical composition of soluble salts,(c) quality of the water (in terms of amount and composition of salts) used for leaching,(d) leaching method,(e) water-table depth, (f)efficiency of the drainage system, and (g) salt tolerance of crops to be grown. The amount of water of known salt concentration (c_{iw}), required for leaching of salts form the initial level of soil salinity (c_o) to the pre-determined level of soil salinity after leaching (c_f) can be worked out form the relation of $(c_f-c_{iw})/(c_o-c_{iw})$ with D_w/D_s, i.e. the depth of water (D_w) displaced form a given depth of soil (D_s) The quantity of salts removed per unit depth of water applied determined the efficiency off the leaching process.

Leaching requirement

In the soils irrigated with waters having different concentration of salts (c_{iw}), the control on the building of salts at a given depth of the soil will depend upon the concept that the outputs of salts leaving and area should be more than, or equal to, the inputs , i.e. the quantity of salts entering the area. Keeping this In view, the first salt and water balance equation for internally well drained well upland soils can be rewritten as expression:

$$D_{iw}.c_{iw}-D_{dw}.C_{dw}+D_{rw}.C_{rw}=S \text{ ----------(1)}$$

And the second equation for low land soils as Equation :

$$D_{iw}.C_{iw}+D_{cw}.C_{cw}+D_{rw}.C_{rw}-D_{dw}.C_{dw}-D_{ew}.C_{ew}=S \qquad (2)$$

Assuming the concentrations of salts rain water (rw) and evapotranspired water (ew) as negligible, the salt content of a given soil volume at any time, ‗S_T' for upland areas is given by Equation:

$$S_T=D_{iw}.C_{iw}-D_{dw}.C_{dw} \text{ ---------------- (3)}$$

and for low lying areas, by Equation :

$$S_T=D_{iw}.C_{iw}-D_{dw}.C_{dw}+D_{ew}.C_{ew} \text{ ---------------------(4)}$$

When S_T is zero at steady state condition, Equation (3) for upland soils reduces to the following relationship:

$$D_{iw}.C_{iw}= D_{dw}.C_{dw}$$

$$\frac{D_{dw}}{D_{iw}} = \frac{C_{iw}}{C_{dw}} = \text{Leaching Fraction (LF) ------ (5)}$$

$D_{dw}=D_{iw}.Ciw/C_{dw}$= Leaching Requirment (LR)---------(6)

and Equation (4) for low-lying soils reduces to Equation :

$D_{dw}=(D_{iw}.C_{iw}+D_{cw}.C_{cw})/ C_{dw}$=LR (7)

The above equation indicates that with increase in salinity of irrigation water, more water (D_{iw}) will have to be applied to control salt build-up below the desired level. These LR calculations are sufficiently accurate for most of the crops. Leaching Fraction (LF) refers to the fraction of the depth of applied irrigating water that leaves the root zone as drainage water. These equations can be further modified by including the leaching efficiency factor.

Leaching Methods

Ponding continuously or intermittently with sufficient depth of good quality water on the surface on the soil and ensuring downward movement of water is traditionally the most commonly used method for leaching or salts. The effectiveness of this method depends upon how uniformly the water is applied and how much of it passes through the root zone soil. Land levelling is, therefore, an extremely important step before initiation of the leaching process. Variations in micro-relief within the field often lead to rise in salinity in the raised areas and leaching in the depressions. The permeability and initial salinity of the soil largely control the rate of leaching As a general rule, leaching should be done with the depth of water equivalent to the depth of soil to be reclaimed the passage of 1m leaching water per metre of soil depth under continuous ponded condition normally removes approximately 80% of solute salts form the soil.

The basin furrow method of leaching is considered to be more efficient. Under this method, water is allowed to meander back and forth across the field through adjacent is much less than that needed for ponding method of leaching.

Drainage system

Drainage system in saline soils should be designed to regulate the water and salt balance of both the surface soil and sub-soil. Sub-soil drainage is not very effective in highly impervious sodic soils. In areas where water-table remains shallow for most part of the year and the quality of ground water is poor, installation of sub-soil drainage system will be more useful. The need for the development of either surface of subsurface drains has to be worked out on the basis of the nature of soil, ground water condition, climate, cropping pattern, economic considerations, etc. Installation of sub-surface drains is much more costly than the surface drains.

Chemical Amelioration

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

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

Where _x' is soil- exchange complex.

This can be accomplished by the application of chemical amendments (the materials that directly or indirectly furnish or mobilize divalent cations, usually Ca^{2+} for the replacement of sodium from the exchange complex of the Soil) followed by leaching to remove soluble salts and other reaction products. The type of chemical compound and their quantities required for reclamation of alkali/ sodic soils depend upon physic-chemical properties of the soil, desired rate of replacement of sodium ions, and economic considerations. The chemical amendments used for ameliorations of these soils can be broadly grouped as follows:

(1) Soluble sources of calcium: Gypsum ($CaSO_4.2H_2O$), calcium chloride ($CaCl_2$) and phospho-gypsum (An industrial by-product)

(ii) Sparingly soluble calcium salts: Calcite $CaCO_3$, and

(iii) Acids or acid-formers: Sulphur, sulphuric acid, sulphates of iron and aluminium, pyrites, lime –sulphur.

The effectiveness of each of these amendments mainly depends upon the presence or absence of alkaline-earth carbonates (Particularly $CaCO_3$) in the soil. When soils contain $CaCO_3$, any soluble source of calcium and acids or acid formers may be used. When the soils are no calcareous, application of acids and acid- form sources of calcium should be used. Application of sparingly soluble $CaCO_3$ for the reclamation of Sodic soils is not recommended because its solubility decreases with increase in pH of the soil.

The reactions of these amendments in the soils containing $CaCO_3$ can be illustrated by Equations:

Gypsum:

$2Na\text{-}X+CaSO_4= Ca\text{-}X +Na_2SO_4$

Calcium Chloride:

$2Na\text{-}X+ CaCl_2= Ca\text{-}X +2NaCl$

Sulphur- Microbial oxidation:

$2S+2O_2 = 2SO_3$

$SO_3+H_2O \longrightarrow H_2SO_4$

$H_2SO_4 + 2CaCO_3 \longrightarrow CaSO_4 + Ca(HCO_3)_2$

$2Na\text{-}X + CaSO_4 \longleftrightarrow Ca\text{-}X + Na_2SO_4$

The microbial oxidation of sulphur is mediated by aerobic thiobacilli group of chemoautotrophs .

Pyrite -----Oxidation of pyrites, like sulphur leads to formation of sulphuric acid. The overall reactions are given Equations :

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

$2CaCO_3 + H_2SO_4 = CaSO_4 + Ca(HCO_3)_2$

$2Na\text{-}X + CaSO_4 = Ca\text{-}X + Na_2SO_4$

The rate of oxidation of pyrite is, however, slow and depends upon the moisture content oxygen availability, temperature and particle size. When applied on the basis of water soluble sulphur content, its efficiency in reclamation is quite high,

Lime –sulphur and sulphates of iron and aluminium produce sulphuric acid which further acts like the reactions given above. Calcium chloride is highly soluble in water but its high cost and hygroscopicvity prohibit its use on a large scale. Acids are not generally recommended because of the high cost involved and difficulty in handling them at the field level.

Gypsum is, by far, the most economical and commonly used chemical amendment. In India the resources of gypsum are estimated to be more than 1000 million tonnes. The gypsum requirement (GR) for amelioration of alkali /sodic soil depends upon exchangeable sodium content to be replaced, exchange efficiency and the depth of soil to be reclaimed. The laboratory estimation of GR (US Salinity Laboratory staff, 1954) is carried out by equilibrating a sodic soil with gypsum solution of known calcium concentration and then estimating the calcium deficit (as a result of exchange of sodium with calcium) I n the extract solution .This determination includes Ca^{2+} required to replace the exchangeable Na^+ ions plus that required to neutralize alkalinity.

The quantity of gypsum required to replace an initial l level of exchangeable sodium (E_{nail}) and achieve its reduction to a desired level of exchangeable sodium (E_{Naf}) per unit area and per unit depth of the soil, can also be calculated using Equation:

GR(in cmol/kg soil)= (E_{nai}-E_{Naf}) CEC

Wher,E_{Na} and CEC are in cmol(P^+) /kg soil

Science one coml gypsum/kg soil is equal to 860 kg gypsum/10^6 kg soil, for one hectare to a depth of 0-15 cm (2×10^6kg soil), the GR can be calculated by Equation:

GR(kg/ha)=1720×(E_{nai}-E_{Naf}) CEC

The GR worked out by this method is based on 100% replacement of Na^+ by Ca^{2+} ions. Under actual condition, the efficiency is always much lower. To compensate for the lack of a quantitative replacement, the GR worked out by this method should be multiplied by 1.25. The quantities of different amendments to be applied in comparison with gypsum are given in Table.

Relative quantities of different amendments compared with gypsum

Amendents	Tonnes equivalent to 1 tonne of **gypsum**
Gypsum	1.0
Sulphur	0.18
Lime-sulphur	0.75
Sulphuric acid	0.57
Iron sulphate	1.62
Al-sulphate	1.27
Lime stone	0.58

Gypsum should be broadcast and incorporated in the surface 0-10 cm soil by dicing or by using a cultivar. Mixing of gypsum in deeper soil decreases its effectiveness, as a fraction of the applied gypsum can refract with soluble carbonates to precipitate Ca as $CaCo_3$. the optimum size of gypsum particles is determined on the basis of the required efficiency of reclamation cost of grinding and ease of application Mined gypsum ground to pass through 2-mm sieve has been found to be pass through react faster, gypsum ground to pass through a 2-mm sieve can efficiently reclaim alkali soil.

Biological Amelioration

Organic materials and action of plant roots improve biological activity in the soil. The decomposition of materials increases the concentration of CO_2 and organic acids in the soil which help in mobilizing calcium by dissolving calcium compounds. This can be accomplished by green manuring, incorporation of crop residues, application of FYM, press mud and other organic materials.

Rice is preferred to be grown during reclamation of alkali soils owing to its high tolerance to soil sodicity. The pending of water for optimum rice growth promotes build-up partial pressure of CO_2 and leaching of salts resulting from exchange of sodium by calcium.

Chapter 5
ACID SOILS

Nearly 100.6 m ha of land out of total geographical area of 329 m ha and gross cropped area of 134 m ha suffers from soil acidity. Out of 100.6 m ha 20 m ha is in Assam and North East states, 15.5 m ha in Jammu & Kashmir, 12.6 m ha in Odisha, 9.6 m ha in Karnataka, 8.9 m ha in M.P., 8.3 m ha in A.P., 5.2 m ha in Bihar, 5.0 m ha in H.P., 3.5 m ha in W.B., 3.5 m ha in Kerala, 3.1 m ha in Maharastra, 2.9 m ha in U.P. and 2.6 m ha in T.N. Acid soil occurs in 1/3rd of the cultivated area of India.

Acid soils are often characterised by low CEC, intermediate textured ranging from sandy loam to loam, low organic matter content except in case of hill, terai soils and soils under forest and low P content while the N content is variable. Acid soils have higher number of Fe & Al ions in soil solution and also have high exchangeable H^+ and Al^{3+} ions. Conventionally acid soils have been defined in terms of soil pH and base saturation both of which are low.

Jackson grouped soil acidity as:

1. Strong soil acidity (pH < 4.2)
2. Weak soil acidity (4.2 to 5.2)
3. Very weak soil acidity (5.2 to 6.5 or 7.0)

Causes of soil acidity:

1) *Leaching of bases due to heavy rainfall*: The regions where rainfall or precipitation is high enough to leach appreciable amounts of exchangeable bases from the surface soils and relatively insoluble compounds of AL and Fe remains in the soil. The natures of these compounds are acidic and its oxides and hydroxides reacts with water and release hydrogen ion (H^+) in soil solution and soil become acidic.
2) *Acidic parent materials*: Some soils have parent materials which develop acid such as granite.
3) *Acid forming fertilizers*: The use of ammonium sulphate, $NH_4(SO_4)$
4) When soluble bases are lost, the H^+ ions of carbonic acid and other acids developed in soil replace basic cations from exchangeable sites of colloids through continuous leaching and become acid increasingly.
5) *Soluble salts*: Presence of soluble salts leads to increase in soil acidity due to displacement followed by hydrolysis of adsorbed Fe^{+3}, Al^{+3}, Mn^{+2} ions by the cations of the soil
6) *Carbon-dioxide*: The carbonic acid formed during decomposition of organic residues in soil will contribute soil acidity through weak dissociation.
7) *Acid rain*: Acid rain contain H^+ ion at a concentration > 2 micro molecules. NH_4^+ ion are also present. The positive charge is balanced by variety of anions generally $SO_4^=$ & NO_3^-. The effect of acid precipitation is to acidify the soil.

8) *Sub-soil acidity*: Many highly weathered soil such as Ultisols, sub-soil acidity limits crop yield even when the plough layers is adequately limed. Root proliferation is severely restricted due to Al toxicity and water stored in sub-soil is rendered unavailable to crops. This is an important limiting factor in many acid soils and need special attention.

Kinds of soil acidity:

1. ***Active acidity***:

   Develops due to H^+ and Al^{+3} ions concentration of the soil solution. The magnitude of this acidity is limited and can be reclaimed very easily.

2. ***Exchangeable acidity***:

   Develops due to adsorbed H^+ and Al^{+3} ions on the soil colloids. The magnitude of this acidity is high.

3. ***Potential acidity/ Reserve acidity***:

   H^+ and Al^{+3} ions present inside the soil crystal lattice. Soil constituents capable of contributing H^+ ions to the soil solution through ionization, dissociation, hydrolysis etc. It is the major contributor of soil acidity.

Effect of Soil Acidity on Plants

Except for a few crops like tea, coffee and potato, most of the crops do not find optimum conditions for their growth and development. But the effects are more pronounced when the soil pH is below 6.0. Acidity affects the plants both directly and indirectly.

A. Direct effects

1. Extremely high concentration of hydrogen ions just outside the plant roots has a toxic effect on roots.

2. The permeability of the plasma membrane surrounding root hair is reduced. Consequently, the activity of root hair that absorbs water and nutrients from the soil is highly slackened.

3. Excessive presence of hydrogen ions in soil solution also results in increased absorption of H^+ ions by the plant roots. This phenomenon disturbs acid-base balance inside the plant which virtually inhibits plant growth.

4. Numerous essential chemical reactions are carried out by the enzymes secreted by soil organisms as well as plant itself. These enzymes lose their effectiveness if hydrogen ion concentration goes too high.

B. Indirect effects

1. Availability of nutrients increases *e.g.* P. Cu, Zn.

2. Some essential micronutrients such as Fe, Mn, Cu and Al etc. become highly soluble in acid soils and their availability to the plant roots goes so high that they become toxic to the plants.

3. In most of the acid soils plants show deficiency symptoms of Ca and Mg. This is because of the fact that acid soils are mostly deficient in these elements.

4. Some disease causing agents (especially fungi) flourish well in acid soils. Incidence of disease is, therefore, increased.

5. At the same time a large population of beneficial microorganisms suffers badly due to high concentration of hydrogen ions. This results in decreased soil fertility.

Effects of soil acidity on plant growth:

Most soil used for vegetable cultivation become gradually more acidic as calcium is lost due to leaching by rainwater and irrigation. The process is further accelerated by the use of nitrogenous fertilisers such as ammonium nitrate and ammonium sulphate. Vegetables vary in their tolerance to soil acidity. In general, the most favourable pH range for vegetable is between 5.5 to 6.5 in mineral soil and 5.0 to 6.0 in organic soil.

1. Ca, K, Mg and Na are alkaline elements, which are lost with increasing acidity whereas P is more available in acidic soil conditions.
2. Acidity can also induce deficiencies of micronutrients such as Mo and B, although a deficiency in the latter is more commonly seen in alkaline soils where over-liming has occurred.
3. Acidic soil often causes the stunting and yellowing of leaves, resulting in the decrease in growth and yield of crops as the pH levels falls.
4. Plants grown in adverse pH conditions may be more prone to disease and fungal attack.
5. pH can affect the absorption of nutrients by plant roots pH values above 7.5 cause iron, manganese, copper, zinc and boron ions to be less available to plants.
6. pH values below 6 cause the solubility of phosphoric acid, calcium and magnesium to drop.
7. Aluminium toxicity is the most widespread problem in acid soils. Aluminium is present in all soils, but dissolved Al^{3+} is toxic to plants; Al^{3+} is most soluble at low pH, above pH 5.2 little aluminium is in soluble form in most soils. Aluminium is not a plant nutrient, and as such, is not actively taken up by the plants, but enters plant roots

passively through osmosis. Aluminium damages roots in several ways: In root tips and Aluminium interferes with the uptake of Calcium, an essential nutrient, as well as bind with phosphate and interfere with production of ATP and DNA, both of which contain phosphate. Aluminium can also restrict cell wall expansion causing roots to become stunted.

Management of acid soil:

Lime or liming materials are used to ameliorate soil acidity.

Liming materials:

1. Calcium oxide (CaO)
2. $Ca(OH)_2$
3. Calcite ($CaCO_3$)
4. Dolomite ($CaCO_3$, $MgCO_3$)
5. Marl (Deposition of $CaCO_3$)
6. Basic slag
7. Others: chalk, wood ash etc.

Reactions of liming materials in soil

1. ***Reaction of CaO***:

   This is also known as un-slaked lime or burnt limestone or quick lime. It is a white powder and difficult to handle as it is caustic and explosive. When added to a moist acid soil, the calcium cation in CaO displaces the exchangeable H & Al from surface soil colloids.

$$\text{Soil}\left]\begin{array}{l}H\\H\\Al\\Al\end{array}\right. + 4\,CaO + 2H_2O \Longrightarrow \text{Soil}\left]\begin{array}{l}Ca\\Ca\\Ca\\Ca\end{array}\right. + 2Al(OH)_2\downarrow$$

2. ***Reaction of Ca(OH)₂***

   This is commonly known as slaked lime or building lime. This is prepared by mixing water with calcium oxide under controlled conditions. Much heat is generated in the process. When added to the acid soil

$$Ca(OH)_2 \Longrightarrow Ca^{+2} + 2(OH)^-$$

$$\text{Soil}\left]\begin{array}{l}H\\H\\Al\\Al\end{array}\right. + Ca(OH)_2 \Longrightarrow \text{Soil}\left]\begin{array}{l}Ca\\Ca\\Ca\\Ca\end{array}\right. + 2Al(OH)_2\downarrow$$

3. ***Dolomite ($CaCO_3$, $MgCO_3$):***

Dolomite deposits are found in many places of India. Besides calcium, it also contains nearly equal amount of magnesium which is an essential plant nutrient Acid soils are often deficient in this nutrient.

Lime Requirement (LR) and liming factor

The desirable pH range for most of the crops is 6.0 to 7.0. The amount of lime or liming materials that must be added to the acidic soil to raise the pH of that soil to a desired value is known as *Lime requirement* (LR). Any increase in pH will still depend on the amount of lime applied, with the general rule of thumb being a 0.1 unit increase in pH for every tonne of lime applied.

Liming Factor may be defined as the factor by which the actual amount lime can be calculated from the estimated theoretical amount of lime or liming materials. This depends on rate of lime stone solution, plant uptake and leaching during the reaction period.

Lime requirement to bring the soil to desired level of pH indicated below

pH of soil buffer suspension	Lime required to bring the soil to indicated pH (tones per acre of pure calcium carbonate *i.e.*$CaCO_3$)		
	pH 6.0	pH 6.4	pH 6.8
6.7	1.0	1.2	1.4
6.6	1.4	1.7	1.9
6.5	1.8	2.2	2.5
6.4	2.3	2.7	3.1
6.3	2.7	3.2	3.7
6.2	3.7	3.7	4.2
6.1	3.5	4.2	4.8
6.0	3.9	4.7	5.4
5.9	4.4	5.2	6.0
5.8	4.8	5.7	6.5
5.7	5.2	6.2	7.1
5.6	5.6	6.7	7.7
5.5	6.0	7.2	8.3
5.4	6.5	7.7	8.9
5.3	6.9	8.2	9.4

5.2	7.4	8.6	10.0
5.1	7.8	9.1	10.6
5.0	8.2	9.6	11.2
4.9	8.6	10.1	11.8
4.8	8.1	10.6	12.4

The amount of the liming material greatly depends upon the soil texture. The smaller the soil particles, the greater will be the site exposed for hydrogen ions to stick on. Neutralizing the hydrogen ions present in the soil solution (active acidity) is not enough. The amount of amendment should be enough to neutralize hydrogen ions around the soil particles also. Soil testing for lime recommendation must take this point into account. Reserve acidity is sometimes thousand times greater than active acidity. In clay soils, reserve acidity is very high, whereas in sandy soils it is comparatively low. The amount of liming material required to neutralize total acidity (active + reserve), therefore, varies greatly according to soil texture. Even if amount of liming material is not given in the soil testing report, it can be found out from the table below taking the help of soil testing report (soil pH). Calcium Carbonate needed to increase the pH of a soil textural class by one unit.

Sl. No.	**Soil texture**	**Lime in tonnes/ha**
1	Sand	2.50
2	Sandy loam	3.75
3	Loam	5.00
4	Silt loam	6.25
5	Clay loam	7.50
6	Clay	8.25

Application of lime

Lime is not mobile in the soil. Therefore, it should be spread in the field with maximum possible uniformity and worked well into the soil. This can be done during the preparation of field. Soil should be sufficiently moist at the time of liming or a light irrigation may be given to the field after mixing the lime. If slaked lime is used, seeds should be sown in the field at least 3-4 weeks after liming. To maintain desirable soil reaction in the humid regions, liming at every 3-5 years interval is recommended.

Liming will provide the following benefits:

1. Reduces the possibility of Mn^{2+} and Al^{3+} toxicity.

2. Improves microbial activity.
3. Improves physical condition (better structure).
4. Improves symbiotic nitrogen fixation by legumes.
5. Improves palatability of forages.
6. Provides an inexpensive source for Ca^{2+} and Mg^{2+} when these nutrients are deficient at lower pH.
7. Improves nutrient availability (availability of P and Mo increases as pH increases at 6.0 – 7.0, however, other micronutrients availability increases as pH decreases).
8. Improves fertilizer use efficiency.

Effects of liming

Advantages of liming are three-fold viz. physical, chemical and biological. They are described below:

1. Physical effects

Liming improves physical condition of heavy soils; they become granular in structure and their water holding capacity is improved. Liming also encourage the decomposition of organic matter and consequently, there is greater production of organic colloids. The Ca-humus so produced is believed to be an effective cementing agent in binding the soil particles. Liming also prevents soil erosion because soils which have received liming treatment support good plant growth.

2. Chemical effects

Among the principal chemical properties influenced by liming is the reduction of H ions in the colloidal complex. It increases the availability of almost all the nutrients such as nitrogen, phosphorus, potassium, calcium, magnesium, boron, zinc, copper and molybdenum, and reduces the toxicity caused by soluble iron, aluminium and manganese.

3. Biological effects

One of the outstanding biological effects of liming is to encourage the microbial activity of the soil. By raising the soil pH, it makes the soil more congenial for a number of micro organisms. Nitrifying and nitrogen fixing bacteria, both symbiotic and non symbiotic are stimulated by the addition of lime to an acid soil. Lime also brings about a more rapid decomposition of organic manure, both native and added, as a result of improved microbial activity. This further increases the availability of nitrogen phosphorus and sulphur.

Adverse effects or over liming

1. The main effect of over liming is to reduce the availability of some of the essential nutrients, both major and minor, such as P, K, Fe, Mn, B, Cu, Zn etc, and thus bring about nutritional deficiency.
2. Excess lime also interferes with the absorption of certain elements like potassium, phosphorus, boron, etc. by plants thus hindering their utilization.
3. The very rapid decomposition of organic matter in soils of arid of semi arid regions is also attributed to the accumulation of excess lime in these soils.

Crops Tolerant to Acidity

Most crop plants grow well when the soil pH is between 5.5 and 7.5, a fairly wide range even under field condition. Serious trouble develops when the pH drops below 5.0. Crops which can be successfully grown in acid soils are listed in the following table.

Acid tolerant crops

Sl. No.	Slightly tolerant	Medium tolerant	Very tolerant
1	Berseem	Maize	Mustard
2	Sugarcane	Potato	Buck wheat
3	Cauliflower	Wheat	Coffee
4	French bean	Soya bean	Rubber
5	Cabbage	Barley	Tea
6	Watermelon	Oats	--
7	Lucerne	Rice	--

The effectiveness/efficiency of liming material:

The amount of lime or effectiveness of lime to apply depends on four main factors; neutralizing value, fineness of the lime, purity of lime and soil texture.

1. **Neutralizing value (NV) or** Calcium Carbonate Equivalent (CCE). It is defined as acid neutralizing capacity of an agricultural liming material expressed as a weight percentage of calcium carbonate.

$$\text{CCE of a liming material} = \frac{\text{Molecular wt. of } CaCO_3}{\text{Molecular wt of a liming material whose CCE is to be determined}} \times 100$$

The required amount of various amendments is expressed in terms of Calcium Carbonate Equivalents (CCE). The CCE means amount of calcium carbonate which can neutralise as much acidity as 100 kg of a liming material in question can neutralise. As shown below, 100 kg of CaO can neutralize as much acidity as 179 kg of calcium carbonate and vice versa.

Calcium Carbonate ($CaCO_3$) equivalent of some important liming materials:

Sl.No.	Liming material (100 kg)	Calcium carbonate [$CaCO_3$] (kg)
1	Calcium oxide (CaO)	179
2	Calcium hydroxide	139
3	Dolomite	109
4	Limestone (calcium carbonate)	100
5	Basic slag	60-70

2. **Degree of fineness of material**
   The finer the particles of lime, the faster they react with soil. Lime manufacturers have to specify the percentages of different-sized particles in their product.
3. **Purity of liming materials:** The purer the liming material, the higher will be its effectiveness in amelioration of soil acidity.

Chapter 6
ACID SULPHATE SOILS

In modem 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 sub-layer with yellow colouration due to xarocite.

Soils with sufficient sulphides (FeS_2 and others) to become strongly acidic when drained and aerated enough for cultivation are termed as *acid sulphate soils* or as Dutch refer to those soils as *cat clays*. When allowed to develop aciity, these soils are usually more acidic than pH 4.0. Before drainage, such soils may have normal soil pH and are only potential acid sulphate soils. Generally acid sulphate soils are found in coastal areas where the land is inundated by salt water. In India, acid sulphate soil is, mostly found in Kerala, Orissa, Andhra Pradesh, Tamil Nadu and West Bengal. The area covered under acid sulphate soils in Thailand and India combinedly is about 2 million acres.

Strongly acid sulphate soils results in toxicities of aluminium and iron, soluble salts (unless leached), manganese and hydrogen sulphide (H_2S) gas. Hydrogen sulphide often formed in lowland rice soils causing ***akiochi*** disease that prevents rice plants roots from absorbing nutrients.

Formation of Acid Sulphate Soils

Lands inundated with waters that contain sulphates, particularly salt waters, accumulate sulphur compounds, which in poorly aerated soils are bacterially reduced to sulphides. Soils are not usually ver acidic when first drained in water.

Acid sulfate soils (ASS) are naturally occurring soils and sediments containing iron sulfides, most commonly pyrite. When Acid sulfate soils are exposed to air the iron sulfides in the soil react with oxygen and water to produce a variety of iron compounds and sulfuric acid. Initially a chemical reaction, the process is accelerated by soil bacteria. The resulting acid can release other substances, including heavy metals, from the soil and into the surrounding environment. Potential acid sulfate soils ASS which have not been oxidised by exposure to air are known as potential acid sulfate soils (PASS). While contained in a layer of waterlogged soil, the iron sulfides in the soil are stable and the surrounding soil pH is often weakly acid to weakly alkaline.

Potential acid sulfate soils:

- Often have a pH close to neutral (6.5–7.5)
- Contain unoxidised iron sulphides
- Are usually soft, sticky and saturated with water
- Are usually gel-like muds but can include wet sands and gravels
- Have the potential to produce acid if exposed to oxygen.

Reactions involving the formation of Acid Sulphate Soils

Acid sulphate soils form due to oxidation of sulphides in soils. The slow oxidation of mineral sulphides in soil is non-biological until soil pH reaches an acidity of pH 4.0 but the process is not well understood. Below ph 4.0, the bacteria, *Thiobacillus ferroxidans* are the most active oxidizers and the activity builds up rapidly.

$2S + 3O_2 + 2H_2O \xrightarrow{\text{Microbial oxidation}} H_2SO_4$

(Elemental Sulphur) → (Sulphuric acid)

$H_2S + 2O_2 \xrightarrow{\text{Microbial oxidation}} H_2SO_4$

(Hydrogen Sulphide) → (Sulphuric acid)

Non-Biological

$FeS_2 + 2H_2O + 7O_2 \xrightarrow{\text{Microbial oxidation}} FeSO_4 + H_2SO_4$

(Ferrous Sulphide) → (Ferrous Sulphate) + (Sulphuric acid)

Accelerated by bacteria (*Thiobaccilus ferroxidans*)

$4FeSO_4 + O_2 + 2H_2SO_4 \xrightarrow{\text{Microbial oxidation}} 2Fe_2(SO_4)_3 + 2H_2O$

(Ferrous Sulphate) → (Ferric Sulphate)

Rapid in acid pH (non-biological)

$FeS_2 + 8H_2O + 7Fe_2(SO_4)_3 \xrightarrow{\text{Microbial oxidation}} 15FeSO_4 + 8H_2SO_4$

(Ferrous Sulphate) + (Sulphuric acid)

Managing acid sulfate soils

The easiest and most effective way to avoid the harm caused by acid sulfate soils is to leave them alone—so identification and mapping are important. Avoiding acid sulfate soils is encouraged when possible.

However, acid sulfate soils are common in places where humans live, and sometimes construction in and around these sediments cannot be avoided. In such cases, the first step is to minimise the level of disturbance as much as possible.

Minimising disturbance

Minimising disturbance can be quite easy, and may involve:

- designing a construction project that limits the amount of excavation—for instance, building an above-ground car park instead of a basement, building smaller structures on stilts or push-piles, or placing clean fill in a thick layer before building
- locating a construction project on the part of a property where acid sulfate soils are buried deepest, so the amount of acid sulfate soil removed is reduced
- using construction methods and site management procedures that don't leave acid sulfate soils exposed to air without treatment
- aligning and designing linear infrastructure in tidal areas so that natural water flows (both surface and groundwater) are not blocked
- Making farm and urban drains broad and shallow so they don't dig into buried acid sulfate soil layers, but can still remove excess surface water efficiently.

Treatment

If acid sulfate soil is disturbed, it must be treated.

- **Liming and Leaching:** The most common method of treatment is to mix an alkaline material into the soil, where it can react with acidity and neutralise it. Agricultural lime (powdered calcium carbonate—$CaCO_3$) is the most common neutralising material in use. If these soils are leached during early years of acidification, lime requirements are lowered. Leaching, however, is difficult because of the high water table commonly found in this type of soil and low permeability of the clay. Sea water is sometimes available for preliminary leaching.
- **Keeping the area flooded:** Maintaining the reduced condition of flooded (anaerobic) soil inhibits acid development, which requires oxidation. This solution almost limits the use of the area to rice growing. Unfortunately, droughts occur and can in short time periods cause acidification of these soils. The water used to flood the potential acid sulphate soils often develop acidity and injure crops.
- **Controlling water table:** If a non-acidifying layer covers the sulphuric horizon, drainage to keep only the sulphuric layer under water (anaerobic) is possible.

Chapter 7
COMPACTED SOILS

Compacted soils cannot function healthily, resulting in poor crop establishment and lower crop yields. There is also less infiltration of rainfall, increased runoff and soil erosion.

Causes of soil compaction

Soil compaction occurs when soil density is increased by an energy input into moist or wet soil. The force may be exerted by tyres, tillage tools or animal hooves. In conventional tillage systems, most of the surface area of a paddock receives at least one wheel pass during a fallow. The first pass of a tractor wheel can create 90 per cent of the damage caused by five passes. Most compaction occurs in the top 20 −30 centimetres of the soil.

Repeated tillage at the same depth can form a hardpan a dense, impenetrable layer beneath the tilled soil. The most important factor determining the extent and severity of soil compaction is the moisture content at the time of tyre or implement passage. Other factors like implement design and tyre-inflation pressures are important although secondary to soil moisture content.

Impact of soil compaction

Compacted soil lacks the interconnected air spaces that are essential to the movement of water, gases and plant roots, and critical for a biologically healthy soil.

a. In dry years, crop yields are most affected when plant roots are unable to penetrate compacted layers to enable access to much needed subsoil water.

b. Water-use efficiency is greatly reduced as rain or irrigation water is unable to penetrate the compacted layers of soil to re-fill the subsoil. This results in more run-off and evaporation.

c. Compacted soil requires more horsepower (and fuel) to cultivate. Planting implements are less effective in compacted soil and poor germination is the result.

d. Fertiliser efficiency is also reduced as the large blocks of compacted soil provide few surfaces to retain and release fertiliser for crop growth.

e. Most degradation in grazing lands occurs when surface cover is removed as a result of high grazing pressures. This exposes soils to raindrop impact, runoff and soil loss by erosion.

Chapter 8

ERODED SOILS

Soil erosion is defined as the wearing away of topsoil. Topsoil is the top layer of soil and is the most fertile because it contains the most organic, nutrient-rich materials. Such soils are called as ***Eroded soils***. Soil erosion is the displacement of the upper layer of soil, one form of soil degradation. A low level of erosion of soil is a naturally occurring process on all land. The agents of soil erosion are water and wind, each contributing a significant amount of soil loss each year. Soil erosion may be a slow process that continues relatively unnoticed, or it may occur at an alarming rate causing a serious loss of topsoil. The loss of soil from farmland may be reflected in reduced crop production potential, lower surface water quality, and damaged drainage networks.

Human activities have increased by 10–40 times the rate at which erosion is occurring globally. Excessive (or accelerated) erosion causes both "on-site" and "off-site" problems. On-site impacts include decreases in agricultural productivity and (on natural landscapes) ecological collapse, both because of loss of the nutrient-rich upper soil layers. In some cases, the eventual end result is desertification. Off-site effects include sedimentation of waterways and eutrophication of water bodies, as well as sediment-related damage to roads and houses. Water and wind erosion are the two primary causes of land degradation; combined, they are responsible for about 84% of the global extent of degraded land, making excessive erosion one of the most significant environmental problems worldwide.

Intensive agriculture, deforestation, roads, anthropogenic climate change, and urban sprawl are amongst the most significant human activities in regard to their effect on stimulating erosion. However, there are many prevention and remediation practices that can curtail or limit erosion of vulnerable soils.

Chapter 9

Physical processes responsible for soil erosion

a. Rainfall and surface runoff

Rainfall, and the surface runoff which may result from rainfall, produces four main types of soil erosion: *splash erosion*, *sheet erosion*, *rill erosion*, and *gully erosion*. ***Splash erosion*** is generally seen as the first and least severe stage in the soil erosion process, which is followed by sheet erosion, then rill erosion and finally gully erosion (the most severe of the four).

In ***splash erosion***, the impact of a falling raindrop creates a small crater in the soil, ejecting soil particles. The distance these soil particles travel can be as much as 0.6 m (two feet) vertically and 1.5 m (five feet) horizontally on level ground.

If the soil is saturated, or if the rainfall rate is greater than the rate at which water can infiltrate into the soil, surface runoff occurs. If the runoff has sufficient flow energy, it will transport loosened soil particles (sediment) down the slope. ***Sheet erosion*** is the transport of loosened soil particles by overland flow.

Rill erosion refers to the development of small, ephemeral concentrated flow paths which function as both sediment source and sediment delivery systems for erosion on hill slopes. Generally, where water erosion rates on disturbed upland areas are greatest, rills are active. Flow depths in rills are typically of the order of a few centimeters (about an inch) or less and along-channel slopes may be quite steep. This means that rills exhibit hydraulic physics very different from water flowing through the deeper, wider channels of streams and rivers.

Gully erosion occurs when runoff water accumulates and rapidly flows in narrow channels during or immediately after heavy rains or melting snow, removing soil to a considerable depth.

b. Rivers and streams

Valley* or *stream erosion occurs with continued water flow along a linear feature. The erosion is both downward, deepening the valley, and head ward, extending the valley into the hillside, creating head cuts and steep banks. In the earliest stage of stream erosion, the erosive activity is dominantly vertical, the valleys have a typical **V** cross-section and the stream gradient is relatively steep. When some base level is reached, the erosive activity switches to lateral erosion, which widens the valley floor and creates a narrow floodplain. The stream gradient becomes nearly flat, and lateral deposition of sediments becomes important as the stream meanders across the valley floor. In all stages of stream erosion, by far the most erosion occurs during times of flood, when more and faster-moving water is available to carry a larger sediment load. In such processes, it is not the water alone that erodes:

suspended abrasive particles, pebbles and boulders can also act erosively as they traverse a surface, in a process known as *traction*.

Bank erosion is the wearing away of the banks of a stream or river. This is distinguished from changes on the bed of the watercourse, which is referred to as *scour*. Erosion and changes in the form of river banks may be measured by inserting metal rods into the bank and marking the position of the bank surface along the rods at different times.

Thermal erosion is the result of melting and weakening permafrost due to moving water. It can occur both along rivers and at the coast.

c. Floods

At extremely high flows, vortices are formed by large volumes of rapidly rushing water. Vortex cause extreme local erosion, plucking bedrock and creating pothole-type geographical features called Rock-cut basins.

d. Wind erosion

Wind erosion is a major geomorphological force, especially in arid and semi-arid regions. It is also a major source of land degradation, evaporation, desertification, harmful airborne dust, and crop damage—especially after being increased far above natural rates by human activities such as deforestation, urbanization, and agriculture.

Wind erosion is of two primary varieties: ***deflation***, where the wind picks up and carries away loose particles; and ***abrasion***, where surfaces are worn down as they are struck by airborne particles carried by wind. Deflation is divided into three categories: (1) ***surface creep***, where larger, heavier particles slide or roll along the ground; (2) ***saltation***, where particles are lifted a short height into the air, and bounce and saltate across the surface of the soil; and (3) ***suspension***, where very small and light particles are lifted into the air by the wind, and are often carried for long distances. Saltation is responsible for the majority (50–70%) of wind erosion, followed by suspension (30–40%), and then surface creep (5–25%). Silty soils tend to be the most affected by wind erosion; silt particles are relatively easily detached and carried away.

Wind erosion is much more severe in arid areas and during times of drought. For example, in the Great Plains, it is estimated that soil loss due to wind erosion can be as much as 6100 times greater in drought years than in wet years.

Factors affecting soil erosion

a. Climate

The amount and intensity of precipitation is the main climatic factor governing soil erosion by water. The relationship is particularly strong if heavy rainfall occurs at times when, or in locations where, the soil's surface is not well protected by vegetation. This might be during periods when agricultural activities leave the soil bare, or in semi-arid regions where vegetation is naturally sparse. Wind erosion requires strong winds, particularly during times of drought when vegetation is sparse and soil is dry (and so is more erodible). Other climatic factors such as average temperature and temperature range may also affect erosion, via their effects on vegetation and soil properties. In general, given similar vegetation and ecosystems, areas with more precipitation (especially high-intensity rainfall), more wind, or more storms are expected to have more erosion.

In some areas of the world, rainfall intensity is the primary determinant of erosivity, with higher intensity rainfall generally resulting in more soil erosion by water. The size and velocity of rain drops is also an important factor. Larger and higher-velocity rain drops have greater kinetic energy, and thus their impact will displace soil particles by larger distances than smaller, slower-moving rain drops.

b. Soil structure and composition

The composition, moisture, and compaction of soil are all major factors in determining the erosivity of rainfall. Sediments containing more clay tend to be more resistant to erosion than those with sand or silt, because the clay helps bind soil particles together. Soil containing high levels of organic materials are often more resistant to erosion, because the organic materials coagulate soil colloids and create a stronger, more stable soil structure. The amount of water present in the soil before the precipitation also plays an important role, because it sets limits on the amount of water that can be absorbed by the soil (and hence prevented from flowing on the surface as erosive runoff). Wet, saturated soils will not be able to absorb as much rain water, leading to higher levels of surface runoff and thus higher erosivity for a given volume of rainfall. Soil compaction also affects the permeability of the soil to water, and hence the amount of water that flows away as runoff. More compacted soils will have a larger amount of surface runoff than less compacted soils.

c. Vegetative cover

Vegetation acts as an interface between the atmosphere and the soil. It increases the permeability of the soil to rainwater, thus decreasing runoff. It shelters the soil from winds, which results in decreased wind erosion, as well as advantageous changes in microclimate. The roots of the plants bind the soil together, and interweave with other roots, forming a more solid mass that is less susceptible to both water and wind erosion. The removal of vegetation increases the rate of surface erosion.

d. Topography

The topography of the land determines the velocity at which surface runoff will flow, which in turn determines the erosivity of the runoff. Longer, steeper slopes (especially those without adequate vegetative cover) are more susceptible to very high rates of erosion during heavy rains than shorter, less steep slopes. Steeper terrain is also more prone to mudslides, landslides, and other forms of gravitational erosion processes.

Human activities that increase soil erosion

a. Agricultural practices

Unsustainable agricultural practices are the single greatest contributor to the global increase in erosion rates. The tillage of agricultural lands, which breaks up soil into finer particles, is one of the primary factors. The problem has been exacerbated in modern times, due to mechanized agricultural equipment that allows for deep plowing, which severely increases the amount of soil that is available for transport by water erosion. Others include mono-cropping, farming on steep slopes, pesticide and chemical fertilizer usage (which kill organisms that bind soil together), row-cropping, and the use of surface irrigation. A complex overall situation with respect to defining nutrient losses from soils, could arise as a result of the size selective nature of soil erosion events. Loss of total phosphorus, for instance, in the finer eroded fraction is greater relative to the whole soil. Extrapolating this evidence to predict subsequent behaviour within receiving aquatic systems, the reason is that this more easily transported material may support a lower solution P concentration compared to coarser sized fractions.[41]Tillage also increases wind erosion rates, by dehydrating the soil and breaking it up into smaller particles that can be picked up by the wind. Exacerbating this is the fact that most of the trees are generally removed from agricultural fields, allowing winds to have long, open runs to travel over at higher speeds. Heavy grazing reduces vegetative cover and causes severe soil compaction, both of which increase erosion rates.

b. Deforestation

In an undisturbed forest, the mineral soil is protected by a layer of *leaf litter* and *humus* that cover the forest floor. These two layers form a protective mat over the soil that absorbs the impact of rain drops. They are porous and highly permeable to rainfall, and allow rainwater to slow percolate into the soil below, instead of flowing over the surface as runoff. The roots of the trees and plants hold together soil particles, preventing them from being washed away. The vegetative cover acts to reduce the velocity of the raindrops that strike the foliage and stems before hitting the ground, reducing their kinetic energy. However it is the forest floor, more than the canopy, that prevents surface erosion. The terminal velocity of rain drops is reached in about 8 metres (26 feet). Because forest canopies are usually higher than this, rain drops can often regain terminal velocity even after striking the canopy. However, the intact forest floor, with its layers of leaf litter and organic matter, is still able to absorb the impact of the rainfall.

Deforestation causes increased erosion rates due to exposure of mineral soil by removing the humus and litter layers from the soil surface, removing the vegetative cover that binds soil together, and causing heavy soil compaction from logging equipment. Once trees have been removed by fire or logging, infiltration rates become high and erosion low to the degree the forest floor remains intact. Severe fires can lead to significant further erosion if followed by heavy rainfall. Shifting cultivation is a farming system which sometimes incorporates the slash and burn method in some regions of the world. This degrades the soil and causes the soil to become less and less fertile.

c. Roads and urbanization

Urbanization has major effects on erosion processes—first by denuding the land of vegetative cover, altering drainage patterns, and compacting the soil during construction; and next by covering the land in an impermeable layer of asphalt or concrete that increases the amount of surface runoff and increases surface wind speeds. Much of the sediment carried in runoff from urban areas (especially roads) is highly contaminated with fuel, oil, and other chemicals. This increased runoff, in addition to eroding and degrading the land that it flows over, also causes major disruption to surrounding watersheds by altering the volume and rate of water that flows through them, and filling them with chemically polluted sedimentation. The increased flow of water through local waterways also causes a large increase in the rate of bank erosion.

d. Climate change

The warmer atmospheric temperatures observed over the past decades are expected to lead to a more vigorous hydrological cycle, including more extreme rainfall events. The rise in sea levels that has occurred as a result of climate change has also greatly increased coastal erosion rates.

Studies on soil erosion suggest that increased rainfall amounts and intensities will lead to greater rates of soil erosion. Thus, if rainfall amounts and intensities increase in many parts of the world as expected, erosion will also increase, unless amelioration measures are taken. Soil erosion rates are expected to change in response to changes in climate for a variety of reasons. The most direct is the change in the erosive power of rainfall. Other reasons include: a) changes in plant canopy caused by shifts in plant biomass production associated with moisture regime; b) changes in litter cover on the ground caused by changes in both plant residue decomposition rates driven by temperature and moisture dependent soil microbial activity as well as plant biomass production rates; c) changes in soil moisture due to shifting precipitation regimes and evapo-transpiration rates, which changes infiltration and runoff ratios; d) soil erodibility changes due to decrease in soil organic matter concentrations in soils that lead to a soil structure that is more susceptible to erosion and increased runoff due to increased soil surface sealing and crusting; e) a shift of winter precipitation from non-erosive snow to erosive rainfall due to increasing winter temperatures; f) melting of permafrost, which induces an erodible soil state from a previously non-erodible one; and g) shifts in land use made necessary to accommodate new climatic regimes.

e. Land degradation

Water and wind erosion are now the two primary causes of land degradation; combined, they are responsible for 84% of degraded acreage.

Monitoring, measuring and modeling soil erosion

Monitoring and modeling of erosion processes can help people better understand the causes of soil erosion, make predictions of erosion under a range of possible conditions, and plan the implementation of preventative and restorative strategies for erosion. However, the complexity of erosion processes and the number of scientific disciplines that must be considered to understand and model them (e.g. climatology, hydrology, geology, soil science, agriculture, chemistry, physics, etc.) makes accurate modelling challenging. Erosion models are also non-linear, which makes them difficult to work with numerically, and makes it difficult or impossible to scale up to making predictions about large areas from data collected by sampling smaller plots.

The most commonly used model for predicting soil loss from water erosion is the *Universal Soil Loss Equation (USLE)*. This was developed in the 1960s and 1970s. It estimates the average annual soil loss A on a plot-sized area as:

$$A = RKLSCP$$

where R is the *rainfall erosivity factor*, K is the *soil erodibility factor*, L and S are topographic factors representing length and slope, C is the cover and management factor and P is the support practices factor.

Despite the USLE's plot-scale spatial focus, the model has often been used to estimate soil erosion on much larger areas, such as watersheds or even whole continents. One major problem is that the USLE cannot simulate gully erosion, and so erosion from gullies is ignored in any USLE-based assessment of erosion. Yet erosion from gullies can be a substantial proportion (10–80%) of total erosion on cultivated and grazed land.

Prevention and remediation

The most effective known method for erosion prevention is to increase vegetative cover on the land, which helps prevent both wind and water erosion. Terracing is an extremely effective means of erosion control, which has been practiced for thousands of years by people all over the world. Windbreaks (also called shelterbelts) are rows of trees and shrubs that are planted along the edges of agricultural fields, to shield the fields against winds. In addition to significantly reducing wind erosion, windbreaks provide many other benefits such as improved microclimates for crops (which are sheltered from the dehydrating and otherwise damaging effects of wind), habitat for beneficial bird species, carbon sequestration, and aesthetic improvements to the agricultural landscape. Traditional planting methods, such as mixed-cropping (instead of monocropping) and crop rotation have also been shown to significantly reduce erosion rates. Crop residues play a role in the mitigation of erosion, because they reduce the impact of raindrops breaking up the soil particles. There is a higher potential for erosion when producing potatoes than when growing cereals, or oilseed crops. Forages have a fibrous root system, which helps combat erosion by anchoring the plants to the top layer of the soil, and covering the entirety of the field, as it is a non-row crop. In tropical coastal systems, properties of mangroves have been examined as a potential means to reduce soil erosion. Their complex root structures are known to help reduce wave damage from storms and flood impacts while binding and building soils. These roots can slow down water flow, leading to the deposition of sediments and reduced erosion rates. However, in order to maintain sediment balance, adequate mangrove forest width needs to be present.

Chapter 10
WATERLOGGED SOILS

A waterlogged or submerged soil is defined as the soil which contains moisture above field capacity to water stagnation. In another way we can say water logged soils are soils that are saturated with water for a sufficiently long time in a year to give the soil the following distinctive ***gley horizons*** resulting from oxidation-reduction process.

i. a partially oxidized ―A‖ horizon high in organic matter.

ii. a mottled zone in which oxidation and reduction alternate and

iii. a permanently reduced zone which is bluish green in colour.

The soil is intermittently saturated with water, oxidation of organic matter is slow and it accumulates in the ‗A' horizons. In the second horizon, Fe & Mn are deposited as rusty mottles or streaks if the diffusion of O2 into the soil is slow, if the diffusion is rapid, they are deposited as concretions.

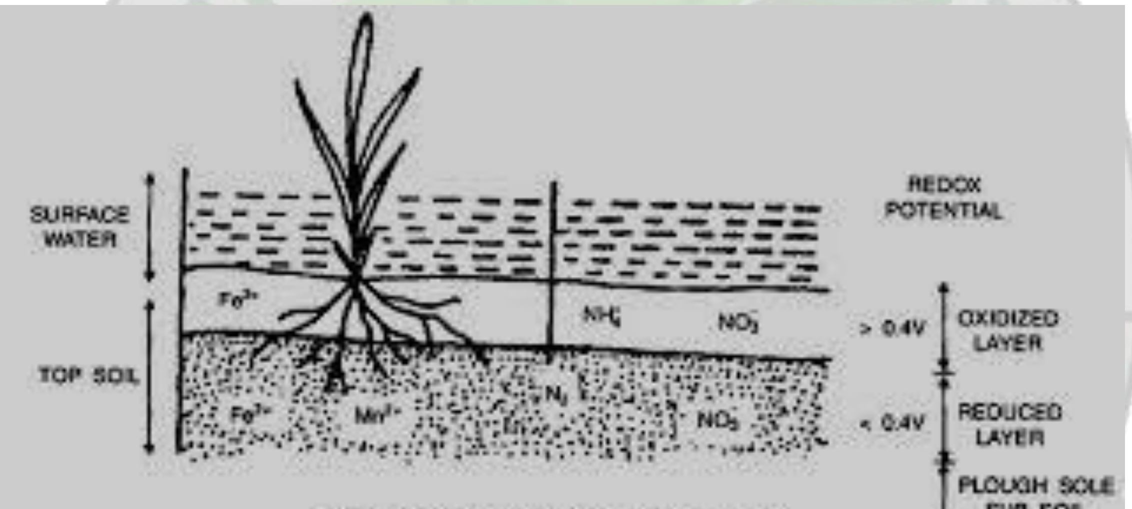


Fig. 22.1. Soil profile of a submerged soil.

Properties of waterlogged soils

Physical properties: (i) Diffusion of molecular oxygen and development of aerobic to anaerobic layer: When a soil is submerged, water replaces the air in the pore spaces. Except in a thin layer at the soil surface, and sometimes a layer below the plough sole, most soil layers are virtually oxygen free within a few hours after submergence and promote anaerobic layer.

(ii) Aeration status of a submerged soil: Immediately after submergence the entry of O_2 and other atmospheric gases in the soil is severely restricted. The escape of soil gases by diffusion is also affected to the same degree. The net result of submergence is the concentration of O_2 in the soil is reduced to a very low value, while that of soil gases, notably CO_2 is increased especially if conditions are favourable for biological activity.

(iii) Accumulation of carbon dioxide: Soil gases like CO_2 and methane accumulate due to submergence and also may escape as bubbles if pressure builds up. It has been recorded that during the first three weeks of submergence some soils may generate CO_2 upto 25 ton ha^{-1}.

(iv) Soil compaction and puddling: In compaction, soil solids are rearranged with compression if liquid and gaseous phases accompanied by volume change. Soil compaction affects the water retention characteristics, water intake rates, and gaseous exchange. In compacted soil, bulk density microvoids, thermal conductivity and diffusivity and nutrient mobility increases, and on the other hand, macrovoids, hydraulic conductivity and water intake rate decreases. Generally medium textured soils are most susceptible to compaction. Puddling influences physical, chemical and biological soil properties which in turn influence rice growth.

Electrochemical properties: (i) Decrease in Redox Potential (Eh) unit volt or millivolt: Redox potential is one of the most important properties of which differentiates between a submerged soil and well drained soil. The Eh value of soil shows whether a soil is in oxidised state or in reduced one. If its value is positive and high, the system is strongly oxidising and if it is negative and low, the system is reducing. The Eh of submerged soil is low (0.2 to -0.4 V) and reflects the reduced system, while that for aerobic soils is high (0.8 V to 0.3 V) reflecting oxidised system.

Effect of soil factors and duration of submergence: Soils having high nitrate (>275 ppm) have positive potential for several weeks after submergence, soils low in OM (<1.5%) or high in Mn (>0.2%) maintain positive potentials even 6 months after submergence. Soils with more than 3% OM and low in active Mn and Fe (sandy soils) attain Eh of -0.2 to -0.3 V within 2 weeks of submergence. Stable potential reached after several week of submergence lie between 0.2 V and -0.3 V. On reaching stable potential the change in Eh is practically unaffected by temperature in the range of 15^0C to 45^0C.

(ii) Changes in pH: When an aerobic soil is submerged, its pH decreases to a minimum due to accumulation of CO_2 produced by respiration of anaerobic bacteria. Then it rises to a stable value of 6.7 to 7.2 a few weeks later due to reduction of Fe. The overall effect of submergence is to increase the pH of acid soils and decrease the pH of alkali or calcareous soils. The decrease in pH of alkali or calcareous soils is due to accumulation of CO_2. Thus due to submergence the pH of acid soils (except those low in Fe) and alkaline soils converge to 7. Draining and exposure to air reverse pH change in paddy soils. The increase in pH of acid soils is one of the benefits of flooding rice soils, because it eliminates Al toxicity and minimises Fe toxicity and increase the availability of phosphate.

(iii) Specific conductance: The specific conductance of the solution of most soils increases after submergence; attain a maximum and declining to a stable value, which varies with the nature and properties of the soil.

Chemical and Microbiological properties: (i) Organic Matter decomposition: Organic matter decomposition in waterlogged soils is only partial and proceeds at a slow rate since it is entirely carried out by anaerobic organisms, which operate at low energy level. Unstable organic substances are produced followed by evolution of CO_2 and methane.

(ii) Ammonification: In waterlogged soils mineralisation of organic nitrogen stops at ammonia stage.

(iii) Denitrification: Denitrification is increased by low oxygen concentration, high organic matter, increase in temperature and low redox potential.

(iv) Nitrogen fixation: Nitrogen fixation in waterlogged soils is carried out by BGA, N-fixing photosynthetic bacteria and nitrogen fixing bacteria.

(v) Phosphorus: Under reduced conditions phosphorus is present in water insoluble and available forms.

(vi) Iron: Iron is reduced and its solubility increased.

Development and classification of water logging

Waterlogging may occur due to several causes which may be classified into two groups:

A. Natural causes: (1) Geological and Geomorphological:

(a). Soil factors: The magnitude of fluctuation of ground water region is high in clayey soil or loamy sand than sandy soil or pebbled. The high infiltration capacity of North Bihar soils is conducive to high water table.

(b). Topography: Generally flattened topography and basin shaped lands are always prone to water logging.

(2) Climate: If the rate of rainfall is higher than the rate of evaporation and infiltration as well as run off due to flattened topography water logging occurs.

(3) Hydrological factors: During monsoon most of the rivers are in floods. The flood water may percolate into the banks and cause arise in the water table or it may overflow the banks and accumulate in the low lying areas having flat or basin shaped topography.

(4) Artesian pressure from underground sources: Wells drilled downwards to penetrate underground aquifers often produce flowing wells, which may or may not be utilised fully for irrigation. Thus the entire valley may become waterlogged because of uncontrolled flow of artesian wells.

B. Defective irrigation and drainage managements:

i. Excessive use of water

ii. Seepage from canals, laterals and ditches.

iii. Poor, inadequate or absence of surface or subsurface drainage system on forms.

iv. Inherent stratification of irrigated soils.

v. Mineral elements in irrigation water or in virgin soils.

vi. Nature of crops.

vi. Absence of basic data on water balance and the ground water of problem areas.

Management of waterlogged soils

1. Improvement of drainage: Drainage is the most important problem of waterlogged areas. No shortcut method can solve all drainage problems. For bringing about improvement in drainage following studies and survey work should be done thoroughly.

i. Field reconnaissance - To find out the number and location of natural waterways and possible location of drainage outlets.

ii. Topographic survey - To identify the slope, undulation, to find out the potential drainage outlet.

iii. Soil Survey – To find out the characteristics of underlying soil layers of waterlogged area and each layer should be analysed in the laboratory to determine their drainabilty.

iv. Water table survey – The position and fluctuation of water table can be determined by installing observation wells.

v. Source of irrigation water –

Source	Remedy
Rainfall	Surface drainage
Seepage of Canal	Interception drainage

2. Besides the above the following cultural practices should be adopted in waterlogged areas.

a. Growing crops tolerant to water logging – Deep water paddy for prolonged flood. Occasional water logging – paddy, sugarcane, jute.

b. Planting trees with high rate of transpiration – grow forest trees, fuel plants like Eucalyptus rebusta, Zizyphus jujube, Napier grass, Guinea grass.

c. Method of planting – Ridge and furrow method of planting reduces the damage due to water logging.

d. Use of balanced fertilizer due to this increase the efficiency of water use by plants.

e. Fish farming

f. Judicious use of irrigation water.

g. Use of early sown and early maturity crop.

Chapter 11
POLLUTED SOIL

Inorganic chemical contamination has become a widespread phenomenon and the problem attains greater significance due to its persistence in soil for longer period. The soil is a primary recipient by design or accident of a myriad of waste products and chemicals used in modern society. Every year millions of tons of products from variety of sources – industrial, domestic and agricultural find their way into the world‘s soils. Once these materials enter the soil, they become part of the biological cycles that affect all forms of life. Although soil acts as a physical factor by its sieving action, a chemical filter by adsorbing and precipitating the chemical substances and a biological filter by decomposing organic materials. But, owing to non-judicious use of manures, fertilizers, pesticides and waste materials into the soils, ground and surface waters get contaminated by excess quantities of nutrients, heavy metals and pollutants. As per an estimate of United Nation Environment Programme (UNEP), 2 billion hectares of land that was once productive has been irreversibly degraded in the past 100 years due to contamination and inaccessibility. Extant of water pollution depends on the solubility of contaminants, size of the contaminants and soil type. Inorganic contaminants such as arsenic, nickel, selenium, zinc, nitrogen and lead are proving quite hazardous for plant and animal health due to bioaccumulation and subsequent biomagnifications in the food web. In order to reduce the impact of inorganic chemical contaminants on human health by preventing their transfer to the food web, there is an urgent need to reduce their transfer to agricultural plats. In view of above facts, an attempt has been made to review the sources of inorganic contaminants, potential hazards and remediation of contamination in the present text.

Sources and ill effects of Inorganic chemical contaminates in soils: Inorganic chemical contaminants inter into soils either through pedogenic or anthropogenic or both pathways. If parent materials of the soil have higher concentration of heavy metals or pollutants than certainly the developed soils and water bodies of nearby area will have higher concentration of inorganic chemical contaminants. Industrialization, faulty method of waste disposal, faulty agricultural practices, mining of minerals and unscientific drainage of effluents are few important anthropogenic sources of chemical contaminants. The toxicity of inorganic contaminants released into environment every year is now estimated to exceed that from organic and radioactive sources combined. The greatest problems most likely involve arsenic, lead, mercury, cadmium, nickel, copper, zinc, chromium, molybdenum, manganese, selenium, fluoride and boron. To greater and lesser degree, all of these elements are toxic to humans and other animals. Cadmium and arsenic are extremely poisonous; lead, mercury, nickel and fluoride are moderately so; boron, copper, manganese and zinc are relatively lower in mammalian toxicity. Table-1 provides background information on the uses, sources and effect of some of these elements.

Irrespective of their sources, toxic elements can and do reach the soil, where they become part of the food chain: Soil → Plant → Animal → Human (Fig. 1). Unfortunately, once the elements become part of this cycle, they may accumulate in animal and human body to toxic levels. This situation is especially critical for fish and other wildlife and for human at the top of the food chain. It has already resulted in restrictions on the use of certain fish and wildlife for human consumption. Also, it has become necessary to curtail the release of these toxic elements in the form of industrial waste.

Permissible limits of heavy metals in soil food and drinking water: Heavy metals entered into living bodies depletes some essential nutrients that are further responsible for decreasing immunobiological defenses, intrauterine growth retardation, impaired psychosocial faculties, disabilities associated with malnutrition and high prevalence of upper gastrointestinal cancer rates. Serious systemic health hazards can develop as a result of extreme dietary accumulation of heavy metals. Permissible limits of heavy metals in soil, food and drinking water reported by Awasthi (2000) have been presented in table-2.

Potential of sewage-sludge to cause chemical hazards: Application of sewage and sludge in soil for crop production is quite common practice adopted by the farmers in India and abroad. It has been concluded on the basis of experimental data that high concentrations of heavy metals in untreated sewage-sludge cause chemical pollution in soil (Table 3). It has been observed that continuous supply of sewage water increases pollutant concentration in soil (Table 4). So, sewage should be applied in field for agriculture purposes only after treatment with suitable amendment. It is pertinent to mention that in some of the cases inorganic chemicals are not sufficiently high to be toxic to the plants and living organisms but biomagnifications makes the concentration of heavy metal toxic to the living organisms.

Forms of heavy metals in soil: On the basis of experimental results it has been found that heavy metals are found in four major forms in our soil system.

1. Soluble or exchangeable forms, which are available to the plants to uptake.
2. The elements are bounded by the soil organic matter and may be released over a period of time.

3. Association of heavy metals in soils is with carbonates

4. Association of heavy metals in soils with oxides of iron and manganese.

Prevention and elimination of inorganic chemical contamination: Three primary methods of alleviating soil contamination by toxic inorganic compounds are-

(1) to eliminate or drastically reduce the soil application of the toxins;

(2) to immobilize the toxin by means of soil management, to prevent it from moving into food or water supplies; and

(3) in the case of severe contamination, to remove the toxin by chemical, physical or biological remediation.

Reducing soil application: The first method requires action to reduce unintentional aerial contamination from industrial operations and from automobile, truck and bus exhausts. Anthropogenic activities including the indiscriminate dumping of urban and industrial effluents responsible for heavy metal accumulation in soil must be stopped or decreased soon. Also, there must be judicious reduction in intended applications of the toxins through chemical pesticides, fertilizers, irrigation water and solid wastes which is possible by popularizing bio-pesticides, bio-fertilizers and treatment of water and wastes by suitable materials. Inorganic amendments used for the reduction of heavy metals have been presented in Table 5.

Immobilizing the toxins

Soil and crop management can help to reduce the continued cycling of these inorganic chemicals. This is done primarily by keeping the chemicals in the soil rather than encouraging their uptake by plants. The soil becomes the sink for the toxins, and thereby breaks the soil-plant-animal cycle through which the toxins exerts its effect. The soil breaks the cycle by immobilizing the toxins. For example, most of these elements are rendered less mobile and less available if the pH is kept near neutral or above. Draining of wet soils will be beneficial, since the oxidized forms of several toxic elements are generally less soluble and less available for plant uptake than the reduced forms. However, the opposite is true for chromium, which occur principally in two forms Cr^{3+} and Cr^{6+} . Hexavalent chromium forms compound that are mobile under a wide range of pH conditions and are highly toxic to humans. Trivalent chromium on the other hand forms oxides and hydroxides that are quite immobile except in very acid soil. Fortunately, active soil organic matter is quite effective at reducing chromium.

Heavy phosphate applications reduce the availability of some metal cat ions but may have opposite effect on arsenic. Leaching may be effective in removing excess boron, although moving the toxin from soil to water, so bioremediation should be alone to save the human being from B toxicity. Covering of soil with unpolluted soil may be useful to reduce lead uptake by the plants.

Care should be taken in selecting plants to be grown on metal contaminated soil. Generally plants translocate much larger quantities of metals to their leaves than to their fruits or seeds. So, leafy vegetables should not be grown in this soil.

Bioremediation

Certain plants have been reported to accumulate heavy metals in considerably higher proportions without showing any toxicity symptoms. Plants have been found that accumulate more than 20,000 mg/kg nickel, 40,000 mg/kg zinc and 1000 mg/kg cadmium. These hyper accumulating plants would pose a serious health hazards if consumed by animals or human beings. But, they may facilitate a new kind of bioremediation for metal contaminated soils because the traditional physico-chemical methods to clean up the polluted soils are typically cost-prohibitive and destructive. Conclusively, it can be stated that a viable and remunerative option could be the cultivation of non-edible crops, which are economically remunerative as well, like cut flower, aromatic and medicinal plants etc..

Genetic and bioengineering techniques are being utilized to develop high yielding hyper accumulating plants that can remove larger quantities of heavy metals contaminating from soils. Also, research to insert genes responsible for contaminant accumulation into other higher yielding plants, such as canola and Indian mustard is underway.

A combination of chelates and phytoremediation has been used to remove lead from contaminated soil. Treatment of lead and arsenic contaminated water with harmless chelating legends may be useful for making the water usable and harmless.

Nano particles: In situ stabilization by nano particles having low environmental impact is one of the most promising techniques. This technique is helpful in reducing the risk of ground water contamination, plant uptake of heavy metals, and exposure of other living organisms to heavy metal ions.

Conclusion: Inorganic chemical contamination in soil, water and food has now become a noticeable issue for thinkers, planners, politicians and scientists because it has started to cause human health hazard. Natural mechanisms governing the maintenance of the ecological and agricultural functions of soil are being jeopardized with the increase in soil contamination brought about by anthropogenic activities. This is very high time to understand about the sources of inorganic chemical contamination and to adopt the preventive or curative measures. Numerous organic materials or inorganic chemicals offer quick remediation of contaminated soil and water to reduce inorganic chemical contamination level in food plants and ultimately to save the humanity.

Fig. 1 : Sources of heavy metals and their recycling

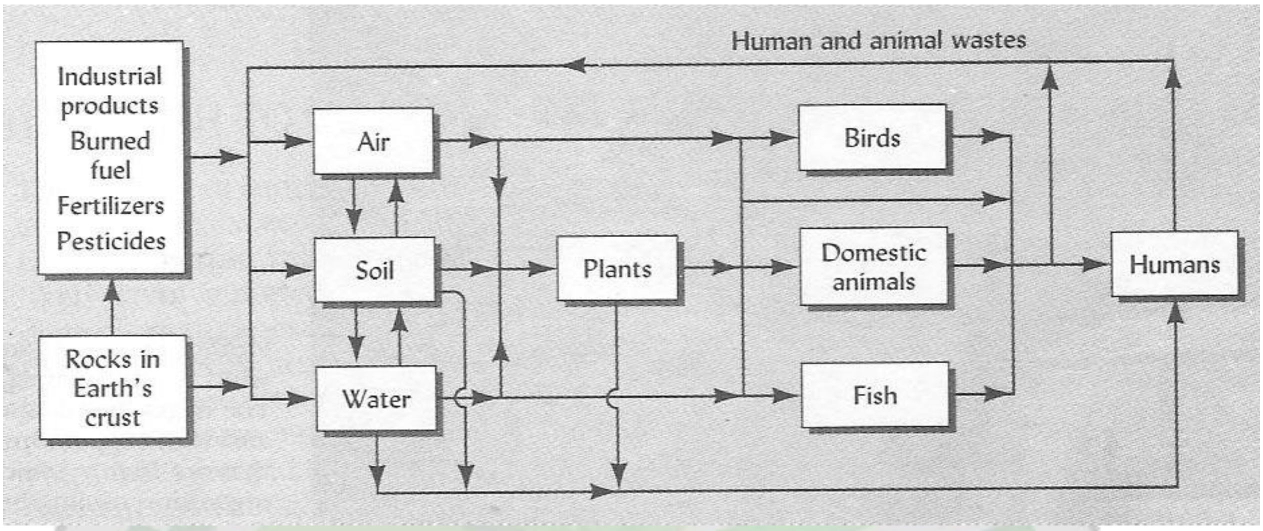


Table 1 : Sources and human health effects of inorganic soil pollutants.

Chemicals	Major uses and sources of soil contaminants	Organisms principally harmed	Human health effects
Arsenic	Pesticides, animal feed additives, coal, petroleum, irrigation water, plant desiccants, detergent	H,A,F,B	Cancer, skin lesions, cumulative poison
Lead	Combustion of oil, gasoline and coal, steel and iron production, solder in water pipes, paint pigment.	H,A,F,B	Brain damage, convulsions
Cadmium	Electroplating, pigments for plastic and paints, plastic stabilizers, batteries and phosphate fertilizers	H,A,F,B, P	Heart and kidney disease, bone embrittlement
Chromium	Stainless steel, chrome plated metals, pigments, leather tanning and refractory brick manufacture	H,A,F,B	Mutagenic
Copper	Fly ash, fertilizers, windblown copper containing dust, water pipes and mine tillage.	F,P	Rare, essential nutrients
Mercury	Pesticides, catalyst for synthetic polymers, metallurgy and thermometers	H,A,F,B	Nerve disease
Nickel	Combustion of coal, gasoline and oil, alloy manufacture, electroplating, batteries and mining.	F,P	Lung cancer
Selenium	High se geological formation and irrigation water containing high content of se	H,A,F,B	Rare, loss of hair and nail, deformities
Zinc	Galvanized iron and steel, alloys, batteries, brass, rubber manufacture, mining and old tires.	F, P	Rare, essential nutrients

H = Human, A = Animals, F = Fish, B = Birds, P = Plants
Source : Brady and Well (2007)

Table 2: Indian standards for heavy metals in soil, food and drinking water

Heavy metal	Soil (mg Kg^{-1})	Food(mg Kg^{-1})	Water(mg L^{-1})
Cd	3-6	1.5	0.01
Cr	-	20	0.05
Cu	135-270	30	0.05
Fe	-	-	0.03
Ni	75-150	1.5	-
Pb	250-500	2.5	0.10
Zn	300-600	50	5.00
As	-	1.1	0.05
Mn	-	-	0.10

Table 3: Regulatory limit and pollutant loading rates of heavy metals in sewage-sludge

Elements	Maximum concentration in sludge USEPA mg/kg	Heavy metals loading rate (mg/kg) in different cities				
		Delhi	Chennai	Nagpur	Ahmadabad	Jaipur
As	75	-	-	-	-	-
Cd	85	5.5	8.3	1.5	3.5	7.3
Cr	3000	53.5	38.5	49.2	60.4	176
Cu	4300	440	210	272	535	265
Hg	57	-	-	-	-	-
Mo	75	-	-	-	-	-
Ni	420	815	60.5	14.8	32.3	37.5
Pb	840	34.5	16.6	24.3	76.8	66.9
Se	100	-	-	-	-	-
Zn	7500	1610	935	832	2141	1720

USPEA = US environmental protection agency (1993)

Table 4: Availabilities of micronutrients and heavy metals of top soil (0-16cm) as affected by sewage irrigation for thirty years in Nagpur district of Maharashtra

Location	Irrigation status	Nutrient content (mg/kg)						
		Fe	Cu	Zn	Mn	Pb	Cr	Cd
Chafegadi	Non irrigated	9.87	1.97	0.25	12.04	0.13	0.018	0.012
	sewage irrigated	19.13	2.91	0.11	12.13	0.28	0.042	0.018
Kuhi	Non irrigated	9.36	2.20	0.14	9.45	0.93	0.018	0.016
	sewage irrigated	17.05	7.69	0.51	14.16	0.70	0.028	0.012
Asoli	Non irrigated	2.12	5.99	1.66	4.13	0.78	0.026	0.010
	sewage irrigated	8.54	8.22	6.11	24.44	2.01	0.030	0.040

Table 5: Mineral amendments used for the reduction of heavy metals

Amendment	Metals immobilized
Al-Montmorillonite	Cd, Ni, Zn
Clinoptilolite	Cd, Pb, Zn
Di ammonium phosphate	Cd, Pb, Zn
Ferrous sulphate	As, Cr
Hydroxyappetite	Cd, Cu, Ni, Zn
Lime	Cd, Cu, Ni, Zn, Pb
Manganese oxide	Cd, Pb
Water treated sludge	Cd, Cu, Pb, Ni, Zn

Chapter 12
IRRIGATION WATER – QUALITY AND STANDARDS

Quality of irrigation water – The concentration and composition of dissolved constituents in a water determine its quality for irrigation use.

Criteria for evaluating of irrigation water – For irrigation waters, the usual criteria include salinity, sodicity (Sodium content) and element toxicities.

(1) Salinity hazard of total concentration of soluble salts or electrical conductivity (dsm^{-1})

<table>
<tr><th>Water</th><th>Ec (ds^{m-1})</th><th>Salt concentration</th><th>Remarks</th></tr>
<tr><td>Low salinity</td><td>0 – 0.25</td><td>< 0.16</td><td>Can be used safely</td></tr>
<tr><td>Medium salinity</td><td>0.25 – 0.75</td><td>0.16 – 0.50</td><td>Can be used with moderate leachling</td></tr>
<tr><td>Highly salinity</td><td>0.75- 2.25</td><td>0.50- 1.50</td><td rowspan="2">Can not be use for irrigation purposes</td></tr>
<tr><td>Very high salinity</td><td>2.25 – 5.00</td><td>1.50 - 30</td></tr>
</table>

(2) Sodium hazard – High concentration of sodium are undesirable in water because sodium adsorbs on the Soil Carbon exchange sites, causing soil aggregates to break down (deflocculation), sealing the pores of the soil and making it impermeable to water flow. The tendency for sodium to increase its proportion on the carbon exchange sites at the expense of other types of cations is estimated by the ratio of sodium content of the content of calcium plus magnesium in the irrigation water.

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+}+Mg^{2+}/2)}}$$

<table>
<tr><th></th><th>Water class</th><th>SAR Value</th><th>Remarks</th></tr>
<tr><td>S_1</td><td>Low medium hazard</td><td>0 – 10</td><td>Little or no hazard</td></tr>
<tr><td>S_2</td><td>Medium sodium hazard</td><td>10 – 18</td><td>Appreciable hazard, but can be used with appropriate management</td></tr>
<tr><td>S_3</td><td>High sodium hazard</td><td>18 – 26</td><td rowspan="2">Un satisfactory for most of the crops</td></tr>
<tr><td>S_4</td><td>Very high sodium hazard</td><td>>26</td></tr>
</table>

(III) Salt index – It is also used for predicting sodium hazard. It is the relation between Na^+, Ca^+ and $CaCo_3$ Present in irrigation water.

Salt index = (Total Na – 24.5) - [(Total Ca – Ca in $CaCO_3$) x 4.85] being reckoned as calcium.

The salt index is negative (-24.5 to 0) for irrigation water of high quality and any positive value of the salt index is harmful for irrigation purposes. The relative degree on both sides (negative & positive sides) depends on the magnitude of the ―Salt index‖ factor.

(1V) Bicarbonate hazard – The bicarbonate (HCO_3) anion is an important in irrigation water as regards calcium and to a lesser degree also of magnesium as their carbonate in the soil. This brings about a change in the soluble sodium percentage (SSP) in the irrigation water and therefore, an increase of the sodium hazard. The RSC is used to evaluate the quality of irrigation water and is expressed in mel^{-1}.

Residue sodium carbonate = RSC

RSC (mel^{-1}) = (CO_3^{2-}+HCO_3^-) – (Ca^{2+} + Mg^{2+})

RSC Value (mel^{-1})	**Water Quality**
< 1.25	Water can be used safely
1.25 – 2.5	Water can be used with certain management
>2.5	Unsuitable for irrigation purposes

(V) Boron Concentration – It is evident that boron is essential for the normal growth of the plant, but the amount required is very small. The occurrence of boron in toxic concentration in certain irrigation waters makes it necessary to consider this element in assessing the water quality. The permissible limits of boron in irrigation water are given below.

Permissible limits of boron in irrigation water in relation to different categories of crops.

Boron Class	Boron Concentration (ppm)			Remarks
	Sensitive Crops	Semi tolerant Crops	Tolerant Crops	
Very low	< 0.33	< 0.67	< 1.00	Can be used safely
Low	0.33 to 0.67	0.67 to 1.33	1.00 too2.00	Can be used with management
Medium	0.67 to 1.00	1.33 to 2.00	2.00 to 3.00	Un suitable for irrigation purposes
High	1.00 to 1.25	2.00 to 2.50	3.00 to 3.75	
Very high	>1.25	>2.50	> 3.75	

(VI) <u>Chloride Concentration</u> – The chloride ion has no effect on the physical properties of a soil and is no adsorbed on the soil complex and so it has generally not been included in modern classification system. However, it can be used as a factor in some regional water classification.

$$Cl^- \text{ Concentration (mel}^{-1}) = \frac{Cl^- + NO_3^-}{CO_3^{2-} + HCO_3^- + SO_4^{2-} + Cl^- + NO_3^-}$$

Cl^- Concentration (mel $^{-1}$)	Water quality
4 – 7	Excellent water
7 – 12	Moderately good water
12 - 20	Slightly usable
>20	Not suitable for irrigation

<u>Table (guide lines are only approximate)</u>

<u>Intensity of Problem</u>

Water Constituent	No problem	Moderate Problem	Service Problem
1. Salinity (dsm^{-1})	< 0.75	0.75 – 3.0	> 30
2. SAR – Soils are			

(a) dominantly montmonillonite	< 6	6 -9	>9
(b) dominantly little vermiculate	< 8	8 - 16	>16
(c) dominantly kaolinite sesquioxide	<16	16 – 24	>24
3. Specific ion toxicity			
(a)Sodium (adjusted SAR)	<3	3 – 9	>9
(b)Chloride (mel^{-1})	<4	4 – 10	>10
(c)Boron (mel^{-1})	< 0.75	0.75 – 2.0	>2.0
4.NO^{-3} or NH4^{+} (mel^{-1})	<5	5 – 30	>30
5. Hco$_3^-$ (mel^{-1})	< 1.5	1.5 – 8.5	>8.5

(VII) Soluble Sodium Percentage (SSP)

$$SSP = \frac{Na \times 100}{Ca+Mg+Na}$$

All soluble cations are expressed in mel^{-1} irrigation water having SSP value of 60 and above are considered as harmful.

(VIII) Magnesium hazard – It is believed that the one of the important qualitative criteria in judging the irrigation water is its magnesium content in relation to total divalent cations, Since high magnesium adsorption by soil affects their physical properties. A harmful effect one soils appears when Ca:Mg ratio declines below 50.

Mg. Adsorption ratio $= 2 = \frac{Mg^{2+}}{Ca^{2+}+Mg^{2+}}$

Magnesium hazard in irrigation water is expected having Mg:Ca ratio more than 1.

(IX) Nitrate Concentration – Very frequency ground waters contain high amount of nitrate. When such type of irrigation water is applied on soils. Continuously various physical properties will be affected very badly which causes poor growth of the plants.

(X) Lithium – Lithium is an important trace element which may be found in most of saline ground – water and irrigated soils. It has been found that small concentration (0.05 – 0.1 ppm) of Lithium in irrigation water produced toxic effects on the growth of citrus crops.

Chapter 13

USE OF SALINE WATER IN AGRICULTURE

Water is a fundamental human need and a critical national asset. According to the United Nations Water Organization (UNWO), the total usable fresh water supply for ecosystem and humans is only 200,000 Km^3 of water – less than one per cent of all water resources. Based on the map published by Consultative Group of International Agricultural Research (CGIAR), the regions suffering most water stress are North America, India, Central Asia, China, Chile, South Africa and Australia. In the other hand, demand of usable water is increasing very sharply to meet out the thrust and hunger of ever increasing human population. As per an estimate of UNWO, water withdrawals are predicted to increase by 50% by 2025 in developing countries and 8% in developed countries. By 2025, 800 million people will live in absolute water scarcity and two third of the world population could be under stress condition. Despite of fast depletion of usable water resources, ground water available in India is being utilized prosperously. Over 65% of irrigation water and 85% of drinking water is obtained from ground water resources. However, on current trends it is estimated that 60% of ground water sources will be in critical state within the next twenty years. Volume of underground water used for irrigation purposes in India has been increased by 117% within 48 years (1961-2009). The National Commission for Integrated Water Resource Development (NCIWRD) has estimated that against the total annual availability of 1953 BCM (billion cubic meter) of ground water and 1521 BCM of surface water, only 55.6% can be put to use. The high level of pollution further restricts the utilization of water. So, this is very high time to recharge our underground water resources, saving of underground water and use of saline water (as such or treated) for agricultural and other proposes.

Total volume of water available on earth is 1.4 X 10^9 $Km^3$and out of which 97.7% is saline. Slightly to moderate saline water can be used for agricultural purposes; however, strong saline water can only be used for irrigation and other purposes after their proper treatment/desalinization. Now, we have technologies and plant machineries to desalinize the brackish/ saline/ briny water for agriculture and human consumption. Solar or nuclear energy-based desalinization plants have been established in various part of the globe. Management of saline water in agriculture includes an important aspect of safe use of saline water to irrigate the crops. Saline/ briny water can be classified on the basis of electrical conductivity, sodium adsorption ratio ($Na^+/[(Ca^{++} + Mg^{++})/2]^{1/2}$) and residual sodium carbonate [(CO_3^{--} +HCO_3^{--})-(Ca^{++} + Mg^{++})]. As per United State Salinity Laboratory, water containing less than 0.25 dSm^{-1} electrical conductivity can be used any type of soils. However, Water containing 0.25-0.75, 0.75-2.25 and 2.25-5.0 dSm^{-1} electrical conductivity can be used by providing small, good and very good drainage facilities in respective soils. If salinity level in irrigation water is > 5.0 dSm^{-1} than only salt tolerant crops can be grown with good drainage facility. As far use of water for irrigation of crop on the basis of sodium adsorption ratio is concerned, water having 0-10SAR can be used in any kind of soils and crops. Water having SAR values 10-18, 18-26 and >26 can be used with moderate, good and very good drainage facility (combined with gypsum) respectively. Water having more than 10.00 meL^{-1} RSC can safely be used in soil receiving more than 700mm annual rainfall but if rain fall is lesser than we should not use the water having >7.5 meL^{-1} RSC. To prevent the excessive accumulation of salt in the root zone from irrigation, extra water (or rainfall) must be applied in excess of that needed for evapotranspiration (ET) and must pass through the root zone in a minimum net amount; over the long term. This amount may be referred to as the "leaching requirement" (L_r, the fraction of infiltrated water that must pass through the root zone to keep salinity within acceptable levels; US Salinity Laboratory Staff, 1954).

While discussing the global water security through use of saline water in agriculture, we must not surpass the anthropogenic addition of pollutants through either run-off from agricultural chemicals or poor management practices. Carbonates and bi-carbonates of sodium and/or potassium play an important role for poor irrigation water quality.

Saline water can also be used for irrigation purposes, but the methods of treatment depend on extent of salinity in water (Table 1).

Table 1: Classification of irrigation water based on its electrical conductivity

EC (µ mhos/cm)	**Use in Agriculture**
<250	Safe to use in agriculture for irrigation.
250-750	Can be used with some leaching facility
750-2250	Can be used with good drainage facility
2250-5000	Salt tolerant crops can be grown with good drainage facility
>5000	Salt tolerant crops can be grown with good drainage facility

Leaching requirement (LR) can be calculated by following formula:

$LR = C_i/C_d = D_d/D_i$

where, C_i =Salt concentration in irrigation water

C_d =Salt concentration in drainage water

D_i =Depth of irrigation water

D_d =Depth of drainage water

However, depth of irrigation water (D_i) based on electrical conductivity can be calculated by following formula:

$D_i = [EC_d/(EC_d - EC_i)]D_c$

Where, ECd = EC of drainage water

EC_i = EC of irrigation water

D_i = Depth of irrigation water, and

D_c = Equivalent depth of water representing consumptive use

Based on sodium adsorption ratio (SAR), water can be classified as under:

SAR	**Use in Agriculture**
<10	Safe to use in agriculture for irrigation.
10-18	Can be used with some leaching facility
18-26	Can be used with good drainage facility
>26	Can be used in combination with gypsum to grow salt tolerant crops

Irrigation water can also be classified based on residual sodium carbonate (RSC), which is as under:

RSC (me/L)	**Remark**
<1.25	Safe
1.25-2.5	Marginal
>2.5	Unsafe

Conclusively, it can be stated that saline water can also be used for irrigation purposes. But, irrigation water having high EC, SAR and RSC values can be used for agricultural purposes only after proper treatment.

Chapter 14

REMOTE SENSING AND GIS IN DIAGNOSIS AND MANAGEMENT OF PROBLEM SOILS

Introduction

Remote sensing and GIS (Geographic Information Systems) technology provides an important tool for the assessment and monitoring of the natural resources. Due to rapidly expanding opportunities, different organizations and research sectors are interested to adopt this technology in their business or research work, and lots of funds are being invested on these fields. Remote sensing and GIS (Geographic Information Systems) technology directly and indirectly involved for the enhancement of geospatial information and their management in geo-database in which spectral properties of the targets *viz.* soil, water and vegetation of the earth surface played an important role. Materials of the surface reflect and absorb the energy at differently level of wavelengths interval and they are categorized as targets, can be differentiated by their spectral reflectance or signatures in the remotely sensed images and digital images acquired from the satellite sensors used for information extraction. To achieve this target, geospatial softwares like Erdas Imagine, Envi, TNT Mips, Arc-GIS and Q-GIS are used for digital image processing and mapping. Main objective of this topic ―*Application of remote sensing and GIS in Agriculture"* is to introduce the concept of remote sensing and GIS, methodology/flow chart and the application in agriculture,

In initial stage, remote sensing means obtaining information about an object, area or phenomenon without actual touch or coming in direct contact with it. However, modern remote sensing means acquiring information about earth‘s land and water surfaces by using reflected or emitted electromagnetic energy. Over this concern, optical remote sensing makes use of visible, near infrared and short-wave infrared sensors to form images of the earth's surface by detecting the solar radiation reflected from targets on the ground but thermal remote sensing work on emitted energy. Hence, different materials reflect and absorb differently at different wavelengths. Thus, the targets can be differentiated by their spectral reflectance signatures in the remotely sensed images. There are different stages involved in RS-GIS in which source of energy or illumination is most important element provides electromagnetic energy to the target of interest whatever assigned. Further when the energy travels from its source to the target, it will come in contact with and interact with the atmosphere then it passes through and reached to the ground surface and interacts with the target. Depending on the properties of both the target and the radiation, the energy may reflect by, or emitted from the target and that energy recorded by the sensor and converted into images. Pectoral data whatever recorded in form of reflected energy or emitted energy the data are processed into an image (hardcopy and/or digital) in receiving and processing station further processed image is interpreted, visually and/or digitally or electronically, to extract information about the target which was illuminated.

Electromagnetic Radiation and Electromagnetic Spectrum

Electromagnetic Radiation consists of an electrical field which varies in magnitude in a direction perpendicular to the direction in which the radiation is travelling, and a magnetic field oriented at right angles to the electrical field. Both these fields travel at the speed of light is the first requirement for remote sensing. However, the **electromagnetic spectrum is a complete set of wavelength interval where** ranges start from the shorter wavelengths (including gamma and x-rays) to the longer wavelengths (including microwaves and broadcast radio waves). The light which our eyes can detect is part of the **visible spectrum** an important to decimate between objects. In same manner, there is a lot of radiation around us which is "invisible" to our eyes, but can be detected by remote sensing instruments and applied to our advantage. The visible wavelengths viz, blue, green and red cover a range from approximately 0.4 to 0.7 µm in which longest visible wavelength is red and the shortest is violet. **Blue**, **green**, and **red** are the **primary colours** or wavelengths of the visible spectrum. **Infra Red portion,** the next portion of the spectrum of interest is the infrared (IR) region which covers the wavelength range from approximately 0.7 µm to 100 µm, may be divided into two categories based on their radiation properties - the **reflected IR**, and the emitted or **thermal IR**. The thermal IR region is quite different than the visible and reflected IR portions, as this energy is essentially the radiation that is emitted from the Earth's surface in the form of heat. The portion of the spectrum of more recent interest covers the longest wavelengths (from about 1 mm to 1 m) used for remote sensing known as **microwave region.** The shorter wavelengths have properties similar to the thermal infrared region while the longer wavelengths approach the wavelengths used for radio broadcasts. Satellite sensors identify object and discriminate it from other objects on the basis of reflected/emitted electromagnetic energy received by it. When sensors like cameras or multispectral scanners are mounted on aircraft, the images are recorded on films or magnetic tapes by filter where energy reflected from the targets. This can be done either using electro-optical techniques or more popularly by using computer. Then the output products are generated either in the form of photographs or in digital form. Then the photographs are analysed visually and digital data is analysed by computer software.

Satellite Data Products and their interpretation

The satellite data products give information of objects on the earth surface in the form of photographs or images. The pictorial products provided by aircrafts known as photographs or satellites are called satellite images. These images are generally taken by sensors which use both visible and invisible portion of electromagnetic energy. If images are taken in blue, green and red bands (visible portion of electromagnetic energy) respectively, they can be combined to give natural colour image but images are taken in green, red (visible portion of electromagnetic energy) and infrared band (invisible portion of electromagnetic energy) and blue, green and red colours are assigned to them respectively and then they are combined together, produce a False Colour Composite (FCC) image that is much effective for the extraction the information of geospatial features.(Fig.1). Lay person cannot visualize anything from FCC image. Only an expert can interpret it. Based on digital image processing and applied indices, valuable information may be generated and stored in database. Multispectral, hyper-spectral, thermal and microwave remote sensing are well known for providing satellite images. IRS series and Landsat series satellites provided sun synchronous satellite images. However, Indian meteorological department uses satellite data for weather forecasting.

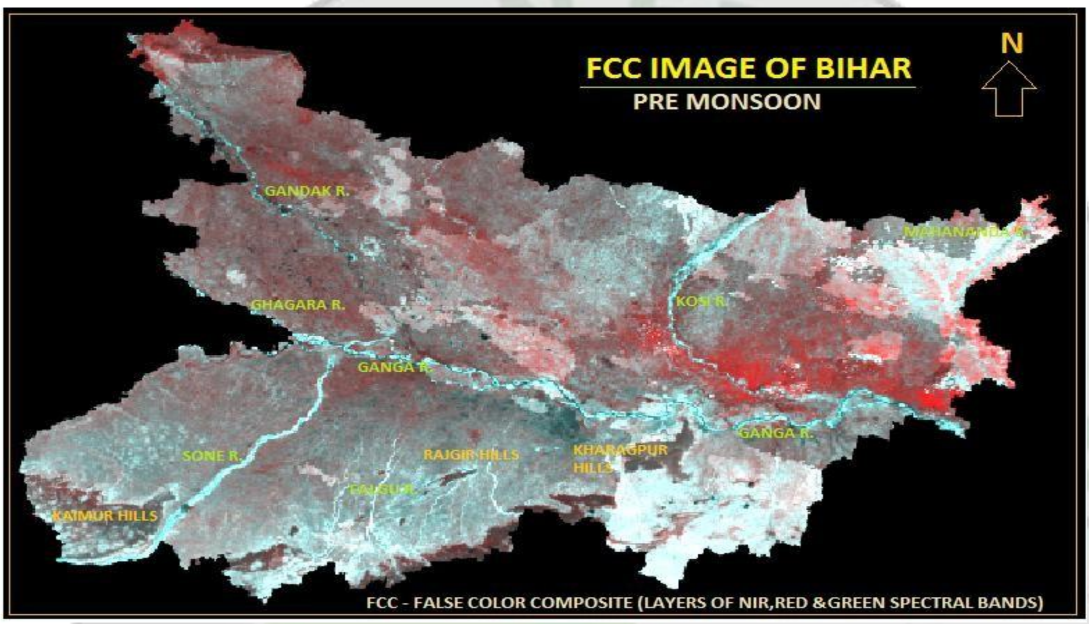


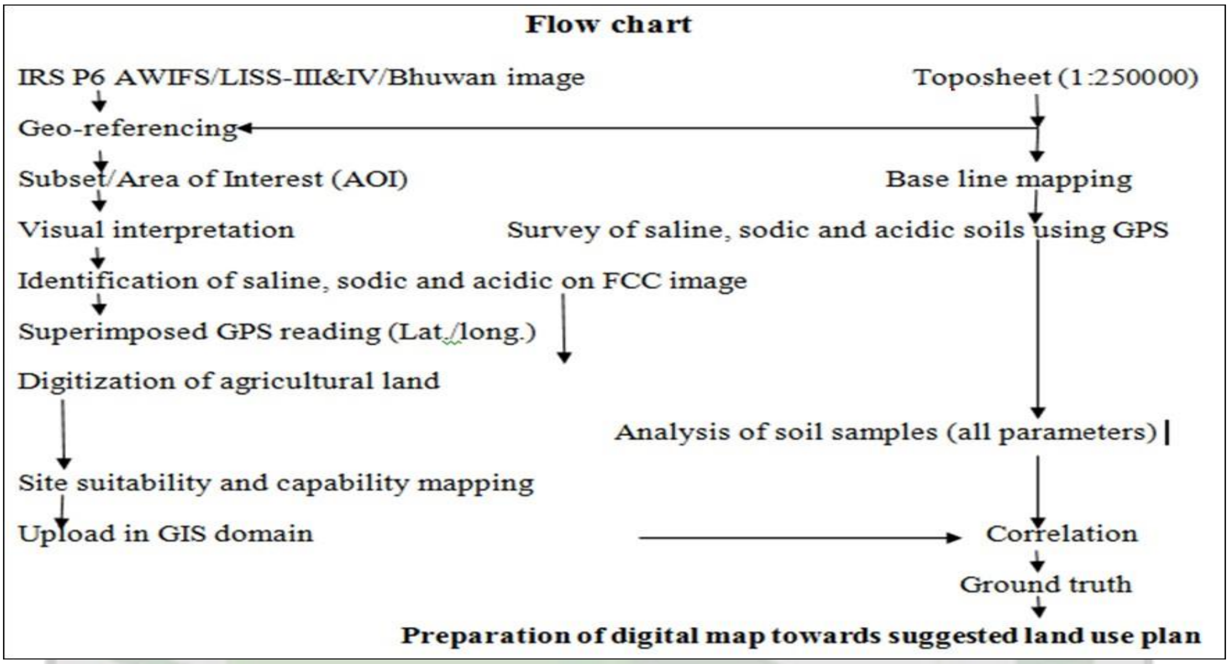
Fig.2 FCC image of Bihar in which vegetation appeared red

Methodology

Flow chart of methodology used in case of presentation of data or information whatever derived in computer system, There are different types of methodologies were applied to fulfil the objectives under ICT, similarly in case of land use pattern or agricultural information system under RS-GIS technology some methodologies were applied. Suppose, there is need to develop a land use plan using geospatial/RS-GIS technology, some steps may be involved which are summarized in a flow chart (Fig.2). Satellite data, toposheets and attribute data are the basic sources for the generation of geospatial data base and over this concern geo-referencing, mosacking, visual interpretation keys, superimposed of GPS reading, digitization and digital image processing are some initial processes were applied for the extraction of geospatial features from the satellite images or attribute data. However, laboratory reports and ancillary data that may be derived or available in documented form may also be applied to fulfil the objectives.

Geographical Information System

GIS is a computer based information system which attaches a variety of qualities and characteristics to geographical location and helps in planning and decision making. Indian



Society of Geomatics (ISG) and Indian Space Application Centre (ISRO) defined GIS as a system which provides a computerised mechanism for integrating various geo information data sets and analysing them in order to generate information relevant to planning needs in a context. GIS primarily deals with geographic data to be analysed, manipulated and managed in an organized manner through computers to solve real world problems. So, GIS operation requires two things – computer system and geographic data.

Fig.2 Flow chart for preparation of digital maps towards land use planning

Computer System and geospatial software and Data for GIS

It includes both hardware and software. GIS runs through computer system ranging from portable personal computers to multi-user super computers which are programmed by wide variety of software languages. ARC View, ARC Info, Map Info., ARC GIS, Auto Cad Map etc. Used for GIS analysis. Data directly or indirectly may be related with geospatial features can be obtained from different sources like aerial photographs, satellite imageries, and digital data, conventional maps, Census, Meteorological department, field data (surveys/GPS) etc for GIS. These data obtained from various sources can be classified into two types – spatial data which describes location and attribute data which specifies the characteristics at that location.

Spatial data tells us, ―Where the object is?‖ Attribute data tells us ―What the object is?‖ or ―How much the object is?‖ In other words, it tells the characteristics at that location.

Spatial Data

The spatial features are very complex. So, data related geospatial features are simplified before they are entered into the computer. The common way of doing this work is to break down all geographic features into three basic entity types known as points, lines and areas (polygons). Points are _one dimensional' objects, used to represent features that are very small, e.g. a pond, an electric pole, a well or tube well etc. Only latitudinal and longitudinal values or a coordinate reference can be given to these features to explain their location, Similarly, lines are two dimensional objects and are used to represent linear features, for example roads and rivers. Lines are also used to represent linear features that do not exist in reality, such as administrative boundaries and international boundaries. Areas are three dimensional objects and are represented by closed set of lines and are used to define features such as agricultural fields, forest areas, administrative areas etc. Area entities are often referred to as polygons.

Attribute Data

Attribute data tells the characteristics of different objects / features on the earth surface. Attribute data can be both qualitative (like land use type, soil type, name of the city/river etc.) and quantitative (like elevation, temperature, pressure of a particular place, crop yield per acre etc.). So, the attribute can be both numeric and textual. Generally, attribute data of different spatial features like point (well), line (river), area (village) kept in tabular form. GIS operational procedure and analytical tasks that are particularly useful for geo-spatial analysis include:

1. Calculation of area, length and perimeter
2. Calculating the distance between geographic features
3. Multi layer operations/ Topological overlay
4. Surface analysis
5. Network analysis
6. Geo-Spatial Modelling

Application of RS- GIS

RS-GIS are rapidly increasing in many fields and disciplines but in the field of agricultural research such as land use and land cover, Yield forecasting and acreage. Utility companies have employed GIS to map and examine agricultural market net networks, analyze use of their product, and determine the best locations for future structures. Entomologist used GIS in emergency response situations to determine the best routes for navigating to a certain location of the insects and their impact. The potential of RS-GIS is huge and over this concern, the following list shows few applications:

- Land evaluation analysis
- Change detection of vegetated areas
- Analysis of deforestation and associated environmental hazards
- Monitoring vegetation health
- Crop acreage and production estimation
- Wasteland mapping
- Soil resources mapping
- Mapping of groundwater potential
- Geological and mineral exploration
- Monitoring forest fire etc

As we know that agriculture plays a dominant role in growth of agricultural economies of both developed and undeveloped countries. A farmer needs to be informed to be efficient, and that includes having the knowledge and information products to forge a viable strategy for farming operations. Over this concern, these tools will help him to understand the health of his crop, extent of infestation or stress damage, or potential yield and soil conditions. In context of yield of the farms, commodity brokers are also very interested to know that how well farms are producing?. Satellite and airborne images are used as mapping tools to classify crops, examine their health and viability, and monitor farming practices so that agricultural applications of remote sensing and GIS include the following:

- Crop type classification
- Crop condition assessment
- Crop yield estimation
- Mapping of soil characteristics
- Mapping of soil management practices
- Compliance monitoring (farming practices)

Government agencies, research institutions and companies employing remote sensing technology in the field of forestry and agro-forestry include the following:

1) Reconnaissance mapping:

- Forest cover type discrimination
- Species inventory
- Agro forestry mapping

- Clear cut mapping / regeneration assessment
- Burn delineation
- Biomass estimation

In context of environmental monitoring conservation authorities are concerned with monitoring the quantity, health, and diversity of the Earth's forests in following concern:

- Deforestation (rainforest, mangrove colonies)
- Species inventory
- Watershed protection
- Coastal protection

Hydrology

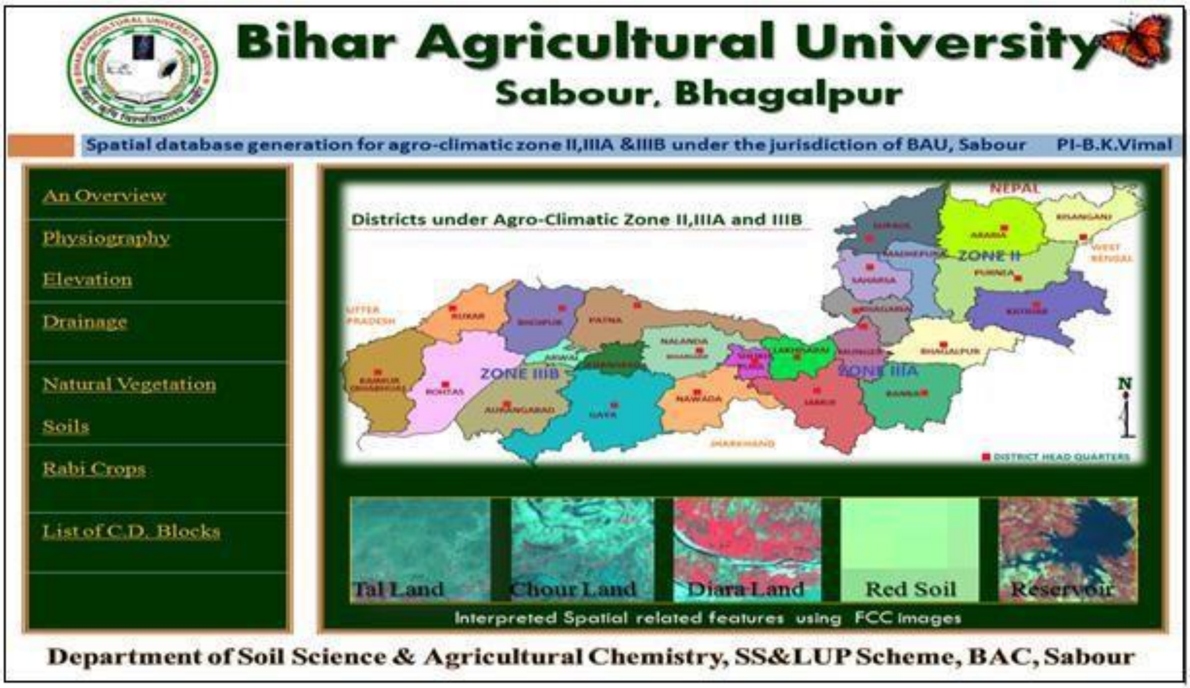
Remote sensing offers a synoptic view of the geo-spatial distribution whatever found on the surface in which hydrological phenomena is also a part. In this continuation, study of water bodies, streams and watershed for the promotion of agricultural activities, Radar has brought a new dimension to hydrological studies with its active sensing capabilities allowing the time window of image acquisition to include inclement weather conditions.

Examples of hydrological applications using remote sensing-GIS include:

- Wetlands mapping and monitoring,
- Soil moisture estimation,
- Snow pack monitoring / delineation of extent,
- Measuring snow thickness,
- Determining snow-water equivalent,
- River and lake ice monitoring,
- Flood mapping and monitoring,
- Glacier dynamics monitoring (surges, ablation)
- River /delta change detection
- Drainage basin mapping and watershed modelling
- Irrigation canal leakage detection
- Irrigation scheduling

Soil Information System

With respect to information technology, spatial distribution of agricultural resources plays an important role towards effective utilization and their sustainability. The scope of spatial analysis for agricultural resource management starts from a simple query about the spatial phenomenon to complicated combinations of attribute queries as well as spatial queries under mapping and their geo-databases. Soil resource is an integral part of agriculture and inventory of the soils provide adequate information in terms of land form, natural vegetation as well as characteristics of soils which can be utilized for land resources management and development. As we know that soil health treated as the wealth of farmers because agricultural land is the asset of farmers and there is need to maintain. Plant growth and their health indirectly governed by soil health. Soil quality decreases due to over use of chemicals, fertilisers, faulty agricultural practices, negligible use of organic manures and leaving land uncultivated for a longer time. In continuation of soil information system, Geo-spatial distribution involve in data input for many discipline that develop spatial concepts, provide means for capturing and processing of spatial information, provide a formal and theoretical foundation. Data bases are the set of compiled information that may be edited, retrievable and addition of new information on demand. Databases are the basic element of DSS (Decision Support System), helped for the planning of natural resources. Remote sensing and GIS provided a scope for the generation of digital data in terms of thematic maps of geospatial features which are the integral part of geo-data base and these integrated databases support to dissemination the information by using of computer system and programming languages, in which ICT played a vital role for designing and displaying of the generated data on a single platform.



Chapter 15
MULTIPURPOSE TREES AND ITS USE FOR BIOREMEDIATION OF SOIL

Multipurpose trees are trees that are deliberately grown and managed for more than one output. They may supply food in the form of fruit, nuts, or leaves that can be used as a vegetable; while at the same time supplying firewood, add nitrogen to the soil, or supply some other combination of multiple outputs. "Multipurpose tree" is a term common to agro-forestry, particularly when speaking of tropical agro-forestry where the tree owner is a subsistence farmer.

Multipurpose trees are defined as all woody perennials that are purposefully grown to provide more than one significant contribution to the production and/or service functions of a land-use system. They are so classified according to the attributes of the plant species as well as to the plant's functional role in the agro-forestry technology under consideration.

While all trees can be said to serve several purposes, such as providing habitat, shade, or soil improvement; multipurpose trees have a greater impact on a farmer‘s well being because they fulfill more than one basic human need. In most cases multipurpose trees have a primary role; such as being part of a living fence, or a windbreak, or used in an ally cropping system. In addition to this they will have one or more secondary roles, most often supplying a family with food or firewood, or both.

When a multipurpose tree is planted, a number of needs and functions can be fulfilled at once. They may be used as a windbreak, while also supplying a staple food for the owner. They may be used as fencepost in a living fence, while also being the main source of firewood for the owner. They may be intercropped into existing fields, to supply nitrogen to the soil, and at the same time serve as a source of both food and firewood.

Role of Multipurpose trees

Agro-forestry can be applied at different scales in a landscape. The smallest scale is the individual farm, where trees might be grown around the homestead or as boundary markers. At the macro scale, agro-forestry practices may be applied to whole watersheds or to large expanses of open cereal farms, where the trees may be used to control water or wind erosion, as contour barriers or shelterbelts.

Forestry Applications

- ✓ Protection forestry,
- ✓ land reclamation and rehabilitation
- ✓ Management of natural vegetation
- ✓ Industrial plantations

- ✓ Community woodlots
- ✓ Farm woodlots.

Common multipurpose trees include:

- *Gliricidia sepium* – the most common tree used for living fences, firewood, fodder, fixing nitrogen into the soil.
- Moringa *(Moringa oleifera)* – edible leaves, pods and beans, commonly used for animal forage and shade (it does not fix nitrogen as is commonly believed)
- Coconut palm – used for food, purified water (juice from inside the coconut), roof thatching, firewood, shade.
- Neem – limited use as insect repellent, antibiotic, adding nitrogen to the soil, windbreaks, biomass production for use as mulch, firewood.

Ideally most trees found on tropical farms should be multipurpose, and provide more to the farmer than simply shade and firewood. In most cases they should be nitrogen fixing legumes, or trees that greatly increase the farmer's food security.

How Do We Know That Trees Improve Soils?

Underlying all aspects of the role of agroforestry in maintenance of soil fertility is the fundamental proposition that trees improve soils. How we know that this is true?

1. The soil that develops under natural forest and woodland is fertile. It is well structured, has a good water-holding capacity and has a store of nutrients bound up in the organic matter. Farmers know they will get a good crop by planting on cleared natural forest.

2. The cycles of carbon and nutrients under natural forest ecosystems are relatively closed, with much recycling and low inputs and outputs.

3. The practice of shifting cultivation demonstrated the power of trees to restore fertility lost during cropping.

4. Experience of reclamation forestry has demonstrated the power of trees to build up fertility on degraded land.

What Makes a Good Soil-Improving Tree?

It would be useful to have guidelines on which properties of a tree or shrub species make it desirable for the point of view of soil fertility. This would help in identifying naturally occurring species and selecting trees for systems which have soil improvement as a specific objective.

Nitrogen fixation and a high biomass production have been widely recognized as desirable. However, many properties are specific to particular objectives of systems in which the trees are used. Even species that are shunned for their competitive effects may have a role in certain designs. An example is the way in which Eucalyptus species with a high water uptake, which adversely affects yields in adjacent crops, have been employed to lower the water table and so reduce salinization.

The properties which are likely to make a woody perennial suitable for soil fertility maintenance or improvement are:

1. A high rate of production of leafy biomass.
2. A dense network of fine roots, with a capacity for abundant mycorrhizal association.
3. The existence of deep roots.
4. A high rate of nitrogen fixation.
5. A high and balanced nutrient content in the foliage; litter of high quality (high in nitrogen, low in lignin and polyphenols).
6. An appreciable nutrient content in the root system.
7. Either rapid litter decay, where nutrient release is desired, or a moderate rate of litter decay, where maintenance of a soil cover is required.
8. Absence of toxic substances in the litter or root residues.
9. For soil reclamation, a capacity to grow on poor soils.
10. Absence of severe competitive effects with crops, particularly for water.
11. Low invasiveness.
12. Productive functions, or service functions other than soil improvement.

Summary of Effects of Trees on Soils

The capacity of trees to maintain or improve soils is shown by the high fertility status and closed nutrient cycling under natural forest, the restoration of fertility under forest fallow in shifting cultivation, and the experience of reclamation forestry and agroforestry.

Soil transects frequently show higher organic matter and better soil physical properties under trees. Some species, most notably *Faidherbia albida*, regularly give higher crop yields beneath the tree canopy. Trees improve soil fertility by processes which:

· increase additions to the soil;
· reduce losses from the soil;
· improve soil physical, chemical and biological conditions

The most important sets of processes are those by which trees:

· check runoff and soil erosion;
· maintain soil organic matter and physical properties;
· increase nutrient inputs, through nitrogen fixation and uptake from deep soil horizons;
· promote more closed nutrient cycling

Trees may also adversely affect associated crops. The effects of allelopathy (inhibition effects) have probably been exaggerated by mistaking them for, or confounding them with, other processes.

Competition for water is a serious but not insuperable problem in all dry environments, whereas competition for nutrients has rarely been demonstrated.

Tree species:

A range of properties have been identified which make tree species suited to soil improvement. For many purposes, high biomass production, nitrogen fixation, a combination of fine feeder roots with tap roots and litter with high nutrient content are suitable. Tolerance to initially poor soil conditions is clearly needed for reclamation.

About 100 species have been identified which are known to fulfil soilimproving functions, but there is much scope to increase this range. The following are the principal trees and shrubs that have been employed for soil improvement.

Acacia auriculiformis, Acacia senegal

Albizia lebbeck

Anacardium occidentale, Alnus acuminate, Alnus spp.

Azadirachta indica

Bactris gasipaes

Bamboo genera

Cajanus cajan

Casuarina cunninghamiana, Casuarina equisetifolia Casuarina glauca

Centrosema pubescens

Crotalaria spp.

Dalbergia sissoo

Erythrina caffra, Erythrina orientalis

Gliricidia sepium

Leucaena diversifolia, Leucaena leucocephala

Prosopis chilensis, Prosopis

Senna reticulate, Senna siamea (Cassia siamea,) Senna spectabilis (Cassia spectabilis)

Sesbania grandiflora Sesbania rostrata Sesbania sesban

Tephrosia vogelii

Ziziphus mauritiana, Ziziphus nummularia, Zizyphus spina-christi

Chapter 16
LAND CAPABILITY AND SUITABILITY CLASSIFICATION

Land Capability Classification

The Land Capability Classification was followed by United States Department of Agriculture. The guiding principles for this classification are the limitations imposed on the sustained use of soils by the basic characteristics of soils in combination with climate, topography,‖ surface drainage, vegetation cover, erodibility and other natural hazards. There are eight land capability classes which are indicated by Roman numbers I to VIII. Then, there are capability sub-classes and capability units. The classes I to IV include lands suited for cultivation and should be maintained under natural vegetation of forests or grasses.

Capability Sub-Classes: These are subdivisions of capability classes, made on the basis of four dominating limitations, namely, (i) risk of erosion (e), (ii) wetness, drainage or overflow (w), (iii) rooting zone limitations (s), and (iv) climatic limitations (c). The sub-classes are mapped by adding the limitation symbol to the capability class number, e.g., IIe, IIIs, etc. There are no sub-classes in Class I.

The various classes and their characteristic features are as follows:

Class I: Soils in this class are very good. The soils are deep, productive and easily worked and nearly level. They are not subject to overflow (runoff) damage. Class-I soils used for crops need practices‘ to maintain soil fertility and soil structure. These practices involve use of fertilisers, cover cropping, green manure crop and crop rotation.

Class-II: As far as natural conditions are concerned, the land is excellent, but some limitation is possible. Soils of this group have gentle slopes and are subject to moderate erosion. They are also subject to moderate overflows. These soils may require special practices, such as contour tillage, crop rotation and water-control devices.

Class III: These are moderately good soils. They can be used regularly for crops. These soils have steep slopes and suffer from either some ecological problem (as soil erosion) or climatic problem (rainfall irregularity) which inhibits intensive commercial exploitation. Also, these soils are inherently low in fertility. These soils require cropping systems that produce adequate plant cover.

Class IV: These soils are affected by severe permanent hazards like waterlogging and water deficiency. They occur frequently on steep slopes which are vulnerable to erosion. The soils are low in fertility. Soil and moisture conservation measures, like water disposal of terraces, contour tillage and stabilization of gullies, should be undertaken.

Class V: These soils are found in foothills or in mountain valleys and are suitable for grasses, shrubs, etc. These soils should be used for pasture or forestry operations. Cultivation is not feasible because these soils are wet and stony. The land is nearly level and subject only to slight erosion by wind or water, if properly managed. There are few permanent limitations. Grazing should be regulated in these soils.

Class VI: These soils have moderate permanent limitations and are unsuitable, for cultivation. These soils should be used for grazing and forestry. They are steep and shallow and more prone to erosion than class V soils. Grazing should not be permitted in these soils. They suffer from certain environmental constraints as well and are the environmentally fragile zones of our country.

Class VII: The severity of environmental constraints is much greater in these soils, compared to class VI soils. As a result, these soils are subject to severe permanent hazards. They are fair to poor for grazing or forestry. These soils are steep, eroded, shallow or swampy and are completely unsuitable for cultivation. Strict management should be applied to these soils.

Class VIII: These soils can serve the purposes of preserving some rare species or acting as a water catchment zone. Soils of this class are extremely rough, arid or swampy and are unsuitable for cultivation. They are not suited for forestry or grazing. They may be used for wildlife sanctuaries, recreation or watershed uses.

Chapter 17
LAND SUITABILITY CLASSIFICATION

Suitability Criteria

Most of the plant species need well drained, moderately fine to medium texture soils, free of salinity and having optimum physical environment. Soil resource maps based on several parameters, can aid in predicting the behaviour and suitability of soils for growing field crops, horticultural crops, forest species and other plantation crops once the suitability criteria is established. Within limits, it may also find application in transfer of technology to other areas with comparable soil-site characteristics.

Land suitability units:

This grouping is used to identify land development units having minor differences in management requirements. This can indicate the relative importance of land development works. It is indicated by Arabic numerals, enclosed in parenthesis, following the subclass symbol.

The FAO land suitability classification system has four different categories:

- **Orders,**
- **Classes,**
- **Subclasses**
- **Units.**

There are two orders(S and N) which reflect the kind of suitability (S for suitable and N for unsuitable land).

Order "S" -Suitable land

Land on which sustained use for the defined purpose in the defined manner is expected to yield benefits that will justify required recurrent inputs without unacceptable risk to land resources.

Order "N"-Unsuitable land

Land having characteristics which appear to preclude its sustained use for the defined purpose in the defined manner or which would create production, upkeep and/or conservation problems requiring a level of recurrent inputs unacceptable at the time of interpretation.

Land Suitability Classes:

The framework at its origin permits complete freedom in determining the number of classes within each order. However, it has been recommended to use only 3 classes within order S and 2 classes within order N. The class will be indicated by an Arabic number in sequence of decreasing suitability within the order and therefore reflects degrees of suitability within the orders.

Examples:

S1 : Suitable

S2: Moderately suitable

S3: Marginally suitable

N1 : Actually unsuitable but potentially suitable

N2 : Actually and potentially unsuitable

Land Suitability Subclasses:

The sub classes reflect kinds of limitations or main kinds of improvement measures required within classes. They are indicated in the symbol using lower case letters.

c: Climatic conditions

t: Topographic limitations

w: Wetness limitations

n: Salinity(and/or alkalinity) limitations

f: Soil fertility limitations not readily to be corrected

s: Physical soil limitations(influencing soil/ water relationship and management).

Structure of the FAO land suitability classification

S	**SUITABLE**	**The land can support the land use indefinitely and benefits justify inputs**
S1	Highly suitable	Land without significant limitations. Include the best 20-30% of suitable land as S1. This land is not perfect but is the best that can be hoped for
S2	Moderately suitable	Land that is clearly suitable but which has limitations that either reduce productivity or increase the inputs needed to sustain productivity compared with those needed on S1 land
S3	Marginally suitable	Land with limitations so severe that benefits are reduced and/or the inputs needed to sustain production are increased so that this cost is only marginally justified
N	NOT SUITABLE	Land that cannot support the land use on a sustained basis, or land on which benefits do not justify necessary inputs
N1	Currently not suitable	Land with limitations to sustained use that cannot be overcome at a currently acceptable cost
N2	Permanently not suitable	Land with limitations to sustained use that cannot be overcome
Examples of classes in the third category		
S2e	Land assessed as S2 on account of limitation of erosion hazard	
S2w	Land assessed as S2 on account of inadequate availability of water	
N2e	Land assessed as N2 on account of limitation of erosion hazard	

Chapter 18
PROBLEMATIC SOILS UNDER DIFFERENT AGRO-ECOSYSTEM IN INDIA

Land, agriculture and ecology are intrinsically related and govern our agricultural systems holistically. Climatic factors such as temperature, rainfall, humidity, sunshine and wind are the primary determinants of climate of any region. And climate and soil interactions provide suitable environment for agricultural production, and also affect physical processes of land degradation. To conserve natural resources for sustainable food production, an inclusive approach is needed to create relatively homogeneous regions in terms of soil, climate and physiography, termed as agro-ecological regions. Delineation of such regions will help understanding of agricultural potentialities of the regions for different land uses and also for conservation of their physical environment. Agroclimatic region is the land unit in terms of major climate, superimposed on length of growing period (moisture availability period), and an agro-ecological zone is the land unit carved out of the agroclimatic region, superimposed on the landform, which acts as a modifier to climate and length of growing period (Sehgal and Abrol, 1994).

To understand implications and role of climatic and edaphic resources in agricultural and allied sectors, the NBSS&LUP prepared an agro-ecological map, based on the physiography, soils, bioclimate and length of growing period (GP), and refined it through several approximations. The data from 474 meteorological stations were used for preparing water balances (Thornthwaite and Mather, 1955). Length of growing period (LGP) was calculated using FAO (1983) model, adopted after Higgins and Kassam (1981). The GP as per the model starts when precipitation (P) exceeds 0.5 potential evapotranspiration (PET) and ends with utilization of 100 mm of stored soil moisture once P falls below PET. Growing period values for 474 observation sites were plotted and isolines were drawn at 30 days intervals. It has been observed that arid regions generally correspond with growing period of less than 90 days and semi-arid region with 90–150 days. Subhumid zone has GP more or less between 150 and 210 days. Humid and per-humid zones correspond with GP of 210 to 270 days and more than 270 days per year.

The different Agro Ecological Region (AER) in India is given below.

1. Cold Arid Eco-region with Shallow Skeletal Soil.
2. Hot Arid Eco-region with Desert and Saline Soils
3. Hot Arid Eco-region with Red and Black Soils
4. Hot Semi-Arid Eco-region with Alluvium Derived soils
5. Hot Semi Arid Eco-region with Medium and Deep Black Soils
6. Hot Semi-Arid Eco-region with Shallow and Medium (Dominant) Black Soils
7. Hot Semi Arid Eco-region with Red and Black soils
8. Hot Semi-Arid Eco-region with Red Loamy soils
9. Hot subbumid (Dry) Eco-region with Alluvium- Derived Soils

10. Hot Subhumid Eco-region with Red and Black Soils
11. Hot Subhumid Eco-region with Red and Yellow Soils
12. Hot Subhumid Eco-region with Red and Lateritic soils
13. Hot Suhhumid (Moist) Eco-region with Alluvium-derived soils
14. Warm Subhumid to Humid with Inclusion of Perhumid Eco-region with Brown Forest and Podzolic Soils
15. Hot Subhumid (moist) to Humid (inclusion of perhumid) Eco-region with alluvium-derived soils
16. Warm Perhumid Eco-region with Brown and Red Hill Soils
17. Warm Perhumid Eco-region with Red and Lateritc Soils
18. Hot Subhumid to Semi-arid Eco-region with Coastal Alluvium-derived soils
19. Hot Humid Pemhumid Eco-region with Red, Lateritic and Alluvium-derived soils
20. Hot Humid/Perhumid Island Eco-region with Red loamy and Sandy Soils.

Table: Area under degraded and wastelands of India under different AERs

AERs	Degraded and wastelands classes* ('000 ha)																			Total degraded area ('000 ha)
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
1	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19
2	638	123	0	0	0	11,419	1,106	6	0	110	60	0	405	1	30	0	0	8	7	13,913
3	2,341	76	0	0	0	0	1	0	0	0	0	0	75	47	0	0	0	20	0	2,560
4	12,109	1,024	0	1	0	6	367	7	0	0	0	0	929	423	0	1	11	14	68	14,960
5	6,455	983	3	22	0	0	184	2	0	0	0	0	25	15	0	0	5	6	0	7,700
6	10,374	257	0	0	0	0	171	6	0	0	0	0	269	175	0	0	1	17	0	11,270
7	4,376	465	12	7	0	0	0	0	0	0	0	0	79	15	0	0	1	31	0	4,986
8	4,412	391	272	151	60	0	3	1	0	0	0	0	287	36	0	17	2	48	5	5,685
9	3,122	378	3	3	0	0	2	3	0	0	0	0	368	293	0	2	0	9	89	4,272
10	6,934	822	119	308	28	0	0	0	0	0	0	0	35	20	0	1	0	21	0	8,288
11	3,843	514	653	726	159	0	0	0	0	0	0	0	11	3	0	0	0	16	0	5,925
12	4,917	1,512	469	1,089	142	0	2	0	0	0	0	0	0	0	0	0	0	38	24	8,193

13	3,803	48	41	41	0	0	40	9	0	0	0	5	2	24	0	0	0	1	163	4,177
14	4,009	1,025	75	289	222	0	0	0	0	0	0	0	10	0	0	0	0	4	61	5,695
15	2,011	213	647	1,229	328	0	64	0	0	0	0	0	0	0	0	0	0	1	242	4,735
16	576	229	275	651	782	0	0	0	0	0	0	0	0	0	0	0	0	0	10	2,523
17	210	992	439	516	5,330	0	0	0	0	0	0	0	0	0	0	0	0	1	31	7,519
18	928	48	43	12	3	0	574	4	0	0	0	25	115	6	0	0	0	10	83	1,851
19	2,944	187	2,029	674	76	0	40	1	20	0	0	0	0	0	0	0	0	15	76	6,062
20	0	0	0	0	0	0	77	0	0	0	0	0	0	0	0	0	0	0	0	77
Total	**74,021**	**9,287**	**5,080**	**5,719**	**7,130**	**11,425**	**2,631**	**39**	**20**	**110**	**60**	**30**	**2,610**	**1,058**	**30**	**21**	**20**	**260**	**859**	**120,410**

Note: Classes*: 1. Exclusively water erosion (>10 tonnes /ha/yr); Water erosion under open forest, 2. Forest; 3. Exclusively acid soils (pH <5.5); 4. Acid soils under water erosion; 5. Acid soils under open forest; 6. Exclusively wind erosion; 7. Exclusively saline soils; 8. Eroded saline soils; 9. Acid saline soils; 10.Saline soils under wind erosion; 11. Saline soils under open forest; 12.Water logged saline soils; 13. Exclusively sodic soils; 14.Eroded sodic soils; 15. Sodic soils under wind erosion; 16. Sodic soils under open forest; 17. Eroded sodic soils under open forest; 18.Mining / Industrial waste; 19. Waterlogged area (Permanent)

The area estimates of the degraded and wastelands in different AERs reveal that region 4 is highly degraded with area coverage of 14,960 thousand ha. The other AERs having appreciably high area coverage are AER-2 (13,913 thousand ha), AER-5 (11,270 thousand ha), AER-10 (8,288 thousand ha), AER-12 (8,193 thousand ha), and AER-17 (7,519 thousand ha). Though all the AERs are affected but the least affected are AER-1 and AER-20.

Water erosion (classes 1, 2) has affected almost all AERs and AERs with large affected areas are: AER-4 (13,133 thousand ha), AER-6 (10,631 thousand ha), AER-5 (7,438 thousand ha), AER-12 (6,429 thousand ha), AER-14 (5,034 thousand ha), AER-7 (4,841 thousand ha) and AER-8 (4,803 thousand ha). Least affected AERs are AER-20, AER-1 and AER-17. Soil acidity (classes 3,4,5) has been observed in all AERs, excepting AER-1, AER-2, AER-3 and AER-20. Very little land areas are affected in AER-4 and AER-6. Highly affected AERs are AER-17 (6,285 thousand ha), AER-19 (2,779 thousand ha), AER-15 (2,204 thousand ha), AER-12 (1,700 thousand ha) and AER-11 (1,538 thousand ha).

Salinity affected (classes 7,8,9,10,11,12) agro-ecological regions are located in the semi-arid and sub-humid climatic zones of the country. Highest area coverage with salinity is in AER-2 (1,282 thousand ha), followed by AER-18 and AER-4 with 603 and 374 thousand ha, respectively.

Sodicity and salinity are observed in combination in some of the AERs. Notable among them are AER-2, AER-4, AER-6 and AER-18. Agroclimatic conditions coupled with management practices (including irrigation) are the main reasons for the development of soil sodicity. Highest sodicity (classes 13,14,15,16,17) is observed in AER-4 (1,364 thousand ha), followed by AER-9 (663 thousand ha), AER-6 (445 thousand ha), AER-2 (436 thousand ha), AER-8 (342 thousand ha), and it is not a problem in AER-1, AER-11, AER-12, AER-15, AER-16, AER-17, AER-19 and AER-20. Wind erosion (class 6) is predominant in AER-2 and has a little affected area in AER-4.

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