Problematic Soils and Their Management

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Problematic Soils and Their Management

Course Name	Problematic soils and their Management
Lesson 1	Concept of Soil Quality and Health
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Learning Objectives

- *Understand and express the capacity of soils to perform their designated ecological functions from the standpoint of a layman and a professional.*
- *Define the physical, chemical and biological aspects of soil quality.*
- *Understanding the influence of management interventions such as; tillage, application of fertiliser and manure, irrigation, pesticides, production potential of crop, fallowing etc. on soil health.*

Glossary of terms

1. **Soil quality:** It is the capacity of a specific kind of soil to function within ecosystem and land use boundaries, to sustain biological productivity, maintain environmental quality, and sustain plant, animal, and human health.
2. **Soil health:** It is defined as being a state of dynamic equilibrium between flora and fauna and their surrounding soil environment in which all the metabolic activities of the former proceed optimally without any hindrance, stress or impedance from the latter.
3. **Soil Resilience:** Ability of a system to return after disturbance to a new dynamic equilibrium or ability of a soil to resist adverse changes under a given set of ecological and land use condition and return to its original dynamic equilibrium even after disturbance.
4. **Soil Resistance:** Defined as the capacity of a soil to continue to function without changing elsewhere throughout the disturbance.

1.1 Introduction

Soil health in terms of its quality is a researchable area of interest. Soil quality by definitions are more or less different, but they always relate to the functions of the soil to supply nutrients and other physico-chemical conditions for plant growth, to promote and sustain crop production, to provide habitat to soil organisms, to ameliorate environmental pollution, to resist degradation of land and to maintain or improve human and animal health. More explicitly, soil quality can be defined 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 (Karlen et al., 1997).

By soil quality we mean suitability or limitation of a soil for a particular use. Some (pl. specify) defines it as the “fitness for use” and others as the capacity of the “soil to function”. For improving and ensuring soil quality, the main considerations should be identification and development of suitable methods to measure their quality. Subsequently, the management sensitive key indicators of soil quality should be identified and used for monitoring and predicting the changes periodically.

1.2 Why soil quality?

Soils are fundamental to the well being and productivity of agricultural and natural ecosystems. Soil quality is a concept being developed to characterize the usefulness and health of soils. In the United

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States, soil quality includes soil fertility, potential productivity, resource sustainability and environmental quality. A general definition of soil quality is the degree of *fitness* of a soil for a specific use (Gregorich et al., 1994). The existence of multiple definitions suggests that the soil quality concept continue to evolve.

Resonance for assessing soil quality in an agriculture or managed system may be somewhat different than resonance for assessing soil quality in a natural ecosystem. In an agriculture contest, soil quality may be managed to maximize crop production without adverse environmental effect, while in a natural ecosystem, soil quality may be observed, as a baseline value or set against which future change in the system may be compared.

1.3 Soil Quality and Soil Health

The term soil quality and soil health are often used interchangeably in the scientific literature; scientists, in general prefer “soil quality” and producers/farmers prefer “soil health”. When farmers are asked to recognize a healthy soil, they list different soil properties. Most frequently mentioned were biological and physical properties of surface horizons. Besides, farmers also use to indicate plant, animal and human health, and water properties to judge the health of their soils.

Soil quality: It is the capacity of a specific kind of soil to function within ecosystem and land use boundaries, to sustain biological productivity, maintain environmental quality, and sustain plant, animal, and human health (Doran and Parkin, 1994).

Soil health: It is defined as being a state of dynamic equilibrium between flora and fauna and their surrounding soil environment in which all the metabolic activities of the former proceed optimally without any hindrance, stress or impedance from the latter.

***Soil health is considered as the state of a soil at a particular time, equivalent to the dynamic soil properties that change in short term, while soil quality may be considered as soil usefulness for a particular purpose over a long time scale, equivalent to intrinsic or static soil quality.*

1.4 Soil Degradation, Soil Resilience and Resistance

Soil degradation is an antonym of soil quality. Soil degradation is a major concern of the day because of its adverse impacts on productivity, human and animal health, air and water quality, especially on local, regional and global scales.

Soil Resilience means ability of a system to return after disturbance to a new dynamic equilibrium or ability of a soil to resist adverse changes under a given set of ecological and land use condition and return to its original dynamic equilibrium even after disturbance. A disturbance is broadly defined as any event that causes a significant change from the normal pattern functioning in an ecosystem.

Soil Resistance is defined as the capacity of a soil to continue to function ***without any change throughout disturbance***. The magnitude of decline in the capacity to function defines the degree of resistance. A small decline indicates a high resistance, whereas a relatively large decline indicates a low resistance to change through a disturbance.

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Soil quality encompasses at least six diverse simultaneous functions:

i) Biomass production
ii) Filtering, buffering and transformation
iii) Source of Biodiversity
iv) Infrastructure developments
v) Geogenic source of origin
vi) Cultural heritages of land form

1.5 Multiple functions of soils

Soil performs multiple functions:

i) providing physical support to terrestrial plants,
ii) supplying fundamental resources *viz*., water, nutrients and oxygen required for terrestrial primary production
iii) providing habitat to a variety of soil organisms, with taxonomic identity and functions of several organisms still unknown/lesser known to the scientific and wider community,
iv) regulating hydrological and mineral/nutrient cycling, with significant impacts on global climate,
v) detoxification of organic and inorganic substances, leading to purification of water resources
vi) resisting erosion

A given soil function is achieved through several mechanisms/processes and a given mechanism/process may contribute to several functions. Thus, litter decomposition and mineralization contribute to detoxification as well as nutrient supply/agricultural production functions of soil. The overall assessment about whether a soil is good or bad depends on the objective of assessment and the net outcome of different soil processes and functions in given conditions. Thus, a soil may supply huge quantities of nutrients supporting high primary production but may not provide suitable habitats to many soil organisms, e.g., cropping soon after deforestation using agrochemicals. One may get high crop productivity but with contamination of water and infected food products, a situation of high production but low detoxification function. In situations where low agricultural productivity is the one and the only problem faced by the mankind, one may ignore functions of soil other than production function (i.e., capacity of soil to supply water, nutrients and oxygen and to reduce crop yield losses due to pests and diseases). However, in the present widespread scenario of multiple problems (including increased levels of greenhouse gases in the atmosphere, soil erosion and land degradation, production of infected crop products, depletion and pollution of water resources, and depletion of biodiversity), there is a need of addressing multiple functions of soil in an objective manner. The concept of soil quality/health is essentially an elaboration of the concept of soil productivity/fertility to deal with the multiple and complex problems faced by the world today. This perspective of optimizing multiple functions makes soil health an integral dimension of agroecosystem relating to health and sustainable development. The soil functions can be weighted according to the relative importance of each function in fulfilling the management goals based on expert opinions. Regulation of each function is determined by a large number of soil attributes and a single attribute or a statistical/mathematical derivative of several attributes (in the form of an index) can be viewed as an indicator of one or more soil functions if a systematic relationship exists between the attribute(s) or its derivative with the soil functions. As a single measurable soil attribute is unlikely to be correlated with soil function(s) and measurement of 'all' soil attributes is not practical, one needs to draw a minimum number of indicators (minimum data set) (Doran and Parkin, 1996).

Table 1 Ecological functions of soil (FAO 1995) and their indicators

Ecological Functions of Soil	**Indicators of Proper Functioning**
Production function	High levels of crop yields and incomes
Biotic environmental function/living space function	High levels of species richness and functional dominance of beneficial organisms
	High levels of crop yields and incomes and high quality food and habitation
Climate-regulative function/storage function	High levels of carbon stocks and slow rates of greenhouse gas emissions
Hydrologic function	Adequate availability of water/reduced risks floods
Waste and pollution control function	High levels of crop yields and incomes and high quality food and habitation
Archive or heritage function	

Connective space function	

1.6 Factors Affecting Soil Quality

The major causes of poor soil quality are:

i) Wider gap between nutrient demand and supply coupled with low and imbalanced fertilizer use
ii) Emerging deficiency of secondary and micronutrients due to improper use of inputs such as water, fertilizers, pesticides etc.
iii) Decline in organic matter content in soil and insufficient use of organic inputs
iv) Acidification and Al^{3+} toxicity
v) Development of salinity and alkalinity in soils
vi) Development of adverse soil conditions such as heavy metal toxicity
vii) Disproportionate growth of microbial population responsible for soil sickness
viii) Natural and man-made calamities such as erosion and deforestation occurring due to rapid industrialization and urbanization, etc.

1.7 Strategies for Improving Soil Quality

The properties of soil which represent the dynamic soil quality can be improved by several management practices which are described as follows:

1.7.1 Enhancement of Organic Matter

Organic matter is considered as the storehouse of all nutrients maintaining good soil quality. Regular additions of organic matter improve soil structure, enhance water and nutrient holding capacity, protect soil from erosion, hard setting and compaction and support a healthy community of soil organisms. Practices that increase organic matter include: leaving crop residues in the field, choosing crop rotations that include high residue plants, using optimal nutrient and water management practices to grow healthy plants with large amounts of roots and residue, growing cover crops, applying manure or compost, using low or no tillage systems, using sod-based rotations, growing perennial forage crops and mulching.

1.7.2 Reduction in the Intensity of Tillage

Reducing tillage minimizes the loss of organic matter and protects the soil surface with plant residue. Tillage is used to loosen surface soil, prepare the seedbed and control weeds and pests. But tillage can also break up soil structure, speed up the decomposition and loss of organic matter, increase the rate of erosion, destroy the habitat of helpful organisms and cause compaction.

1.7.3 Efficient Management of Pests and Nutrients

Efficient pest and nutrient management means testing and monitoring soil and pests; applying only the necessary chemicals, at the right time and place to get the job done; and taking advantage of non-chemical approaches to pest and nutrient management such as crop rotations, cover crops and manure management. The terms integrated pest management (IPM) and integrated nutrient managements (INM) are very much popular nowadays. In case of IPM, the pests are managed without much dependence on the chemicals. In case of INM also, dependence on chemical fertilizers is reduced considerably.

1.7.4 Prevention of Soil Compaction

Soil compaction reduces the amount of air, water and space available to roots and soil organisms. Compaction is caused by repeated traffic, heavy traffic or traveling on wet soil. Deep compaction by heavy equipment is difficult or impossible to rectify, so prevention is essential. Subsoil tillage is only effective on soils with a clearly defined root-restricting plough pan. In the absence of a plough pan, subsoil tillage to eliminate compaction can reduce yield. Prevention is the best method to manage compaction and not the tillage.

1.7.5 Maintenance of Ground Cover

Soil without adequate cover or bare soil is very much susceptible to wind and water erosion, and to drying and crusting. Ground cover protects soil; provides habitats for larger soil organisms, such as insects and earthworms and can improve water availability. Ground can be covered by leaving crop residue on the surface or by planting cover crops. In addition to ground cover, living cover crops provide additional organic matter, and continuous cover and food for soil organisms. Ground cover must be managed to prevent problems with delayed soil warming in spring, diseases and excessive build-up of phosphorus at the surface.

1.7.6 Diversification of Cropping Systems

Diversity is beneficial for several reasons. Each plant contributes a unique root structure and type of residue to the soil. A diversity of soil organisms can help control pest populations and a diversity of cultural practices can reduce weed and disease pressures. Diversity across the landscape can be increased by using buffer strips, small fields or contour strip cropping. Diversity over time can be increased by using long crop rotations. Changing vegetation across the landscape or over time not only increases plant diversity, but also the types of insects, microorganisms and wildlife that live in the soil.

1.8 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 for humans and most of the other species. In particular, we are challenged to develop agricultural management systems that balance the needs for production of food and fiber with those for maintenance of the environment. More simply, "a sustainable agriculture — sustains the people and preserves the land." Soil quality is conceptualized as the major linkage between the strategies for agricultural conservation management practices and achievement of the major goals of sustainable agriculture. In short, the assessment of soil quality or health, and direction of change with time, is the primary indicator of sustainable land management (Karlen et al., 1997). 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 leading to the imbalance of C, N, and water cycling in soil. 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 application of pesticide and fertilizer influence water quality. In addition, these management practices can also affect atmospheric quality through changes in the soil's capacity to produce or consume Green House Gases (GHGs) 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

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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 (Doran and Zeiss, 2000).

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Course Name	Problematic soils and their Management
Lesson 2	Soil Quality Indicators
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Learning Objectives

- *Develop an understanding of the measures of the soils' capacities to perform their designated functions.*
- *Differentiate between basic soil properties and their use / function as indicators of soil quality*

Glossary of terms

1. **Aggregate stability:** Aggregate stability refers to the resistance of soil aggregates to breakdown by water and mechanical force.
2. **Biological Indicators:** Biological indicators reflect on the organisms that form the soil food web responsible for decomposition of organic matter and nutrient cycling. Information about the numbers of organisms, both individuals and species, that perform similar jobs or niches, can indicate a soil's ability to function or bounce back after disturbance (resistance and resilience).
3. **Chemical Indicators:** Chemical indicators give you information about the equilibrium between soil solution (soil water and nutrients) and exchange sites (clay particles, organic matter); plant health; the nutritional requirements of plant and soil animal communities; and levels of soil contaminants and their availability for uptake by animals and plants.
4. **Physical Indicators:** Physical indicators provide information about soil hydrologic characteristics, such as water entry and retention on plant available forms. Some indicators are related to nutrient

availability by their influence on rooting volume and aeration status while the others indicating about the erosion status.

5. **Soil Infiltration:** Soil water infiltration measures the rate at which water enters into the soil surface, and are transmitted through the immediate soil depth.
6. **Soil Quality Indicator:** Is a simple attribute of the soil which may be measured to assess quality with respect to a given function.
7. **Visual Indicators:** Visual indicators of soil health may be obtained from observation or photographic interpretation.

2.1 Introduction

A soil-quality indicator is a simple attribute of the soil which may be measured to assess quality with respect to a given function. It is important to be able to select attributes that are appropriate for the task considering the complex nature of the soil and the exceptionally large number of pre-determined soil parameters. The selection of soil indicators will vary, depending upon the nature of the soil function under consideration. These soil attributes can be classified in three broad groupings: physical, chemical, or biological indicators. Many of the physical and chemical soil attributes are permanent in time (inherent parameters). In contrast, biological and some physical attributes are dynamic and exceptionally sensitive to changes in soil conditions and in management practices (dynamic parameters). They appear to be very responsive to different agricultural soil conservation and management practices such as non-tillage, organic amendments, and crop rotation.

2.2 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 (mention 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 (Advances in Agronomy) are as under:

Physical Indicators

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

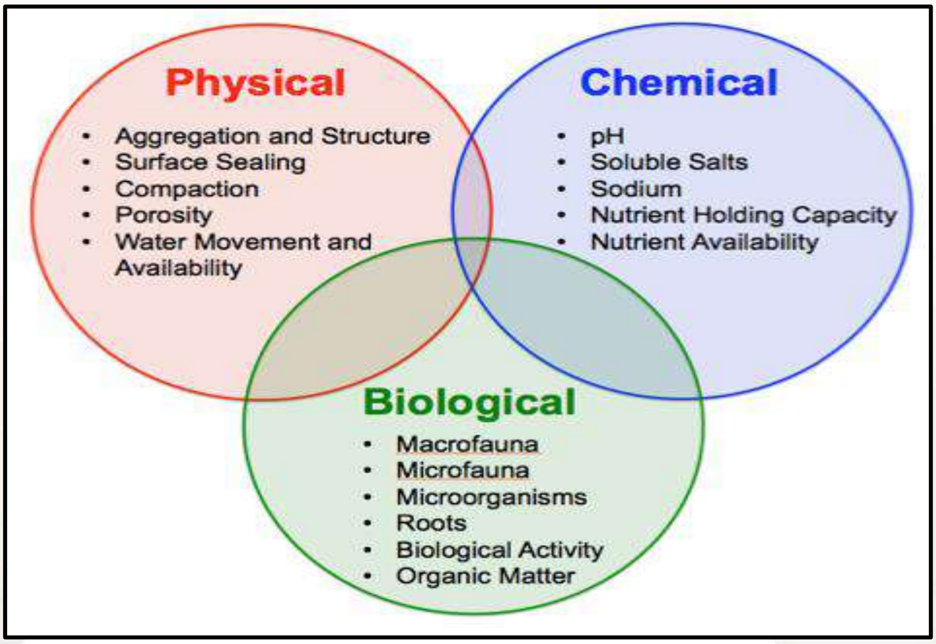
Chemical Indicators

- Total soil organic matter
- Active organic matter
- pH
- Electrical conductivity

- Extractable N, P and K

Biological Indicators

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



2.2.1 Physical Indicators

Physical indicators of soil health reflect the capacity to accept, store, transmit and supply water, oxygen and nutrients within ecosystem. The study of these indicators includes monitoring of soil structure through pore size distribution, aggregate stability, saturated hydraulic conductivity, infiltration, bulk density, and surface crust. Rooting depth provides a good indicator of buffering against water, air and nutrient stress. Soil surface cover can be used as an indicator of soil surface protection against raindrop impact, and hence enhanced infiltration, reduced surface crust, and reduced soil erosion and runoff. Soil water infiltration measures the rate at which water enters soil surface, and transmitted through the immediate soil depth. Rainfall is rapidly absorbed by soil with high infiltration rate. But as the soil structure deteriorates, usually with the loss of organic matter, there is increase in exchangeable sodium and low electrolyte concentration and the infiltration rate of a soil becomes low. This increases the tendency for soil erosion and runoff in sloping soils and water logging in flat soils. Aggregate stability refers to the resistance of soil aggregates to breakdown by water and mechanical force. Aggregate stability is affected by quality and quantity of organic matter, types of clays, wetting and drying, freezing and thawing, types and amounts of electrolyte, biological activity, cropping systems and tillage practices. For monitoring trends in soil health, sampling procedures for aggregate stability need to be standardized. Bulk density that varies with the structural condition of the soil is altered by cultivation, loss of organic matter, and compression by animals and agricultural machinery, resulting in compact plough layer. It generally increases with depth in-soil profile. In cracking clay soils such as Vertisols, it varies with water content.

Table 1 Major soil physical indicators and related processes

Indicator	**Processes and soil functions**
A. Mechanical	
Texture	Crusting, gaseous diffusion, infiltration
Bulk density	Compaction, root growth, infiltration

Aggregation	Erosion, crusting, infiltration, gaseous diffusion
Pore size distribution and continuity	Water retention, and transmission, root growth and gaseous exchange
B. Hydrological	
Available water capacity	Drought stress, biomass production, soil organic matter content
Non-limiting water range	Drought, water imbalance, soil structure
Infiltration rate	Runoff, erosion, leaching
C. Rooting zone	
Effective rooting depth	Root growth, nutrient and water use efficiencies
Soil temperature	Heat flux, soil warming activity and species diversity of soil fauna Source: Lal (1994)

2.2.2 Chemical Indicators

Dominant chemical indicators include soil pH, electrical conductivity, adsorption and cation exchange capacity (CEC), organic matter, and available nutrients. The other useful indicators, especially those which are needed for plant growth and development can also be included. Soil pH is an indicator that can provide trends in change in soil health in terms of acidification (surface and sub-surface), soil salinization, electrical conductivity exchangeable sodium (soil structural stability), increased incidence of root disease: influence root growth, biological activity, and nutrient availability (e.g. P availability at either high pH >8.5 or low pH <5; Zn availability at high pH >8.5). The change in soil pH also provide capacity of the soil for pesticide retention and breakdown as well as the mobility of certain pesticides through the soil. These processes affect soil health on-farm and have effects beyond farm gate. Electrical conductivity is a measure of salt concentration and therefore, its measure can provide trends in salinity for both soil and water.

Organic matter is fundamental in maintenance of soil health because it is essential for optimal functioning of a number of processes important to sustainable ecosystems. Soil organic matter is a source and sinks of C and N and partly of P and S. It affects micronutrient availability through complexation, chelation and production of organic acids, thus altering soil pH. Conversely, it ties up metals present in toxic amounts (*e.g.* Cu, As, Hg). Organic matter is essential for good soil structure especially in low clay content soils, as it contributes towards both formation and stabilization of soil aggregates. Other functions include: contribution to cation exchange capacity especially in low clay content in soils, as it contributes toward both formation and stabilization of soil aggregates. Trends in available plant nutrients, for example, N, P, S and K indicate sustainable land use, especially, if the nutrient concentration and availability are approaching but remain above the critical or threshold values. In the long-term, nutrient balance of the system (e.g. input efficiency = output) is essential to sustainability. Thus, available nutrients are indicators of the capacity to support crop growth, potential crop yield, grain protein content, and conversely, excessive amounts may be a potential environmental hazard (e.g. algal biomass, eutrophication).

2.2.3 Biological Indicators

There are myriads of organisms in the thin layer of the soil surface which play key roles in the decomposition of soil organic matter, nutrient cycling, soil pollutant degradation, and the formation and stability of soil structure. They adapt to changes in their environment, such as stress due to drought, flooding, substrate shortages (e.g., food shortages), and contaminants. Soil biota also responds rapidly to soil management and land use changes and can be candidates for soil quality indicators. There are, however, limitations in directly measuring soil organisms as indicators of soil quality. Because of this, biological dynamic properties (respiration, Particulate Organic Matter, Particulate Mineral Nitrogen, and enzymes) are often selected as surrogates for measurement of processes mediated by soil biota. Phospholipid fatty acids and DNA are also gaining popularity in academic and research laboratories. Soil respiration is measured at the field and in field office. Earthworms, which are not often diverse and are easy to count, are the only biota that have been considered usable as biological indicators by personnel regardless of special training and that are presently measured in the field by determination of their abundance. Biological indicators may reflect the overall number, type, and activity of microorganisms and the diversity of the living organisms in soil, particularly the microbial population. Some biological indicators are linked to the organic matter fractions (POM, β-glucosidase), nitrogen pools (PMN), or soil biota (respiration).

Table 2 Major soil chemical, nutritional and biological indicators and related soil processes

Indicator	Processes and soil functions
pH	Acidification and soil reaction, nutrient availability
Base saturation	Adsorption and desorption, solubilization
Cation exchange capacity	Ion exchange, leaching
Total and plant available nutrients	Soil fertility, nutrient reserves
Soil organic matter	Structural formation, mineralization, biomass carbon, nutrient retention
Earthworm population and other soil, macro fauna and activity	Nutrient cycling, organic matter decomposition, formation of soil structure
Soil biomass carbon	Microbial transformations and respiration, formation of soil structure and organo-mineral complexes
Total soil organic carbon	Soil nutrient source and sink, bio-mass carbon, soil respiration and gaseous fluxes Source: Lal (1994)

2.2.4 Visual Indicators

Visual indicators of soil health may be obtained from observation or photographic interpretation. Exposure of subsoil, change in soil color, ephemeral gullies, pounding, runoff, plant response, weed species, and decomposition are only a few examples of potential locally determined indicators. Visual evidence can be a clear indication that soil quality is threatened or changing.

2.3 Criteria for indicators of soil quality

Criteria for indicators of soil quality and health relate mainly to their utility in defining ecosystem processes and integrating physical, chemical, and biological properties, their sensitivity to management and climatic variations, and their accessibility and utility to agricultural specialists, producers, conservationists, and policy makers. Measurements of soil organisms meet many (though not all) of the criteria for useful indicators of sustainable land management. For this reason, soil organisms (including their abundance, diversity, food web structure, and community stability) were the focus of the conference published in this issue (FAO, 1995). Most of the subsequent papers in this issue address the questions of which of the presently known organisms and ecological parameters are most useful as indicators. But any indicator of soil health or soil quality should meet the following five criteria.

2.3.1 Sensitivity to variations in management

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To be useful as an indicator of the sustainability of land management practices, a soil parameter must respond to changes in management sensitively. Specifically, ‘the indicators should be sensitive enough to reflect the influence of management and climate on long-term changes in soil quality but not be so sensitive as to be influenced by short-term weather patterns. Soil organisms meet this criterion, because they respond sensitively to anthropogenic disturbance.

2.3.2 Well correlated with beneficial soil functions

Soil health is worth quantifying because soils and their biota provide ecosystems functions that benefit humans. These ecosystem services can be of considerable value and include soil functions of storing and releasing water, decomposing plant and animal residues, transforming and recycling nutrients, sequestering and detoxifying organic toxicants, and promoting plant health by suppressing plant-pathogenic microbes and phytophagous fauna. It is often possible and desirable to measure soil function directly.

2.3.3 Useful for elucidating ecosystem processes

To aid farmers, ranchers, conservationists, foresters, and other land managers in selecting appropriate interventions, an indicator of soil quality must do more than merely predicting whether a soil will provide a beneficial function. The indicator should also elucidate why the soil will or will not function as desired. For example, plant productivity and health are invaluable indicators because they are well correlated with multiple soil functions. Nonetheless, if plant productivity or health are measured and found to be lower than desired, it is not obvious what remedial action is required. Therefore, indicators are needed that help land managers understand the chain of cause and effect that links land management decisions to ultimate productivity and health of plants and animals. Soil organisms meet this criterion, because they play a direct role in many ecosystem processes including conversion of nutrients into forms available to plants and suppression of noxious organisms. Further, by affecting soil structure, soil organisms play a critical indirect role in processes such as changing the rate of water infiltration.

2.3.4 Comprehensible and useful to land managers

The ultimate determinant of soil quality and health is the farm owner or operator, rancher, forester, golf course superintendant, conservationists, etc. who actually manage the land. Thus, the land manager is the ultimate judge of which indicators of soil quality are worth measuring. Considerable thought and creativity are required to develop measurements of soil organisms that are comprehensible and useful to land managers.

2.3.5 Easy and inexpensive to measure

Because the ultimate determinant of soil quality and health is the land manager, indicators of soil quality and sustainability should be both accessible to them and economic in terms of both time and money. This argues against the use of species richness (‘biodiversity’) as an indicator, because quantifying species richness requires substantial knowledge of taxonomy and can be extremely time consuming and costly. However, it may be possible to develop measures of functional diversity measurable by non-taxonomists. In general, quantifying soil organisms neither is inherently expensive nor requires much specialized. In summary, measurements of soil organisms are sensitive to anthropogenic perturbations, are well correlated with beneficial soil functions, and are excellent teaching tools because they elucidate ecosystem processes. However, it is a challenge to develop measurements of soil organisms that are meaningful to land managers, and that can be quantified within the time frame and skills available to land managers. Thus, as for any indicator, the utility of quantifying soil organisms as part of a program for promoting soil quality and health will depend on the objectives of the specific program.

Table 3 Strategies for sustainable agricultural management and proposed indicators of crop performance, soil and environmental health

Sustainability strategy	**Indicators for producers**
Conserve soil organic matter through	
Maintaining soil C & N levels by Reducing tillage	Direction/change in organic matter levels with time (visual or remote sensing by color or chemical analysis)
Recycling plant and animal manures	Specific OM potential for climate, soil, and vegetation
And/or increasing plant diversity, where C inputs≥C outputs	Soil water storage
Minimize soil erosion through	
Conservation tillage	Visual (gullies, rills, dust, etc.)

Increased protective cover (residue, stable aggregates, cover crops, green fallow)	Surface soil properties (topsoil depth, organic matter content/texture, water infiltration, runoff, ponding, cover %)
Balance production and environment through	
Conservation and integrated management systems (optimizing tillage, residue, water, and chemical use)	Crop characteristics (visual or remote sensing of yield, color, nutrient status, plant vigor, and rooting characteristics)
Synchronizing available N and P levels with crop needs during year	Soil physical condition/compaction ;Soil and water nitrate levels
	Amount and toxicity of pesticides used
Better use of renewable resources through	
Relying less on fossil fuels and petrochemicals	Input/output ratios of costs, energy, and renewable/non-renewable resources
More on renewable resources and biodiversity (crop rotations, legumes, manures, IPM, etc.)	Leaching losses/soil acidification
	Crop characteristics (as listed above)
	Nitrate levels in soil and water

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Course Name	Problematic soils and their Management
Lesson 3	Soil Quality Assessment
Content Creator Name	Dr. SHWETA SHAMBHAVI
University/College Name	Bihar Agricultural University, Bhagalpur
Course Reviewer Name	DIBYENDU MUKHOPADHYAY
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Learning Objectives

- Understanding the basic premise and practical requirement of quantitative parameters along with functional relationships for expressing soil quality.

Glossary of terms

1. **Qualitative Assessment:** A qualitative assessment is the determination of the nature of an indicator.
2. **Quantitative Assessment:** A quantitative assessment is the accurate measurement of an indicator.
3. **Principal Component Analysis (PCA):** Principal Component Analysis (PCA) is a data compression technique designed for data that are in the form of continuous measurements, though it has also been applied to other kind of data, such as, presence/ absence of an element or measurements in the form of discrete variables.

1.1. Introduction

Any evaluations of soil quality must consider the multiple soil uses (e.g., agricultural production, forest, rangeland, nature conservation, recreation, or urban development). However, the most widely accepted concept of soil quality and the most significant in a global context concerns agro-ecosystems. In soil-quality evaluation or assessment, the two main questions that must be answered are: (i) how does the soil function; and (ii) what procedures are appropriate for making the evaluation. After answering those questions, a range of parameter values or indexes that indicate a soil is functioning at full potential can be calculated using landscape characteristics, knowledge of pedogenesis, and a more complete understanding of the dynamic processes occurring within a soil. Soil-quality assessment focuses on dynamic aspects to evaluate the sustainability of soil management practices and on inherent soil factors.

1.2 Why is Soil Quality Assessment Necessary?

Periodic assessment is needed to identify the condition of soil resources at all scales – within a lawn, field, farm, watershed, county, state, nation, or the world. Why? Because historically, humankind has neglected its soil resources more than once – often ending in failure of the dominant society and culture (Hillel, 1991). Even after more than 1,000 years of abandonment, soils of the Tikal rain forest have not recovered from the Maya occupation (Olson, 1981). Similarly, the catastrophic land management failures of the 1930's began with ignorance of the Great Plains' soil resource, which was described as "indestructible and immutable" in the 1909 Bureau of Soils Bulletin 55 (Whitney, 1909). Implementation of a wheat (Triticum aestivum L.) – fallow cropping system and use of intensive tillage throughout the Great Plains contributed to the "Dust Bowl" that fostered Hugh Bennett's 1933 indictment of Americans as "the great destroyers of land" (Baumhardt, 2003).

1.3 Key concepts in soil quality assessment

1.3.1 Soil Quality Indicators

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Soil quality assessments are conducted by evaluating indicators. Indicators can be physical, chemical, and biological properties, processes, or characteristics of soils. They can also be morphological or visual features of plants. Indicators are measured to monitor management induced changes in the soil. Soil quality indicators are selected because of their relationship to specific soil properties and soil quality (Figure 1). For example, soil organic matter is a widely used indicator, because it can provide information on various properties such as soil fertility, soil structure, soil stability, and nutrient retention. Similarly, plant indicators, such as rooting depth, can provide information about the bulk density or compaction of the soil.

Indicators can be assessed by qualitative and/or quantitative techniques. A **qualitative assessment** is the determination of the nature of an indicator that determines the accurate measurement of an indicator. For example, if erosion is the indicator being evaluated, a qualitative assessment would be the observation of rills and gullies in the field, indicating that erosion is occurring. A quantitative assessment would measure the amount of erosion occurring in the field. In another example, a qualitative assessment of infiltration would be the observation of excessive runoff water from a field. A quantitative assessment would measure the infiltration rate.

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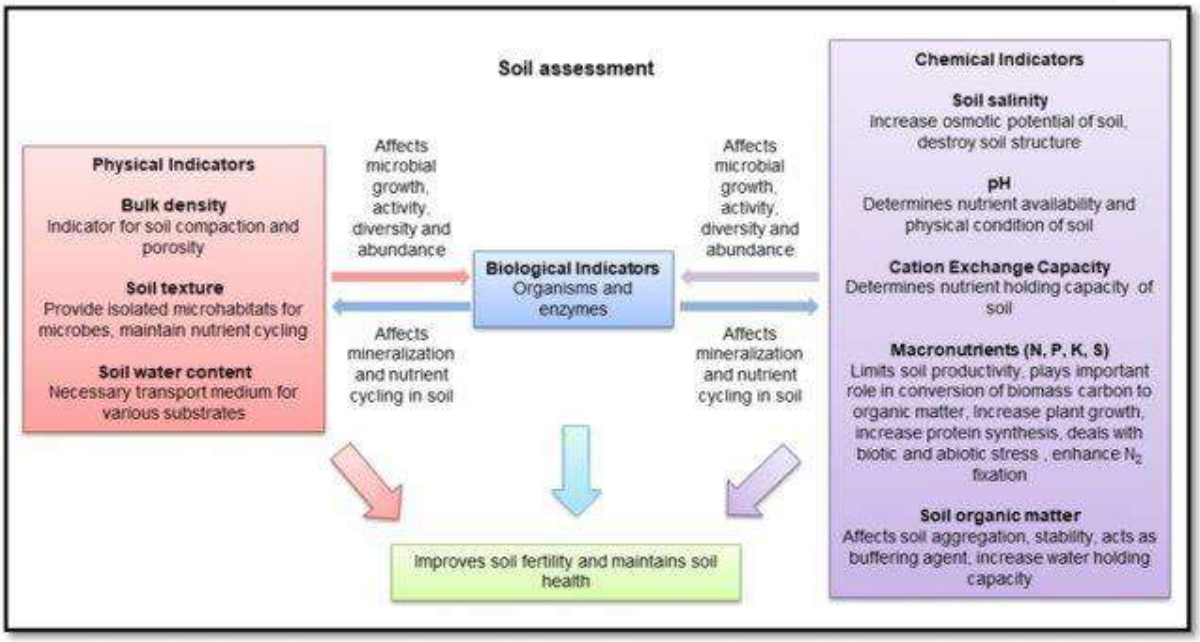

Figure 1 Chart depicting the role of various indicators, viz, physical, chemical, and biological for assessing the quality of soil (Andrews et al. 2002)

1.3.2 Minimum Data Sets and Indicators

Since it is impractical to measure every ecosystem or soil property, many researchers have proposed a minimum data set, which is the smallest set of soil properties or indicators needed to measure or characterize soil quality. Identifying key soil properties or attributes that are sensitive to change in soil functions establish a minimum data set. Table 1 is an example of a minimum data set, which shows the relationship of each indicator to soil health concerns. A minimum data set does not usually encompass all relevant properties for a region or farming system. It is an example of a minimum set of indicators required to obtain a comprehensive understanding of the soil evaluated.

Each minimum data set is tailored to a particular region or soil map unit (soil type) and includes only those properties relevant to the soil types, farming system, and land uses of the areas being evaluated. For example, a minimum data set for the Northeast United States would probably not include such indicators as salt accumulation and electrical conductivity, while a data set for areas with arid and semi-arid soils would include these indicators. Compiling a minimum data set helps to identify locally relevant indicators and to evaluate the link between indicators selected and significant soil and plant properties for the region (Table 2).

Table 1 Key soil indicators for soil quality assessment

Selected indicator	**Rationale for selection**
Organic matter	Defines soil fertility and soil structure, pesticide and water retention, and use in process models
Topsoil-depth	Estimate rooting volume for crop production and erosion
Aggregation	Soil structure, erosion resistance, crop emergence an early indicator of soil management effect
Texture	Retention and transport of water and chemicals, modeling use
Bulk density	Plant root penetration, porosity, adjust analysis to volumetric basis
Infiltration	Runoff, leaching and erosion potential
pH	Nutrient availability, pesticide absorption and mobility, process models

Electrical conductivity	Defines crop growth, soil structure, water infiltration; presently lacking in most process models
Suspected pollutants	Plant quality, and human and animal health
Soil respiration	Biological activity, process modeling; estimate of biomass activity, early warning of management effect on organic matter
Forms of N	Availability of crops, leaching potential, mineralization/ immobilization rates, process modeling
Extractable N, P and K	Capacity to support plant growth, environmental quality indicator

Table 2 Interrelationship of soil indicators (based on Arshad and Martin 2002)

Selected indicator	**Other soil quality indicators in the MIDS affecting the selected indicator**
Aggregation	Organic matter, microbial (especially, fungal) activity, texture
Infiltration	Organic matter, aggregation, electrical conductivity, ex-changeable sodium percentage (ESP)
Bulk density	Organic matter, aggregation, topsoil-depth, ESP, biological activity
Microbial biomass	Organic matter, aggregation, bulk density, pH, texture, ESP and/or respiration
Available nutrients	Organic matter, pH, topsoil-depth, texture, microbial parameters (mineralization and immobilization rates)

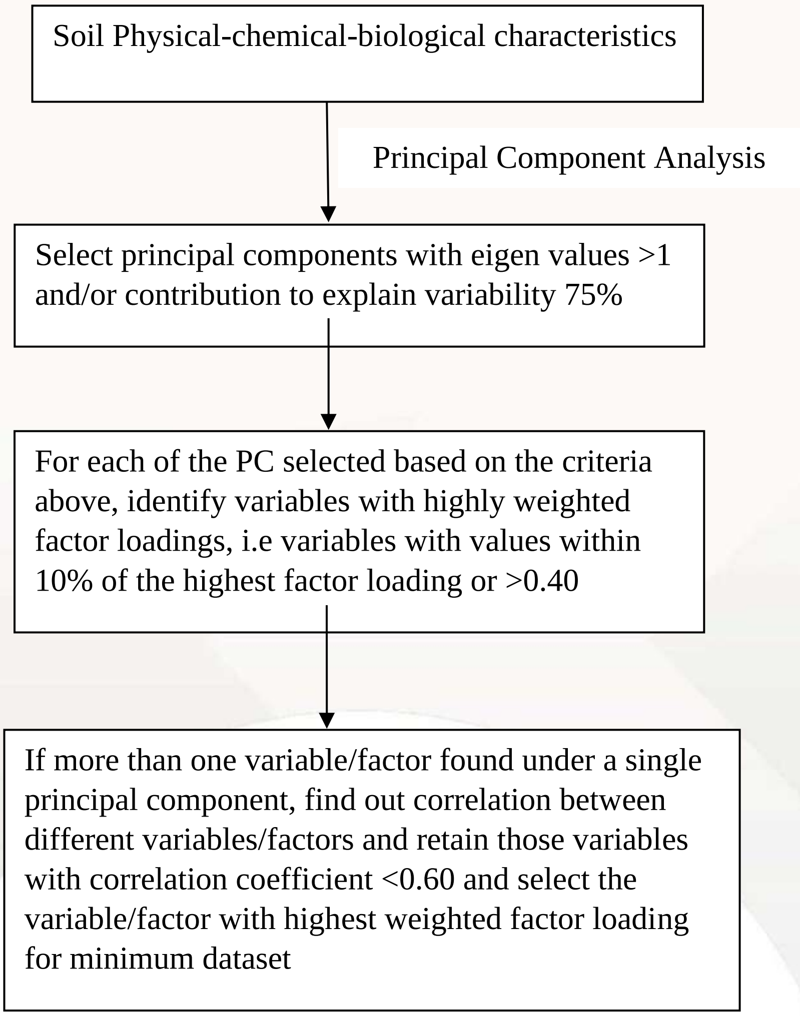

Figure 2 Approach to selection of variables/factors for minimum data set (from Andrews et al. 2002)

1.4 Methods of Soil Quality Assessment

A variety of methods or approaches are currently used to measure and assess soil quality. The methods discussed in this guide range from primarily qualitative to purely quantitative. They are as follows:

- Soil Health Card
- Natural Resources Conservation Services (NRCS) Soil Health Card Template (NRCS Template)
- Soil Quality Test Kit
- Laboratory analysis

These methods provide important information about soil quality, whether the goal is to determine changes in soil health over time or to compare management effects on soil quality in different fields or pastures. Various combinations of these methodologies may be used. No single one is inherently better or more effective.

Soil Health Cards: The soil health, or soil quality, assessment card is a qualitative tool designed by and for farmers. The cards contain farmer-selected soil quality indicators and associated ranking descriptions typical of local producers. Generally, indicators listed, such as soil tilth, abundance of earthworms, or water infiltration, can be assessed without the aid of technical or laboratory equipment

NRCS Soil Health Card Template (NRCS Template): If qualitative soil quality assessment information is desired for an NRCS conservation plan, adapt for local use the NRCS Template that comes with this guide. Although technically this template can be used as is, the indicators and rankings it uses have been collated from various parts of the United States and are very general.

Soil Quality Test Kit: The Soil Quality Test Kit, developed by the ARS, is an on-farm soil quality assessment tool. It was modified and enhanced by the

NRCS Soil Quality Institute with NRCS field staff. The kit is used as a screening tool to give a general direction or trend of soil quality; e.g., whether current management systems are maintaining, enhancing, or degrading the soils. It can also be used to troubleshoot problem areas in the field.

Laboratory Analysis: Soil testing laboratories throughout the countries have tests for many soil properties that are useful for soil quality evaluation. While some of these tests can also be done with the Soil Quality Test Kit, farmers may not have the time to run the tests, or they may prefer to obtain their results from an accredited laboratory.

1.5 General Indicator of Soil Quality (GISQ)

Soil organisms and biotic parameters (e.g., abundance, diversity, food web structure, or community stability) meet most of the desired criteria of soil quality indicators (Doran and Zeiss, 2000). The use of faunal groups as indicators for soil quality needs a choice of organisms, that (a) form a dominant group and occur in all soil types, (b) have high abundance and high biodiversity and (c) play an important role in soil functioning, e.g., food webs. Velasquez et al. (2007) developed a general indicator of soil quality (GISQ) based on estimation of around 50 soil properties related to macrofauna, chemical fertility, physical state, organic matter fractions and soil morphology. The computational procedure involved four steps: (i) PCA analysis of the variables allowing testing of the significance of their variation among land use types; (ii) identification of the variables that best differentiate the sites according to the soil quality; (iii) creation of sub-indicators of soil physical quality, chemical fertility, organic matter, morphology and soil macrofauna, with values ranging from 0.1 to 1.0; (iv) combination of all five sub-indicators into a general one. This indicator allows the evaluation of soil quality and facilitates identification of problem areas through the individual values of each sub-indicator.

1.6 Development of Soil Quality Index (SQI)

1.6.1 Data Compression

Principal Component Analysis (PCA) is a data compression technique designed for data that are in the form of continuous measurements, though it has also been applied to other kind of data such as presence/ absence of an element or measurements in the form of discrete variables. Ordination, a collective term for multivariate techniques that arrange sites along axes on the basis of soil properties can help to show whether important environmental variables have been overlooked. Ordination is like a linear regression model, but with the major difference that the explanatory variables here are theoretical variable and not known environmental variables. Principal Components (PCs) for a data set are defined as linear combinations of the variables that account for maximum variance within the set by describing vectors of closest fit to the n observations in p-dimensional feature space, subject to being orthogonal to one another. The PCA output gives as many PCs as the input variables but it is assumed that PCs receiving high eigen values (setting a threshold, e.g., eigen values > 1) or those explaining variation in the data exceeding a limit (e.g., > 5% of the variability) are 'important' and not the others. Contribution of a variable to a particular PC is represented by a weight or factor loading. Only the highly weighted variables are retained from each PC and highly weighted factor loadings identified based on thresholds such as those variables with absolute values within 10% of the highest factor loading or > 0.4. When more than one factor is retained under a single PC, multivariate correlation coefficients are employed to determine if variables could be considered redundant and if the variables are correlated, that with the highest value is chosen for multi dimensional scaling (MDS).

1.6.2 Data Transformation

The selected indicators can be transformed following a linear or a non-linear scoring rule. For 'more is better' indicators, each observation is divided by the highest observed value such that the highest observed value received a score of 1. For 'less is better' indicators, the lowest observed value (in the numerator) is divided by each observation (in the denominator) such that the lowest observed value receives a score of 1. For some indicators, observations are scored as 'higher is better' up to a threshold value and as 'lower is better' above the threshold. The values of different variables can be transformed to a common range, between 0.1 to 1.0 with homothetic transformation:

$$y = 0.1 + (x-b)/(a-b) * 0.9$$

where, y = value of the variable after transformation, x= the variable to transform, a = the maximum value of the variable, and b = the minimum value of the variable

Non-linear scoring functions are constructed based on literature review and consensus of the collaborating researchers. Masto et al. (2007) used the following equation for deriving non-linear scores:

Non-linear score (y) = 1/1+e –b (x-a)

where, x = soil property value, a = the baseline or value of the soil property (the scoring function equals 0.5 and equals the midpoint between the upper threshold value and the lower threshold value), and b = slope. The upper threshold value is the soil property value for which the score equals 1 and which corresponds to the most favourable level. The lower threshold value is the soil property value where the score equals 0 and which corresponds to an unacceptable level. Baselines are generally regarded as the minimum target values.

1.6.3 Data Integration

There are basically two ways of integrating indicators to derive one soil quality index – by summing the scores from MDS indicators and by summing MDS variables after weighting them by considering the % variation explained by a PC, standardized to unity, as the weight for variable(s) chosen under a given PC.

1.7 Integrated Approach for soil quality assessment

For integrated soil-quality assessment, the development of relationships between all the soil-quality indicators and the numerous soil functions may be a monumental task. Therefore, a stepwise agro-ecological approach for soil-quality evaluation and monitoring was proposed by De la Rosa (2005). Two steps relating to: (i) inherent soil quality, and (ii) dynamic soil quality are involved.

Step 1: Land evaluation is an appropriate procedure for analyzing inherent soil quality from the point of view of long-term agro-ecological changes. Within this complex context, land-evaluation models may serve as a first step to develop a soil quality assessment procedure (Arshad and Martin, 2002). The first step will result in defining agro-ecological zones, land suitability, and vulnerability classes.

Step 2: A short-term evaluation and monitoring procedure would be basically considered for the soil biological quality in each agro-ecological zone defined in the first step. By measuring appropriate indicators, changes in soil dynamic quality can be assessed. These indicators would be compared with the desired values (critical limits or threshold level), at different time intervals (Arshad and Martin, 2002) (Figure 3). This comparison of single indicator should be of natural soils that have not been disturbed with soils that have been under a certain use and management system for a number of years. Because soil biological parameters are most variable and sensitive to management practices, a monitoring system (observed change over time) would provide information on the effectiveness of the selected farming system, land-use practices, technologies, and policies. For example, dehydrogenase activity in Mediterranean forest soils proved to be very sensitive to both natural and management changes, and showed a quick response to the induced changes. Also, enzyme activities have been found to be very responsive to different agricultural management practices such as non-tillage. Because of the complex nature of the soil and its high spatial and temporal variability, it is appropriate to develop soil-quality assessment based on biological indicators after the traditional land evaluation using basically physico-chemical parameters. This agro-ecological approach should focus on dynamic soil aspects (biological factors) but with awareness of inherent soil aspects (physical and chemical factors).

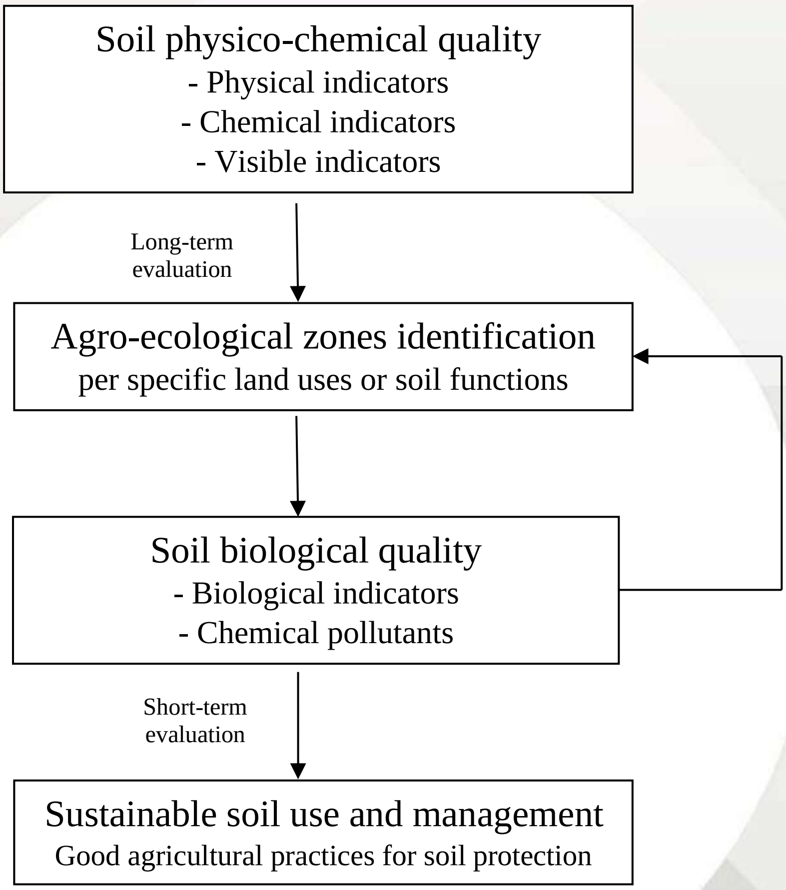

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Figure 3 Graphical representation of a stepwise agro-ecological approach for soil-quality assessment

Disclaimer: All the acknowledgements are made from where the text, images and tables are taken and there are no copyright violations in the prepared course content

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Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Course Name	Problematic soils and their Management
Lesson 4	On Farm Soil Health Assessment
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Learning Objectives

- Understand and demonstrate the prominent characteristics / morphology / rapid test parameters of healthy soils.
- Learn about soil texture and structure, soil colour, soil tilth, infiltration, drainage and water holding capacity.
- Understand about soil biological diversity and interrelationships between soil, plant, animal and human health

4.1. Introduction

On farm assessment of soil quality and health is recommended to assist farmers evaluate the effects of their management decisions on soil productivity. This approach permits interaction between researchers, extension and political personnel while providing interpretation to link on farm-based knowledge to soil health information. The main challenge is to develop soil quality and soil health standards to assess changes which are practical and useful to farmers.

4.2 In-field soil health assessment

Qualitative, on-farm, in-field assessment of soil health does not need to involve special analyses, only the informed observation and interpretation of soil characteristics are considered This is usually done by visual assessment, but the smell and feel of soil may also be involved. Field test kits for measuring several indicators are also available (e.g. NRCS soil quality test kit). While this approach is more subjective and therefore can reflect user bias, the results can be very informative in making management decisions when detailed guidelines and training have been provided. Guided, in-field assessment can also be particularly effective to increase awareness and understanding of how important it is to maintain healthy soils, and the importance of key soil processes. Some specific soil indicators, such as compaction measurement using a penetrometer in the root zone, are always measured better directly in the field than in a laboratory.

Proposed indicators for measuring the sustainability of agricultural systems at the farm level

Farmer/society needs (acceptable)	Resource/environmental conservation (adequate/acceptable)
Yields	Soil organic matter
Profits	Topsoil depth
Risk/stability	Soil protective cover (%)
Input/output ratio (energy and costs)	Leachable salts (NO_3) (soil electrical conductivity)

4.2.1 Scorecards: The use of scorecards for on farm soil quality assessment is emphasized where qualitative observations of soil health are scored to obtain an overall measure of soil quality and soil health. These cards may be developed to evaluate soil health through farmers' observation of soil physical, chemical and biological properties.

For example, such as, observation on earthworm numbers can yield a general index of biological activity in the soil.

4.2.2 Soil quality test kits: Assessment tools such as soil quality test kits focus on farmer based evaluations and education regarding various soil and smallholder management practices. Further, they aim to produce an educational tool to increase public awareness of the importance of soil quality.

4.2.3 Soil quality indices: Various soil quality indexing approaches are available and can be applied to derive a range of critical test values within which soil quality and soil health assessment parameters can be fitted.

4.3 Developing and using in-field assessments

- Participatory approach in developing qualitative soil health monitoring procedures locally have had significant educational value and opened up communication among farmers and between farmers and other agriculture professionals.
- A number of score cards and kits for measuring soil health in the field have been developed. These have used more than 30 physical indicators and more than 10 biological, chemical, and crop observation based indicators of soil health (Table 1). In this approach, soil physical characteristics might be scored for soil 'feel', crusting, water infiltration, retention or drainage, and compaction. Soil biological properties might include soil smell (low score for sour, putrid or chemical odors vs. high score for 'earthy,' sweet, fresh

aroma), soil color and mottling (which reflects balance of aerobic vs. anaerobic bacterial activity), and earthworm or overall biological activity through in-field respiration measures. Crop indicators of soil functioning such as root proliferation and health, signs of compaction (such as thick angular roots), legume nodulation, and signs of residue decomposition can also provide useful information.

- The rating scales used in soil health score cards vary from just a few categories ("poor, fair, or good") to scales of 1 to 10. The descriptions that define categories or rating scales are best based on local terminology and preferences. High quality photographs are an excellent way to train users and achieve somewhat standardized scoring (Table 2).

4.4 Soil Health Report

The raw data from the individual indicators and background information about sample location and management history are synthesized into an auto generated and grower friendly report. The standard soil health test report presents soil health information for a field in a way that enables the identification of areas where soil management efforts may be targeted.

The soil health test report is presented on a single page and consists of different sections laid out in visually enhanced format to present information to the growers and agricultural service providers. The sections of the report include:

1. **Background Information:** The information collected during sampling is presented in this section. This includes the farm name and contact information, the sample number, the date of sampling, the local extension educator name, current crop and tillage and their history over the past 2 years, drainage and slope conditions, soil type and soil texture.
2. **Indicator list:** This section gives a list of indicators that were measured for soil health assessment. They are colour coded to separate the physical, biological and chemical indicators.
3. **Indicator values:** This presents the values of the indicators that were measured either in the laboratory or field.
4. **Ratings:** This section presents the scores and colour coded ratings of the soil quality indicators. The indicators are scored on a scale of 1-100 based on scoring functions developed for individual indicators. In addition, the indicators are rated with colour codes depending on their scores. Generally, a score of less than 30 is regarded as low and receives a red colour code. A score from 30-70 is considered medium and is colour coded yellow. A score value higher than 70 is regarded as high and colour coded green.
5. **Constraints:** If the ratings of a particular indicator is poor/low (red colour code), the respective soil health constraints will be highlighted in this section. This is very useful tool for identifying areas to target their management efforts.

6. **Overall quality score:** An overall quality score is computed from individual indicator scores. This core is further rated as follows: less than 40% is regarded as very low, 40-55% is low, 55-70% is medium, 70-80% is high and greater than 85% is regarded as very high. The highest possible quality score is 100 and the least score is 0, thus it is a relative overall soil health status indicator.

Table 1 Selected Soil indicators

Indicator	Poor	Medium	Good
Earthworms	0-1 worms in shovelful of top foot of soil. No casts or holes.	2-10 in shovelful. Few casts, holes, or worms.	10+ in top foot of soil. Lots of casts and holes in tilled clods. Birds behind tillage.
Organic Matter Color	Topsoil color similar to subsoil color.	Surface color closer to subsoil color.	Topsoil clearly defined, darker than subsoil.
Organic Matter Roots/Residue	No visible residue or roots.	Some residue, few roots.	Noticeable roots and residue.
Subsurface Compaction	Wire breaks or bends when inserting flag.	Have to push hard, need fist to push flag in.	Flag goes in easily with fingers to twice the depth of plow layer.
Soil Tilth Mellowness Friability	Looks dead. Like brick or concrete, cloddy. Either blows apart or hard to pull drill through.	Somewhat cloddy, balls up, rough pulling seedbed	Soil crumbles well, can slice through, like cutting butter. Spongy when you walk on it.
Erosion	Large gullies over 2 inches deep joined to others, thin or no topsoil, rapid run-off the color of the soil.	Few rills or gullies, gullies up to two inches deep. Some swift runoff, colored water.	No gullies or rills, clear or no runoff.
Water Holding Capacity	Plant stress two days after a good rain.	Water runs out after a week or so.	Holds water for a long period of time without puddling.
Drainage Infiltration	Water lays for a long time, evaporates more than drains, always very wet ground.	Water lays for short period of time, eventually drains.	No ponding, no runoff, water moves through soil steadily. Soil not too wet, not too dry.
Crop Condition (How well it grows)	Problem growing throughout season, poor growth, yellow or purple color.	Fair growth, spots in field different, medium green color.	Normal healthy dark green color, excellent growth all season, across field.
pH	Hard to correct for desired crop.	Easily correctable.	Proper pH for crop.
Nutrient Holding Capacity	Soil tests dropping with more fertilizer applied than crops use.	Little change or slow down trend.	Soil tests trending up in relation to fertilizer applied and crop harvested.

Assessment Sheet

Date__________ Crop______________

Farm/Field ID__________________

Soil Quality Poor Medium Good

INDICATORS	1	2	3	4	5	6	7	8	9
Earthworms									
Organic Matter Color									
Organic Matter Roots/residue									
Subsurface Compaction									
Tilth/Friability Mellowness									
Erosion									
Water Holding Capacity									
Drainage Infiltration									
Crop Condition									
pH									
Nutrient Holding Capacity									
Other (write in)									
Other (write in)									

Assessment Guide

Indicator	Best Assessed
Earthworms	Spring/Fall Good soil moisture
Organic Matter Color	Moist soil
Organic Matter Roots/Residue	Anytime
Subsurface Compaction	Best pre-tillage or post harvest Good soil moisture
Soil Tilth Mellowness Friability	Good soil moisture
Erosion	After heavy rainfall
Water Holding Capacity	After rainfall During growing season
Drainage Infiltration	After rainfall
Crop Condition	Growing season Good soil moisture
pH	Anytime, but at same time of year each time
Nutrient Holding Capacity	Over a five year period, always at same time of year.

Table No 2: Brief Descriptions of the selected soil health assessment indicators

PHYSICAL	**Aggregate Stability:** is a measure of the extent to which soil aggregates resist falling apart when wetted and hit by rain drops. It is measured using a rain simulation sprinkler that steadily rains on a sieve containing a known weight of soil aggregates between 0.5mm and 2.0mm. The unstable aggregates slake (fall apart) and pass through the sieve. The fraction of soil that remains on the sieve determines the percent aggregate stability.
	Available Water Capacity: reflects the quantity of water that a disturbed sample of soil can store for plant use. It is the difference between water stored at field capacity and the wilting point, and is measured using pressure chambers.
	Surface Hardness: is a measure the maximum soil surface (0 to 6 inch depth) penetration resistance (psi) determined using a field penetrometer.
	Subsurface Hardness: is a measure of the maximum resistance (in psi) encountered in the soil at the 6 to 18 inch depth using a field penetrometer.
BIOLOGICAL	**Organic Matter:** is any material that is derived from living organisms, including plants and soil fauna. Total soil organic matter consists of both living and dead material, including well decomposed humus. The percent OM is determined by loss on ignition, based on the change in weight after a soil is exposed to approximately 500°C in a furnace.
	Active Carbon: is a measure of the fraction of soil organic matter that is readily available as a carbon and energy source for the soil microbial community (the fuel of the soil food web). Active carbon is a "leading indicator" of soil health response to changes in crop and soil management, usually responding much sooner than total organic matter content. The soil sample is mixed with potassium permanganate (deep purple in color) and as it oxidizes the active carbon, the color (absorbance) is measured using a spectrophotometer.
	Potentially Mineralizable Nitrogen: is the amount of nitrogen that is converted (mineralized) from an organic form to a plant-available inorganic form by the soil microbial community over seven days in an incubator. It is a measure of soil biological activity and an indicator of the amount of nitrogen that is rapidly available to the plant.
	Root Health Rating: is a measure of the quality and function of the roots as indicated by size, color, texture and absence of symptoms and damage by root pathogens such as *Fusarium, Pythium, Rhizoctonia,* and *Thielaviopsis*. Been seeds are grown in a portion of the soil sample in the greenhouse for four weeks. Low ratings (1 to 3) suggest healthy roots because pathogens are not present at damaging level and /or are being suppressed by the beneficial microorganisms in the soil.
CHEMICAL	**Soil Chemical Composition:** a standard soil test analysis package measures levels of pH, plant nutrients and toxic elements. Measured levels are interpreted in the framework of sufficiency and excess but are not crop specific.

SOIL HEALTH TEST REPORT (COMPREHENSIVE)				
Name of farmer:			Sample ID:	
Location:			Agent:	
Field/ Treatments:			Agent E mail:	
Tillage:			Soil Texture:	
Crops grown:			Date sampled:	
	Indicators	**Value**	**Rating**	**Constraint**
PHYSICAL	Aggregate stability	18	18	Aeration, infiltration, rooting
	Available water capacity	0.18	64	
	Surface hardness	348	2	Rooting, Water transmission
	Subsurface hardness	472	3	Subsurface pan, deep compaction
BIOLOGICAL	Organic matter	1.7	9	Energy storage, C sequestration
	Active carbon	312	5	Soil biological activity
	Potential mineralizable	2.0	0	N supply capacity
	Root health rating	7.0	25	
CHEMICAL	pH	7.3	89	
	Extractable phosphorus	17.0	100	
	Extractable potassium	73	100	
	Minor Elements		100	
Overall quality score (Out of 100): 43.0 Low				
Measured soil textural class: Silt Loam Sand (%): 37.0Silt (%): 55.0 Clay (%): 8.0				
Location (GPS): Latitude and Longitude				

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Course Name	Problematic soils and their Management
Lesson 5	Distribution of Waste land in India
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Learning Objectives

- *Learn about the geographic distribution of area under wastelands across various states of India.*
- *Understand the underlying reasons for development of wastelands and approaches for managing them.*

Glossary of terms

1. **Barren Rocky Area**: These are rock exposures of varying lithology often barren and devoid of soil and vegetative cover. They occur amidst hill-forests as openings or as isolated exposures on plateau and plains. Barren rocky areas occur on steep isolated hillocks/hill slopes, crests, plateau and eroded plains associated with barren and exposed rocky/stony wastes, lateritic out-crops, mining and quarrying sites. The category also includes steep sloping areas devoid of vegetation cover that were classified separately in the earlier exercise.
2. **Coastal sand**: Coastal sands are the sands that are accumulated as a strip along the seacoast due to action of seawater. These are not being used for any purpose like recreation.
3. **Desertic sand**: Desertic sands are those confined to arid environment where the rainfall is scanty. These lands are characterized by accumulation of sand in the form of varying size of sand dunes and height that have developed as a result of transportation of soil through aeolian processes. The following two categories of desert sands could be mapped based on their vertical approximate heights.

Semi-stabilized to stabilized dunes with >40 m height Semi-stabilized to stabilized moderately high dunes with heights ranging between 15 and 40 m

4. **Degraded pastures/grazing land**: These are the lands in non-forest areas that are either under permanent pastures or meadows, which have degraded due to lack of proper soil and water conservation and drainage development measures.
5. **Degraded land under plantation crop:** These are the degraded lands that have been brought under plantation crops after reclamation and are located outside the notified forest areas.
6. **Gullied and/or Ravinous Land:** Gully is a narrow channel when surface water flow increases in response to clearing and excessive use of land. Other factors that play a role in gully initiation are the type of landscape, geology, rainfall, soil texture, hill-slope, length and seasonal climatic extremes. The intricate network of gullies is referred to as ravines. Two categories of ravines viz., medium ravines and deep ravines could be delineated based on their depth.

   a. Medium Ravines: These are the ravines with a depth of gullies ranging between 2.5 and 5 meters. Generally, these are seen confined to the head region of the stream close to agricultural land.

   b. Deep Ravines: The depth of ravines is more than 5 meters. Deep ravines, generally, occur along the higher order stream areas that are close to the main river.

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7. **Land affected by salinity/alkalinity:** Land affected by salinity/alkalinity has excess soluble salts (saline) or high exchangeable sodium. Salinity is caused due to capillary movement of water, during extreme weather conditions leaving salt encrustation on the surface. Alkali soils have exchangeable sodium percentage (ESP) values of 15 or more, which is generally considered as the limit between normal and alkali soils. The predominant salts in alkali soils are carbonates and bicarbonates of sodium. Considering the degree of salinity and or alkalinity, the following two sub-classes viz., moderately saline / alkali and strongly saline / alkali areas could be delineated.

   a. Moderately Saline/Alkali land: These are the areas located in the fluvial plains with the degree of salinity (ECe) ranging from 8 to 30 (dS/m), pH between 9.0 – 9.8 and the Exchangeable Sodium Percentage (ESP) values ranging between 15-40.

   b. Strongly Saline/Alkali land: These are the salt-affected lands with ECe values greater than 30 dS/m, pH values more than 9.8 and ESP values of >40.

8. **Mining /Industrial wastelands**
   a. **Mine dumps:** Are those lands where waste debris is accumulated after extraction of minerals. Included in this category is the mine / quarry areas subject to removal of different earth material (both surface and sub-surface) by manual and mechanized operations. Large scale quarrying and

mechanical operations result in creation of mine dumps. It includes surface rocks and stone quarries, sand and gravel pits, soil excavation for brick kilns, etc.

b. **Industrial:** These are areas of stockpile of storage dump of industrial raw material or slag/effluents or waste material or quarried/mixed debris from earth's surface.

9. **Riverine sand**: Riverine sands are those that are accumulated in the flood plain of the river as sheets, or sand bars. It also includes inland sand which was accumulated along the abandoned river courses or by reworking of sand deposits by wind action leading to long stretches of sand dunes or sand cover areas noticed in Indo-Gangetic alluvial plains.

10. **Sand (coastal/desert/riverine)**: This category refers to land with accumulation of sand, in coastal, riverine or inland areas. Generally, these lands vary in size; occur in various shapes with contiguous to linear pattern. These lands are mostly found in deserts, riverbeds and along the shores.

11. **Scrubland:** This is the land, which is generally prone to deterioration due to erosion. Such lands generally occupy topographically high locations, excluding hilly/mountainous terrain. Based on the presence of vegetation cover, two sub-classes could be delineated i.e., land with dense scrub and land with open scrub.

    a. Land with dense scrub: These areas have shallow and skeletal soils, at times chemically degraded, extremes of slopes, severely

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eroded, and are subjected to excessive aridity with scrubs dominating the landscape. They have a tendency for intermixing with croplands.

b. Land with open scrub: This category is same as mentioned in the earlier category except that it has sparse vegetative cover or is devoid of scrub and has a thin soil covers.

12. **Scrub Forest**: Two sub-classes viz., scrub dominated degraded forest land and agriculture land inside notified forest area have been delineated.

a. Scrub dominated: Land, as notified under the Forest Act and those lands with various types of forest cover with less than 20 % of vegetative cover, are classified as degraded forest. These lands are generally confined to the fringe areas of notified forest.

b. Agricultural land inside notified forest land: This category refers to land that have been notified under the Forest Act, in which agriculture is being practiced, (except for the de-notified forest areas).

13. **Shifting Cultivation Areas**: Shifting cultivation is a traditional practice of growing crops on forested/ vegetated hill-slope by the slash and burn method.

a. Current: The areas that are used for cultivation by the slash and burn practices and are clearly perceptible on the satellite image in pre-burnt /post-burnt conditions.

b. Abandoned: Are those areas that were earlier under shifting cultivation but subsequently left idle for more than one year but less than 5 years, thereby giving a scope for the regeneration of secondary vegetation such as bamboo or grasses. This category has a tendency to get mixed with forests.

14. **Snow Covered and/ or Glacial Area**: These lands are under perpetual snow cover and are confined to the Himalayan region. The mountain peaks and slopes and high relief areas are the places where snow/glacial areas occur.

15. **Waterlogged/Marshy Land**: Waterlogged land is that low lying land where the water is at/or near the surface and the water stands for most part of the year. Depending on duration of water logging, two sub-classes viz., permanently waterlogged and seasonally waterlogged areas could be delineated.

a. Permanent: Permanently waterlogged areas are those where the water logging conditions prevail during most part of the year. These areas are mostly located in low-lying areas, with impervious substratum along the canals/ river banks, coastal inlands, etc.

b. Seasonal: Seasonally waterlogged areas are those where the water logging condition prevails usually during the monsoon period. These lands are mostly located in plain areas associated with the drainage congestion. Use of multi-season satellite data enables delineation of this category.

5.1. Introduction

India can be called as a land of paradoxes—a girdle of high-snow capped mountains, glaciers and high-altitude forests in the north; seas washing both sides of lengthy coastline in the peninsular south; and a variety of geological formations, diversified climates and varied topographies and reliefs. The lofty mountains are highest in the world and river deltas are raised a few metres above the mean sea level. And temperatures vary from arctic cold to equatorial hot. Precipitation varies from less than 100 mm in the arid regions to 11,000 mm/yr in the per-humid regions. This geographical location provides the country with a landscape of diversity of high plateaux, stumpy relic hills, shallow open valleys, rolling uplands, fertile plains, swampy lowlands and dreary barren deserts and a variety of soils developed on these landforms.

5.2 What is essentially in a wasteland?

- The non technical definition of wasteland from the Cambridge Advanced Learner's Dictionary is 'An empty area of land, especially in or near a city, which is not used to grow crops or built on, or used in any way and/or a place, time or situation containing nothing positive or productive, or completely without a particular quality or activity'.
- The Technical Task Group Report of the National Wastelands Development Board Defines the Wasteland as a Land Which is Presently Lying Unutilized due to Different Constraints.
- ICAR proposed that Wastelands are Lands which Due to Neglect or Due to Degradation are not Being Utilized to Their Full Potential.

These can result from inherent or imposed disabilities or both, such as location, environment, chemical and physical properties, and even suffer from management conditions.

- According to Integrated Wasteland Development Programme, Wasteland is a degraded land which can be brought under vegetative cover, with reasonable effort, and which is currently under utilised and land which is deteriorating for lack of appropriate water and soil management or on account of natural causes.
- Accelerating growth of wastelands/degraded lands created a menace to the Government. The growing concern to prevent this extraordinary growth, Government of India has set up the National Wastelands Development Board in 1985 under the Ministry of Environment & Forests.

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 under-utilized and land which is deteriorating for lack of appropriate water and soil management or on account of natural causes".

5.3 Categories of wasteland for Identification

a. Culturable Wasteland- The land which has potential for the development of vegetative cover and is not being used due to different constraints of varying degrees, such as erosion, water logging, salinity etc.

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b. Unculturable Wasteland– The land that cannot be developed for vegetative cover, for instance the barren rocky areas and snow covered glacier areas.

2.2 Categories of Wasteland in India

- Gullied and/ or ravinous land (Medium)
- Gullied and/ or ravinous land (Deep)
- Land with Dense Scrub
- Land with Open Scrub
- Waterlogged and Marshy land (Permanent)
- Waterlogged and Marshy land (Seasonal)
- Land affected by salinity/alkalinity (Moderate)
- Land affected by salinity/alkalinity (Strong)
- Shifting Cultivation - Current Jhum
- Shifting Cultivation - Abandoned Jhum
- Under-utilised/degraded forest (Scrub dominated)
- Under-utilised/degraded forest (Agriculture)
- Degraded pastures/ grazing land
- Degraded land under plantation crop
- Sands – Riverine
- Sands – Coastal
- Sands – Desertic
- Sands - Semi Stability - Stability > 40 m------------------------- clarify Stab in full form

- Sands - Semi Stability - Stability 15 - 40 m
- Mining Wastelands
- Industrial Wastelands
- Barren Rocky Area
- Snow Covered/ Glacial Area

Table 1: India - State-wise distribution of Wastelands (sq.km) during 2015-16

Sl. No.	STATE NAME	Total Geographical Area (TGA)	Total Wasteland (WL)	% to TGA
1	Andhra Pradesh	162989	23981.74	**14.71**
2	Arunachal Pradesh	83743	13906.16	**16.61**
3	Assam	78438	9003.08	**11.48**
4	Bihar	94171	7685.39	**8.16**
5	Chattisgarh	135194	10875.37	**8.04**
6	Delhi	1483	81.27	**5.48**
7	Goa	3702	515.66	13.93
8	Gujarat	196024	21740.39	11.09
9	Haryana	44212	1658.96	3.75
10	Himachal Pradesh	55673	22831.91	40.01
11	Jammu & Kashmir *	222236	175697.01	79.06
12	Jharkhand	79706	11767.08	**14.76**
13	Karnataka	191791	13229.68	6.90
14	Kerala	38863	2288.32	5.89
15	Madhya Pradesh	308252	39536.62	12.83
16	Maharashtra	307690	36075.15	11.72
17	Manipur	22327	5651.89	25.31
18	Meghalaya	22429	4135.77	18.44
19	Mizoram	21081	4300.66	20.40
20	Nagaland	16579	5064.17	30.55
21	Orissa	155707	18422.36	11.83
22	Punjab	50362	462.37	0.92

23	Rajasthan	342239	78851.33	23.04
24	Sikkim	7096	3294.79	46.43
25	Tamil Nadu	130058	8222.24	6.32
26	Telangana	112079	14241.21	12.71
27	Tripura	10486	920.52	8.78
28	Uttarakhand	53483	12726.16	23.79
29	Uttar Pradesh	240928	8537.06	3.54
30	West Bengal	88752	1654.99	1.86
31	Union Territory	9490	306.23	3.23
TOTAL		**3287263**	**557665.51**	**16.96**

Source: Wasteland Atlas of India (2019)

Table 2: India - Category-wise distribution of Wastelands in India (sq.km) during 2015-16

Sl.No.	Category	Total WL	% to TGA
1	Gullied and/or ravinous land-Medium	6484.17	0.20
2	Gullied and/or ravinous land-Deep/very deep ravine	3108.89	0.02
3	Land with dense scrub	73972.04	2.25
4	Land with open scrub	99601.55	3.03
5	Waterlogged and Marshy land-Permanent	1627.15	0.05
6	Waterlogged and Marshy land-Seasonal	5199.45	0.16
7	Land affected by salinity/alkalinity-Moderate	4723.43	0.14
8	Land affected by salinity/alkalinity-Strong	1585.66	0.05
9	Shifting cultivation area-Current Jhum	3871.27	0.12
10	Shifting cultivation area-Abandoned Jhum	4575.49	0.14
11	Under utilised/degraded forest-Scrub dominated	86411.09	2.63
12	Agricultural land inside notified forest land	21691.08	0.66
13	Degraded pastures/grazing land	6450.07	0.20
14	Degraded land under plantation crops	248.81	0.01

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15	Sands- Riverine	3121.21	0.09
16	Sands- Coastal sand	671.24	0.02
17	Sands- Desert Sand	8191.52	0.25
18	Sands- Semi-stabilized to stabilized (>40m) dune	9345.48	0.28
19	Sands- Semi-stabilized to stabilized moderately high (15- 40m) dune	11800.79	0.36
20	Mining Wastelands	2256.33	0.07
21	Industrial wastelands	317.20	0.01
22	Barren rocky area	94483.78	2.87
23	Snow cover and/or glacial area	107927.78	3.28
	Total	**557665.51**	**16.96**

Source: Wasteland Atlas of India (2019)

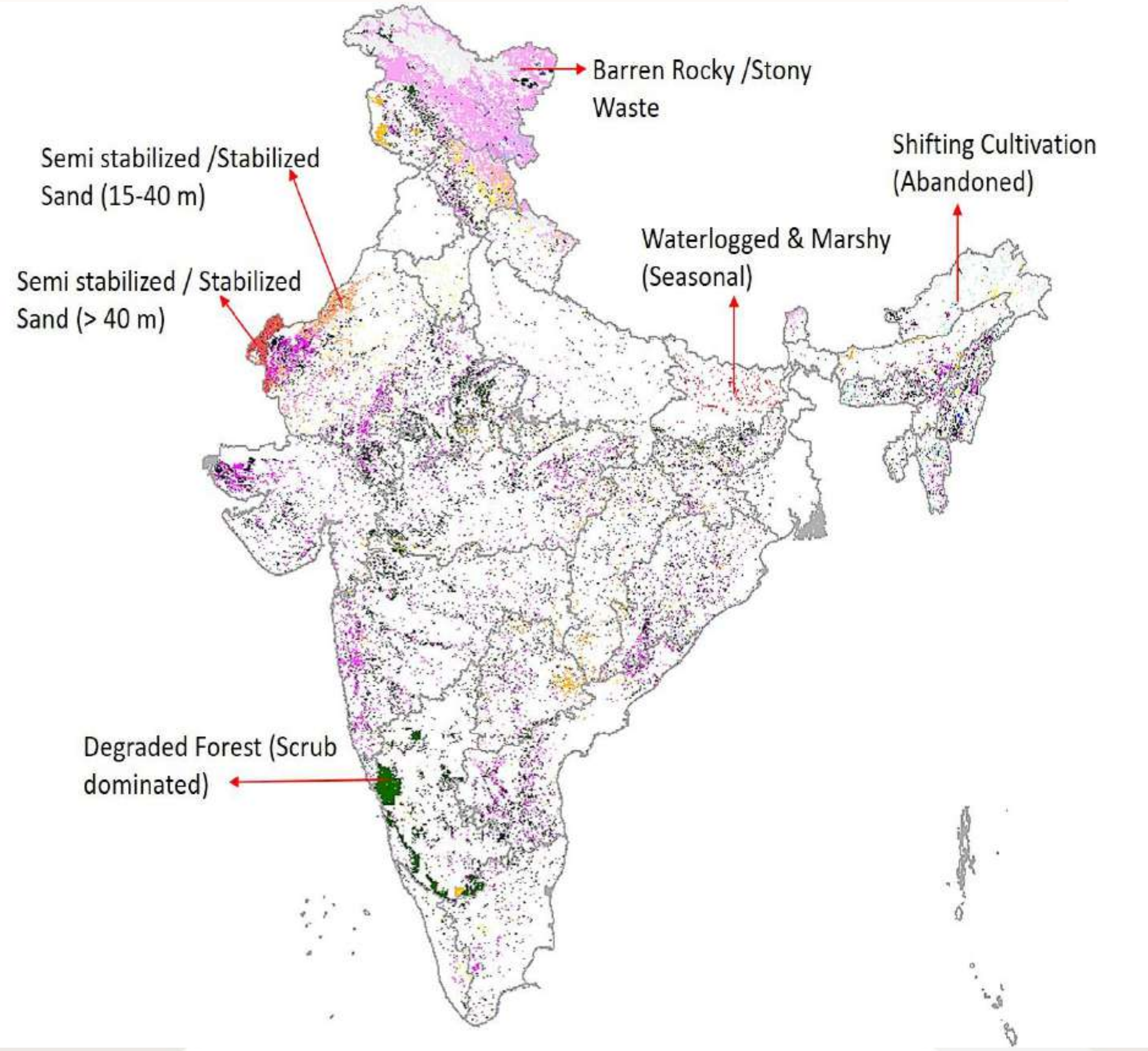

Figure 1: ***Wastelands map of India (generated using LISS-III data of 2015-16) (ICAR, 2010)***

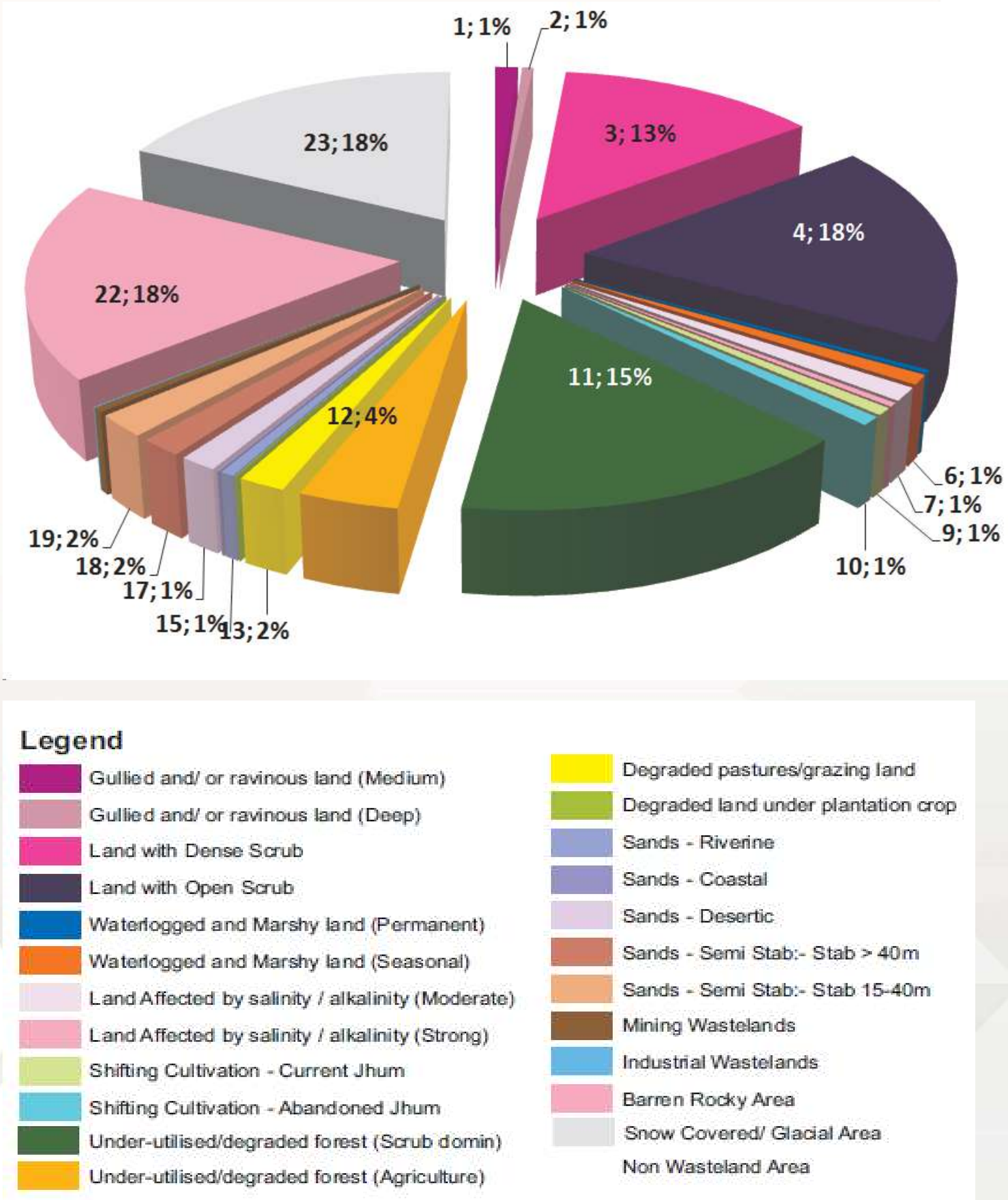

Figure 2: Percentage of Category-wise distribution of Wastelands in India

5.4 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.

5.4 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.

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Course Name	Problematic soils and their Management
Lesson 6	Distribution of Problem soils in India
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Learning Objectives

- Identify various soil problems and problem soils and understand the difference between them.
- Learn about various categories of problem soils and the affected area under each of them.

Glossary of terms

1. **Calcareous soils:** A calcareous soil has abundance of calcium carbonate ($CaCO_3$) . If a calcareous soil is added with hydrochloric acid , the soil will effervesce and give off carbon dioxide and form bubbles because of the chemical reaction.
2. **Clayey soils:** A soil that contains a high percentage of fine particles and colloidal substance and becomes sticky when wet.
3. **Degraded soils:** Soil degradation is the decline in soil condition caused by its improper use or poor management, usually for agricultural, industrial, or urban purposes. Such soils are called as degraded soils.
4. **Permeability:** It may be defined as; "It is a measure of the ease with which water flows through soils and/or rocks. Soils which allow flow of water is called **permeable soils,** while those restrict its movement with ease are termed as **impermeable soils**.
5. **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.

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6. **Sandy soils:** Sandy Soil is light, warm, dry and tends to be acidic and low in nutrients. Sandy soils are often known as light soils due to their high proportion of sand and little clay (clay weighs more than sand). These soils have quick water drainage and are easy to work with.
7. **Waterlogged soils:** Waterlogging is the saturation of soil with water. Soil may be regarded as waterlogged when it is nearly saturated with water much of the time such that its air phase is restricted and anaerobic conditions prevail.

6.1. Occurrence

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. Major problematic soils of India are enlisted in Table 1.

Table 1: Major problematic soils of India

Sr. No.	Problematic Soils	Key Diagnosis	Major constraints
1.	Clay soils	Dominated by clay particles	Water logging, compaction, poor aeration, difficult to cultivate
2.	Sandy soils	Dominated by Coarse sand particles	poor fertility, low SOM, low water holding capacity, erosion
3.	Acid soils	Soil pH is less than 6.5	Fe, Al toxicity (Strong acid soil)
4.	Salt affected soils		

	a. Saline soils	ECe is greater than 4.0 dS/m	High osmotic potential, nutrient imbalance
	b. Sodic soils	ESP is greater than 15	Deteriorated physical condition, Na toxicity, nutrient imbalance
	c. Saline sodic soils	ECe is greater than 4.0 dS/m and ESP is greater than 15	High osmotic potential, deteriorated physical condition, nutrient imbalance
5.	Calcareous soils	$CaCO_3$ is greater than 5.0 %	P, Fe deficiency
6.	Water logged soils	Water Stagnation, Low infiltration rate	Poor aeration
7.	Degraded soils	Based on soil analysis	-
8.	Compacted soils	High bulk density	Poor aeration, poor root penetration, water logging
9.	Impermeable soils	Low hydraulic conductivity (HC) and infiltration rate	Poor aeration, water logging

6.2. 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

6.2.1 Physical problem soils

6.2.1.1 Slow permeable soils/Impermeable soils - The capillary porosity is high leading 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).

6.2.1.2 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.

6.2.1.3 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 called slowly permeable soils. Heavy soil 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.

6.2.1.4 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 tonnes (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.

6.2.2 Chemical Problem soils

6.2.2.1 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 extent and state wise distribution of salt affected soils is presented in table 2 and 3, respectively.

Saline soils: Saline soils is 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: Saline-alkali 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 are dominated by exchangeable sodium, the pH will be more than 8.5 and when soils are dominated by soluble salts, the pH will be less than 8.5.

Table 2 Extent of salt-affected soils in India ('000 ha)

S.No.	State	Saline soils	Sodic soils	Total
1	Gujarat	1680.570	541.430	2222.000
2	Uttar Pradesh	21.989	1346.971	1368.960
3	Maharashtra	184.089	422.670	606.759
4	West Bengal	441.272	0.000	441.272

5	Rajasthan	195.571	179.371	374.942
6	Tamil Nadu	13.231	354.784	368.015
7	Andhra Pradesh	77.598	196.609	274.207
8	Haryana	49.157	183.399	232.556
9	Bihar	47.301	105.852	153.153
10	Punjab	0.000	151.717	151.717
11	Karnataka	1.893	148.136	150.029
12	Orissa	147.138	0.000	147.138
13	Madhya Pradesh	0.000	139.720	139.720
14	Andaman & Nicobar Island	77.000	0.000	77.000
15	Kerala	20.000	0.000	20.000
Total		2956.809	3770.659	6727.468

Source: NRSA (National Remote Sensing Agency) Associates (1996) and adapted from Arora and Sharma (2017)

Table 3: State-wise share (%) of salt-affected soils in India

State	**Sodic soils**	**Saline soils**	**Costal saline soils**	**Total**
Gujarat	14.3	71.2	37.1	32.9
Uttar Pradesh	35.6	1.3	-	20.3
Maharashtra	11.2	10.4	0.6	9.0
West Bengal	-	-	35.4	6.5
Rajasthan	4.7	11.4	-	5.6
Tamil Nadu	9.4	-	1.1	5.5
Andhra Pradesh	5.2	-	6.2	4.1
Haryana	4.8	2.9	-	3.4
Bihar	2.8	2.8	-	2.3
Punjab	4.0	-	-	2.2
Karnataka	3.9	0.1	-	2.2
Orissa	-	-	11.8	2.2
Madhya Pradesh	3.7	-	-	1.1

Andaman & Nicobar Island	-	-	6.2	0.3
Kerala	-	-	1.6	0.3
J & K	0.5	-	-	
Total	**100 (3.78)**	**100 (1.71)**	**100 (1.25)**	**100 (6.74)**

Figures in parentheses indicate total area in million ha. Source: Adapted from Mandal et al. (2018).

6.2.2.2 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. State wise distribution of acid soils in India is presented in Table 4.

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.

6.2.2.3 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 as 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.

Table 4: State wise distribution of acid soils in India (Area in '000 ha)

S.No.	State	Strongly acidic (pH <4.5)	Moderately acidic (pH 4.5 - 5.5)	Slightly acidic (pH 5.5 - 6.5)	Total	TGA	% to TGA
1.	Andhra Pradesh	0.0	0.0	2827.5	2827.5	27504.5	10.3
2.	Arunachal Pradesh	4775.9	1742.7	268.8	6787.4	8374.3	81.1
3.	Assam	23.5	2331.2	2332.7	4687.5	7843.8	59.8
4.	Bihar	0.0	36.7	2324.9	2361.6	9416.3	25.1
5.	Chhattisgarh	156.4	5930.1	4386.6	10473.0	13480.5	77.7
6.	Goa	3.6	113.7	191.1	308.3	370.2	83.3
7.	Himachal Pradesh	0.0	157.0	1620.6	1777.6	5567.3	31.9
8.	Jammu & Kashmir	0.0	93.3	1480.1	1573.4	22223.6	7.1
9.	Jharkhand	0.0	999.6	5772.1	6771.7	7971.4	84.9

10.	Karnataka	0.0	61.4	3254.7	3316.1	19179.1	17.3
11.	Kerala	138.0	2789.6	753.2	3680.7	3886.3	94.7
12.	Madhya Pradesh	0.0	1124.7	10601.8	11726.5	30864.1	38.0
13.	Maharashtra	0.0	240.0	4332.6	4572.6	30771.3	14.9
14.	Manipur	426.9	1437.2	325.1	2189.2	2232.7	98.1
15.	Meghalaya	0.0	1186.3	1054.4	2240.7	2242.9	99.9
16.	Mizoram	0.0	1267.6	777.3	2044.9	2108.1	97.0
17.	Nagaland	118.9	1483.3	55.7	1657.9	1657.9	100.0
18.	Orissa	0.0	261.6	8409.7	8671.3	15570.7	55.7
19.	Sikkim	278.9	323.4	2.8	605.0	709.6	85.3
20.	Tamil Nadu	264.0	347.3	4294.5	4905.8	13005.8	37.7
21.	Tripura	56.6	749.0	237.2	1042.8	1048.6	99.5
22.	Uttar Pradesh	0.0	0.0	337.5	337.5	24104.6	1.4
23.	Uttarakhand	0.0	1183.6	2300.6	3484.2	5336.5	65.3
24.	West Bengal	0.0	555.6	4199.7	4755.3	8875.2	53.6
25.	Others*	0.0	0.0	0.0	0.0	64381	0.0
	Total	**6242.6**	**24414.6**	**62141.2**	**92798.4**	**328726.3**	**28.2**
	Area (%)	**1.9**	**7.4**	**18.9**	**28.2**	**100**	**-**

Others*: Delhi, Gujarat, Haryana, Punjab, Rajasthan, A & N Island, Chandigarh, D & N Haveli, Daman & Diu, Lakshadweep and Pondicherry. (Source: Maji et al., 2012)

6.2.2.4 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.

6.2.2.5 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. The 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.

6.2.3 Biological problems in soils

6.2.3.1 Soil organic carbon (SOC) and microbial population: Biological problems often result 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., humic acids, fulvic acids , 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.

6.2.3.2 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.

6.2.3.3 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.

6.2.4. Nutritional problem soils

In general, the most favourable pH range for crop 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.

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Course Name	Problematic soils and their Management
Lesson 7	Distribution of Problem soils under various Agro-ecological Regions of India
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Learning Objective

- *Understand the reasons of development of problem soils as a function of the agro-ecological setting and their management as per the land capability class*

Glossary of terms

1. **Agro-Ecological Regions (AER):** An agro-ecological region (AER) is the land unit on earth's surface, carved out of agro- climatic region by superimposing climate on landforms and soils, which are the modifiers of climate and length of growing period.
2. **Agro-climatic Region (ACR):** An "Agro-climatic zone" is a land unit in terms of major climates, suitable for a certain range of crops and cultivars. Agro-climatic conditions mainly refer to soil types, rainfall, temperature and water availability which influences the type of vegetations.
3. **Aridity Index (Ia):** An aridity index (Ia) is a numerical indicator of the degree of dryness of the climate at a given location.
4. **Bioclimate:** A climate or climatic zone considered or defined in relation to living organisms and their distribution.
5. **Evapotranspiration (ET):** Water Transpired by plants and evaporated from the surface of the soil or earth is known as evapotranspiration.
6. **Length of Growing Period (LGP):** The length of the "growing season" or "growing period" (LGS or LGP), as defined by the Agro-Ecological Zones, is the period (in days) during a year when precipitation exceeds half the potential evapotranspiration.

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

7. **Moisture Index (Im):** A term based on the computation of an annual moisture budget by C. W. Thornthwaite (1955), and calculated from the aridity and humidity indices, as Im = 100 × (S − D)/PE, where Im is the moisture index, S is the water surplus in months when precipitation exceeds evapotranspiration , D is the water deficit in months when evapotranspiration exceeds precipitation, and PE is the potential evaporation.
8. **Potential Evapotranspiration (PET):** Potential evapotranspiration (PET) is defined as the amount of evaporation that would occur if a sufficient water source were available. If the actual evapotranspiration is considered the net result of atmospheric demand for moisture from a surface and the ability of the surface to supply moisture, then PET is a measure of the demand side.

7.1 Concept

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. The climate and soil interactions provide suitable environment for agricultural production, thatalso affect physical processes of land degradation.

A proper understanding of potential and limitations of natural resources is necessary for sustainable agricultural development at local, regional, and country level. The farm output depends largely on the components like climate, soil and land forms. Therefore, for efficient crop planning in an area and transfer of technology, information concerning requirements of crops and kinds of soils, their extent, geographic condition and local agro-climatic conditions is essential.

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 (AER). 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.

An agro-climatic region is a land unit in terms of major climate and growth period which is climatically suitable for certain range of crops and cultivars, where as an agro-ecological region is characterized by distinct ecological responses to macroclimate as expressed in vegetation and reflected in soil fauna and aquatic systems.

Therefore, an agro-ecological region is the land on earth's surface carved out of agro-climatic region when superimposed on different landforms and soil conditions that acts as modifiers to the length of growing period (LGP) and crop environmental needs.

7.2 Concept of Bio-climate and Length of Growing Period (LGP)

7.2.1 Bio-climate

The climate of a particular region is determined by meteorological parameters like rainfall, temperature and potential evapo-transpiration (PET). For all practical purposes, the quantification of climatic parameters is done within one meter below the soil surface and few meters above the soil surface where biological life sustains. The bioclimatic profile consists of elements which describes the temperature and moisture condition in the study region. The various climatic and moisture balance indices used are Moisture Index (Im), Aridity Index (Ia), Humidity Index (Ih), Summer Concentration (Sc).

The water balance technique and PET values are being used to prepare a bio-climate map. It accounts for the monthly as well as annual water surplus (WS) and water deficits (WD) determining moisture Index (Im) in a particular ecosystem receiving specific amount of rainfall and humidity- specific Evapo-transpiration. Water deficit and water surplus are calculated from the potential and actual evapo-transpiration values (Figure 1)

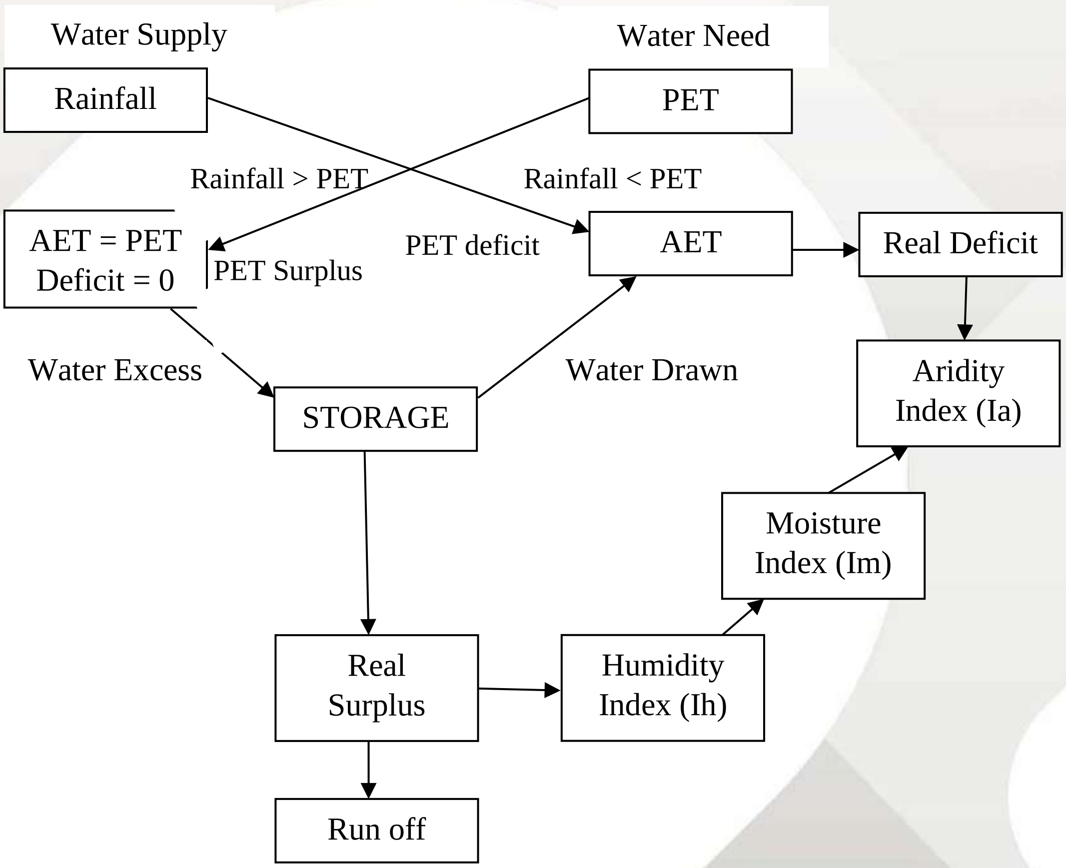


Figure 1: Concept of Water Balance

The moisture index with positive and negative values would indicate moist or dry climate and seasonal variation in effective moisture thermal efficiency is indicative of radiation energy received . The summer concentration represents the percentage of solar radiation in summer.

7.2.2 Length of the Growing Period (LGP)

The growing period or the moisture availability period of crop growth is the period (in days) when the precipitation (P) exceeds 50% of the (PET) plus the time required to evapo-transpire an assumed 100 mm of stored moisture from the deep soil profile. During a normal growing season, crop experiences a humid period (when P>PET), a moist period (when P>0.5 PET but <PET) and moderately dry to dry period (when P<0.5 PET).

Based on the values of P and PET of humid moist and moderately dry periods, the LGP in a year is determined. Moist period is the duration at the beginning of rainy season when most of the crop establishment operations are usually done. The humid period not only meets the full evapo-transpiration demand of crop, but also replenishes moisture deficit in the storage during the moderately dry to dry periods, the crop progressivel ... s drawing moisture from the storage in soil profile (Figure 2).

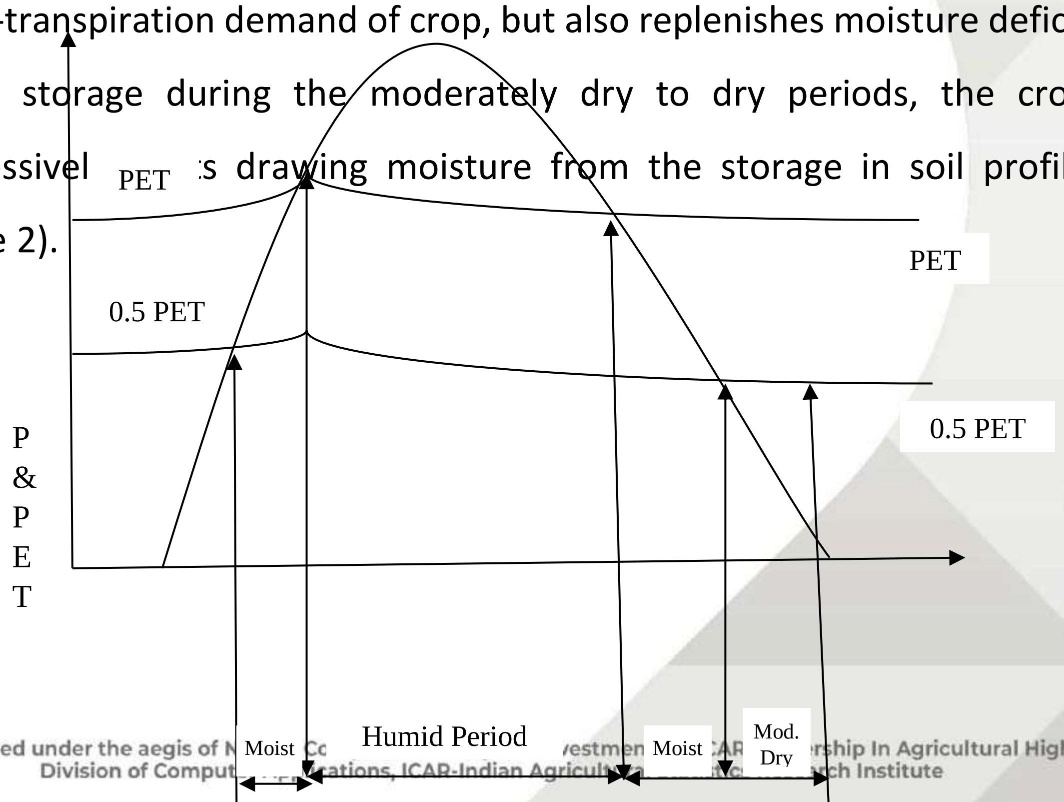


Figure 2: Concept of Growing Period

National Bureau of Soil Survey & Land Use Planning (NBSS&LUP) has delineated 20 agro-ecological regions (AER) in the country using the FAO concept by integrating maps depicting LGP, Bio-climate, and soil scape as per the following scheme (Figure 3).

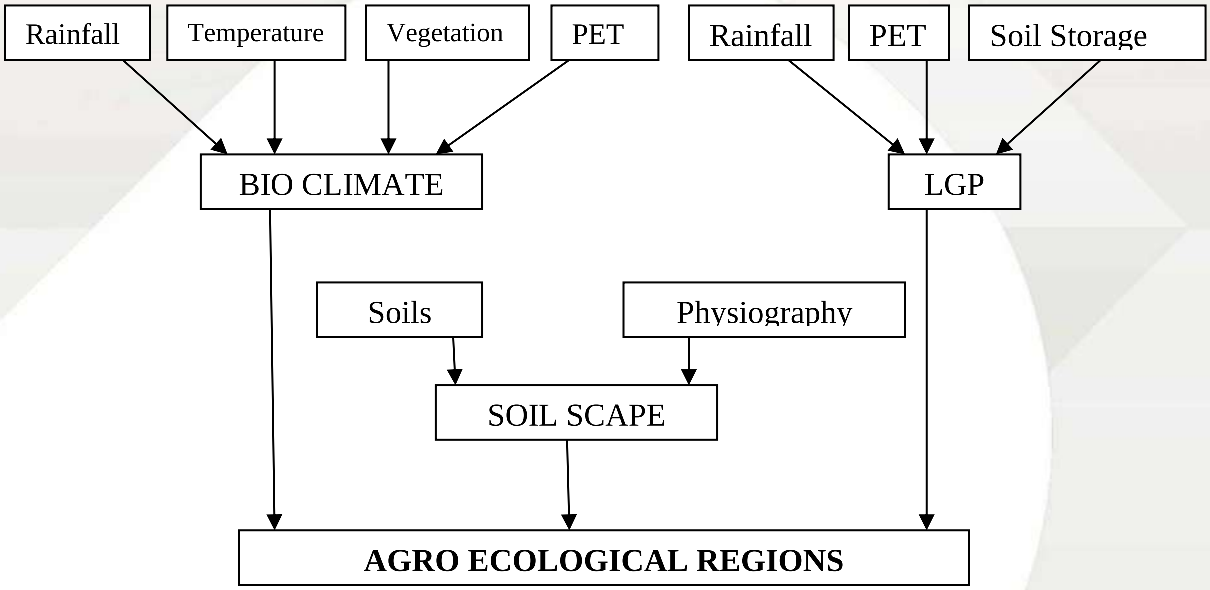
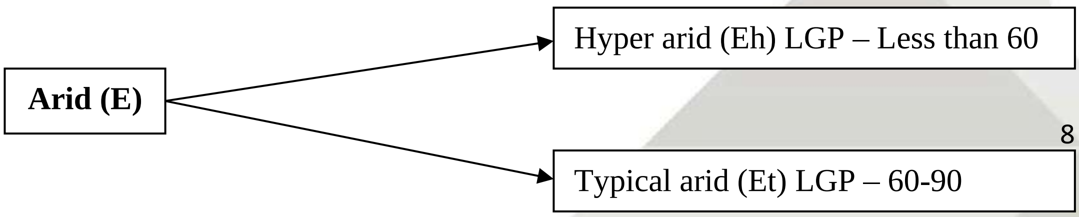


Figure 3: Delineation of Agro-ecological Regions

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.



7.3 The different Agro Ecological Region (AER) in India is as such:

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 sub Humid (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 Sub humid (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 1: 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**

Source: NBSSLUP, Wasteland Atlas (2011)

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 (Table 1) 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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Course Name	Problematic soils and their Management
Lesson 8	Saline Soils - Properties and its Impact in Agriculture
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Learning Objectives

- Learn about the electrical conductivity of soil suspension, its dependence on salt content of soils and the sources of soluble salts
- Understand the ecology of saline soils, the reasons for their development (natural and anthropogenic) and the constraints in agricultural production on these soils.

Glossary of terms

1. **Electrical conductivity (EC):** Electrical conductivity (EC) is a measure of the amount of salts in soil.
2. **Exchangeable Sodium Percentage (ESP)**: ESP corresponds to the amount of adsorbed sodium, compared to the CEC and is expressed as

   ESP = (Exchangeable Na/CEC) x 100

3. **Sodium Adsorption Ratio (SAR):** It is derived from the concentration of sodium, calcium and magnesium in the soil solution.

   $$\text{SAR} = \frac{\mathbf{Na^{+}}}{\sqrt{\mathbf{Ca^{2+}+Mg^{2+}}}}$$

4. **Soil Alkalinity:** A soil raising the pH reaction of 8.5 or above, found especially in dry areas, where the soluble salts, especially the sodium, have not been leached away but have accumulated in the B horizon of the soil profile.

5. **Soil Salinity:** Soil salinity is defined as high concentration of soluble salts including Na^{+}, Ca^{2+}, and Mg^{2+} in soils, causing more than 4 dS/m

for soil electrical conductivity, which is comparable to 0.2 MPa of Osmotic Potential produced by 40 mM sodium chloride (NaCl) in the solution.

8.1 Introduction

Soil salinity is a measure of the concentration of all the soluble salts in soil water, and is usually expressed as electrical conductivity (EC). The major soluble mineral salts are the cations: sodium, calcium, magnesium, potassium and the anions: chloride, sulphate, bicarbonate, carbonate and nitrate.

From the point of view of defining saline soils, when the electrical conductivity of a soil extract from a saturated paste (ECe) equals, or exceeds 4 deci Siemens per meter (dS m^{-1}) at 25 ^{0}C, the soil is said to be saline (USSL Staff 1954).

8.2 Occurrence in India

Around 6.727 million ha area in India, which is around 2.1% of geographical area of the country, is salt-affected (Figure 1), of which 2.956 million ha is saline (Figure 2) and rest 3.771 million ha is sodic. Around 2.347 million ha of the salt-affected soils occur in the Indo-Gangetic plains of the country, of which 0.56 million ha are saline and 1.787 million ha are sodic. Nearly 75% of salt-affected soils in the country exist in the states of Gujarat (2.23 million ha), Uttar Pradesh (1.37 million ha), Maharashtra (0.61 million ha), West Bengal (0.44 million ha), and Rajasthan (0.38 million ha).

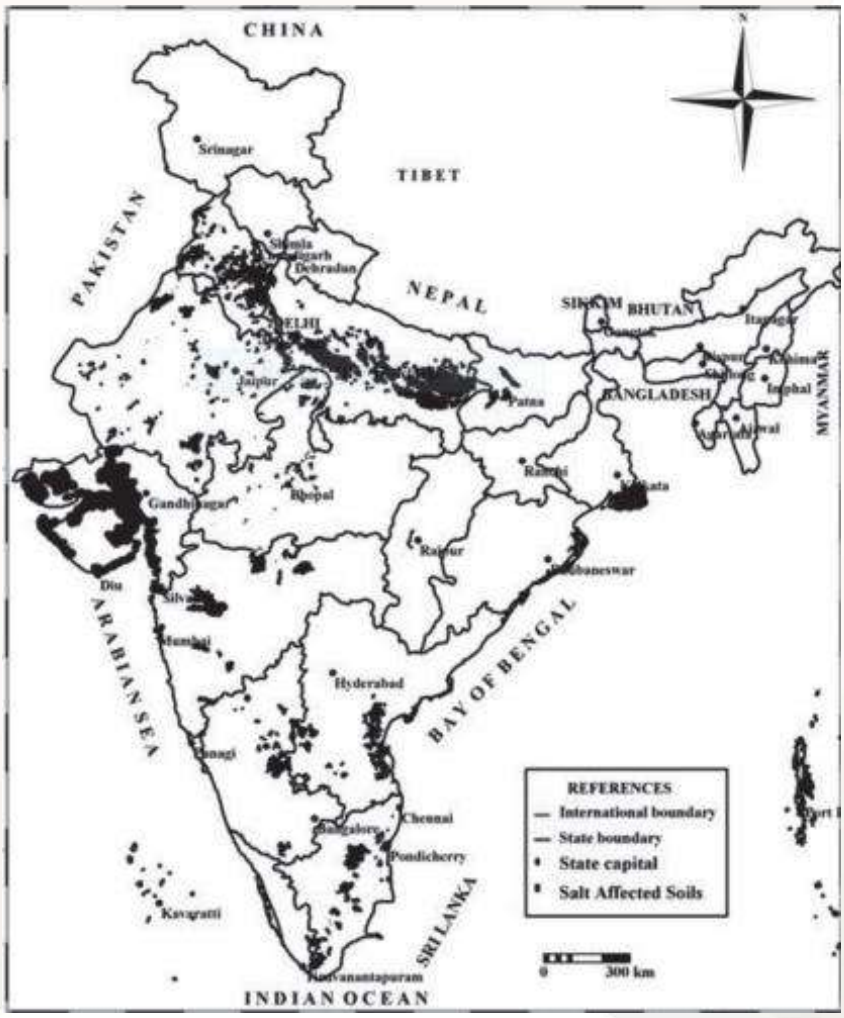

Figure 1 Distribution of salt affected soils in India (Das, 2002)

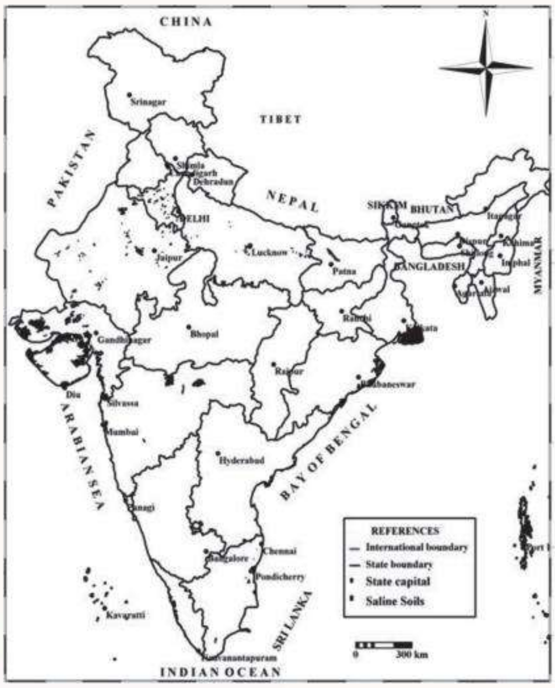

Figure 2 Distribution of saline soils in India (Das, 2002)

8.3. Salinity development in soil- A hypothetical cycle

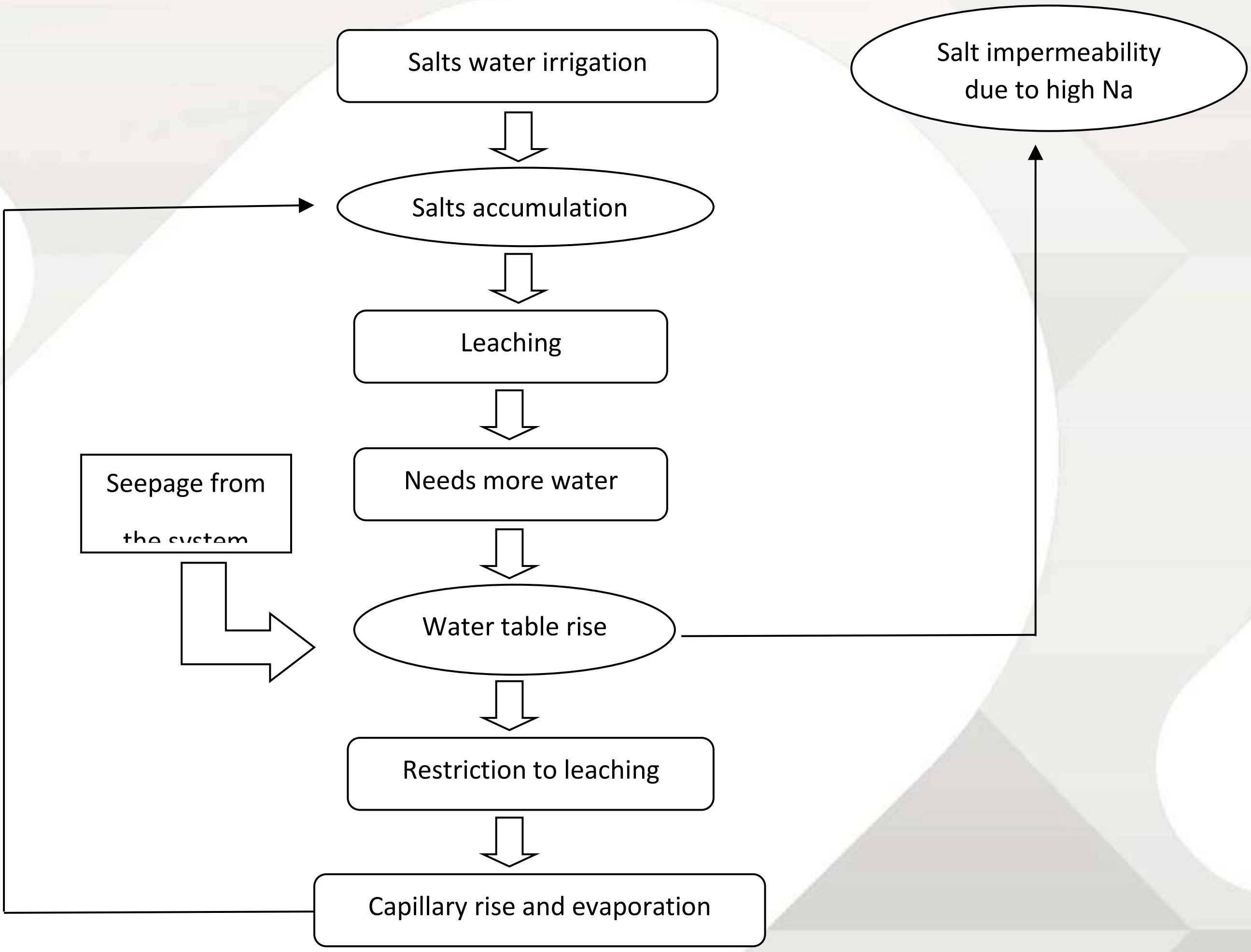

Figure 3 Hypothetical cycle for soil salinity development (Adapted from Zaman et al., 2018)

Generally, salt-affected soils of the arid regions belong to the order Aridisols. However, in some other regions, salt-affected soils have also been classified under the orders Alfisols, Mollisols, Inceptisols and Vertisols. The most common diagnostic horizon is ochric epipedon; sub surface horizon can be argillic, natric, cambic, calcic, gypsic and/or salic. Mica (illite) is the dominant clay mineral followed by kaolinite in the salt-affected soils of the Indo-Gangetic Plains. Other minerals present include chlorite, vermiculite, calcite, K-feldspars, sepiolite and anatase. Salt-affected black soils are rich in swelling and shrinking minerals, i.e. smectites. In addition to the dominance of montmorillonite, these soils also contain varying amounts of chlorite, illite and kaolinite minerals depending upon the type of geological formation and history of soil development (Figure 3).

8.4 Units of soil salinity

Salinity is generally expressed as total dissolved solutes (TDS) in milli gram per liter (mg l^{-1}) or parts per million (ppm). It can also be expressed as total soluble salts (TSS) in milli equivalents per liter (meq l^{-1}).

The salinity (EC) was originally measured as milli mhos per cm (mmho cm^{-1}), an old unit which is now obsolete. Soil Science has now adopted the SI a unit in which mho has been replaced by Siemens (S). Currently used SI units for EC are:

- milli Siemens per centimeter (mS cm^{-1}) or
- deci Siemens per meter (dS m^{-1})

The units can be presented as:

1mmho cm^{-1} = 1 dSm^{-1} = 1mS cm^{-1} = 1000 micro Siemens per cm (1000 µS cm^{-1})

- EC readings are usually taken and reported at a standard temperature of 25 ^{0}C.
- For accurate results, EC meter should be checked with 0.01 N solution of KCl, which should give reading of 1.413 dS m^{-1} at 25 ^{0}C.

8.5 Classification of salt affected soil

The US Salinity Laboratory Staff in 1954 grouped salt-affected soils into three general categories for management purposes (Table 1):

Table 1 Classification of salt affected soil

Salt-affected soil	Soil pH (pHs)	Electrical conductivity (ECe) (ds m^{-1})	Sodium adsorption ratio (SAR)	Exchangeable sodium percentage (ESP)	Typical soil physical condition (soil structure)
Saline	<8.5	>4	<13	<15	flocculated
Sodic	>8.5	<4	>13	>15	dispersed
Saline-sodic	>8.5	>4	>13	>15	flocculated

a. Saline soils (also called “white alkali” or “solonchak” soils): Soils containing calcium, magnesium, and sodium as predominant exchangeable cations (Ca and Mg more than Na), and sulfate, chloride, and nitrate the predominant anions; sodium adsorption ratio (SAR) <13; exchangeable sodium percentage (ESP) <15 of total CEC; pH <8.5; EC of saturation extract >4 dS m^{-1}; white colour due to white crust of salts on the surface; good permeability for water and air; salt problems in general; the salt concentration is enough to adversely affect the growth of most crop plants; mostly found in arid or semi-arid regions where less rainfall and high evaporation rates tend to concentrate the salts in soils; rarely found in humid regions.

b. Sodic soils (also called "non-saline sodic soils" or "alkali soils," or "solonetz"): Soils high in exchangeable sodium compared to calcium and magnesium; sodium carbonate and sodium bicarbonate are the predominant salts; SAR >13; ESP >15; pH = 8.5–10.0; EC of saturation extract < 4 dS m^{-1}; black colour; poor permeability for water and air; soils formed due to exchange of Ca^{2+} and Mg^{2+} ions by Na^{+} ions; generate problems with sodium.

c. Saline-sodic soils: These soils are transitional between saline and sodic soils; SAR >13, ESP >15, pH >8.5; EC of saturation extract >4 dS m^{-1}; air and water permeability depends on the sodium content; soils formed due to combined processes of salinization and alkalization; problems with sodium and other salts; leaching converts these soils into sodic soils.

The selection of the critical value for ECe 4 dS m^{-1} to distinguish a saline soil from non-saline soil is based on the expected salt damage to crops. At this level, the yield of many crops is restricted. At ECe values between 2 and 4 dS m^{-1}, the growth of only sensitive crops is affected. Below ECe value of 2 dS m^{-1}, the effect of salinity is negligibly small. Use of ESP value of 15 is arbitrary since no sharp changes in soil properties have been observed as the proportion of Na^{+} ions on the exchange complex is increased. The U.S. Salinity laboratory has used, from history and experience, the ESP value of 15 as a boundary limit to distinguish sodic from the non-sodic soils.

Based on Indian experience, saline and sodic soils are distinguished on the basis of preponderance of chlorides and sulphates over that of sodium. If $Na^+/(Cl^- + SO_4^{2-})$ ratio is less than 1 and pH of the saturated soil paste (pHs) is less than 8.2, the soil is designated as saline and if ratio of $Na^+/(Cl^- + SO_4^{2-})$ is more than 1.0 and pHs is more than 8.2, soil is defined as the sodic.

The two main groups of salt-affected soils, i.e., saline soils and sodic soils differ not only in their chemical characteristics but also in their geographical and geochemical distribution, as well as in their physical and biological properties. In nature the various sodium salts do not occur absolutely separately, but in most cases either the neutral salts or the ones capable of alkaline hydrolysis or both these processes exercise a dominant role on the soil-forming processes and therefore in determining whether the soil is saline, sodic or saline-sodic in nature (Table 2).

Table 2 Distinguishing features of saline and sodic soils

Characteristics	Saline soils	Sodic soils
1. Chemical	a) Dominated by neutral soluble salts consisting of chlorides and sulphates of sodium, calcium and magnesium.	a) Appreciable quantities of neutral soluble salts generally absent. Measurable to appreciable quantities of salts capable

	of alkaline hydrolysis, e.g. Na_2CO_3, present.
b) pH of saturated soil paste is less than 8.2.	b) pH of the saturated soil paste is more than 8.2.
c) An electrical conductivity of the saturated soil extract (ECe) of more than 4 dS m^{-1} at 25 °C is the generally accepted limit above which soils are classed as ‘saline’.	c) An exchangeable sodium percentage (ESP) of 15 or more is the generally accepted limit above which soils are classed as ‘sodic’. ECe is generally less than 4 dS m^{-1} at 25 °C but may be more if appreciable quantities of Na_2CO_3 etc. are present.
d) No well-defined relationship between pH of the saturated soil paste and ESP of the soil or the sodium adsorption ratio of the saturation extract (SARe).	d) A well-defined relationship between pHs and the ESP of the soil or the SARe for an otherwise similar group of soils such that the pH can serve as an approximate index of soil sodicity (alkali) status.
e) Although Na is generally the dominant soluble cation, the soil solution also contains appreciable quantities of divalent cations, e.g. Ca and Mg.	e) Sodium is the dominant soluble cation. High pH of the soils results in precipitation of soluble Ca and Mg such that their concentration in the soil solution becomes very low.
f) Soils may contain significant quantities of	f) Gypsum is nearly always absent in such soils.

	sparingly soluble calcium compounds, like gypsum.	
2. Physical	a) In the presence of excess neutral soluble salts, the clay fraction is flocculated and the soils have a stable structure. b) Permeability of soils to water and air and other physical characteristics are generally comparable to normal soils.	a) Excess exchangeable sodium and high pH result in the dispersion of clay and the soils have an unstable structure. b) Permeability of soils to water and air is restricted. Physical properties of the soils become worse with increasing levels of exchangeable sodium and pH.
3. Effect on plant growth	Plant growth is adversely affected through i) effect of excess salts on the osmotic pressure of soil solution resulting in reduced availability of water to plant roots and (ii) toxicity of specific ions, e.g. Na, Cl, B, etc.	Plant growth is adversely affected through: i) the dispersive effect of excess exchangeable sodium resulting in poor physical properties, ii) effect of high soil pH on nutritional imbalances including a deficiency of calcium and iii) toxicity of specific ions, e.g. Na, CO_3, HCO_3, Mo, etc.
4. Soil improvement	Improvement of saline soils essentially requires removal of soluble salts in the root zone through leaching and drainage. Application of	Improvement of sodic soils essentially requires the replacement of sodium in the soil exchange complex by calcium through use of soil amendments such as

	amendments is generally not required.	gypsum and leaching and drainage of salts resulting from reaction of amendments to reduce exchangeable sodium.
5. Geographic distribution	Saline soils generally occur in arid and semi-arid regions.	Sodic soils generally occur in semi-arid and sub-humid regions.
6. Ground water quality	Ground water in areas dominated by saline soils has generally high electrolyte concentration and poses a potential salinity hazard.	Groundwater in areas dominated by sodic soils has generally low to medium electrolyte concentration and some of it may have high residual alkalinity having a potential sodicity hazard.

(Choudhary and Kharche, 2018)

8.6 Sources of Salinity and Alkalinity

The main sources and causes of salt accumulation include:

- Geo-chemical weathering of rocks and parent materials and the salts brought down from the upstream to the plains by rivers and subsequent deposition along with alluvial materials
- Derived directly from sea water by flooding or intrusion into groundwater resources
- Salt-laden sand blown by sea winds

- Indiscriminate and injudicious use of irrigation waters of different qualities
- Capillary rise from subsoil salt beds or from shallow brackish ground water
- Lack of natural leaching due to topographic situation and economic activities in arid and semi-arid regions

The major constituents of dissolved salts in soil are the cations viz. sodium (Na^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}), and the anions viz. chloride (Cl^-), sulphate ($SO4^{2-}$), carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-). The salinity can be expressed as electrical conductivity (EC) of the irrigation water (ECw), the soil water (ECss) or the saturated soil extract (ECe). Sodicity is measured in the soil by exchangeable sodium percentage (ESP) and in soil solution by sodium adsorption ratio (SAR).

8.7 Soil salinization processes (Types of soil salinity)

On the basis of types of source, salinization is classified into two types:

8.7.1 Natural processes of soil salinization (i.e., primary salinization)

a. Weathering of parent material: During the process of weathering of rock minerals or sediments with high salt content (physically, chemically, and biologically), salts are released and made soluble. They are transported away from their source of origin through surface or groundwater streams. In arid regions, the concentration of salts gradually increases until they start precipitating in soil due to limited natural precipitation and leaching, high evaporation and transpiration rates. Low-lying areas with high groundwater table and locked topography favours salinization (Kumar and Sharma, 2020).

b. Fossil salts: The fossil salt deposits (e.g., marine and lacustrine deposits) are also responsible for salinization in arid regions. Fossil salts can be dissolved underwater storage or water transmission structures causing salinization (Bresler et al., 1982).

c. Salinization in coastal lands: The ingression of sea-water along the coast increases salt contents in coastal areas (Rao et al., 2014). The salt-laden winds and rains (sea sprays) along sea coasts carry oceanic salts along with them in quantities sufficient to cause salinization in coastal areas. The sea sprays may contain salt content as high as 14.2 µg m^{-3}, and may show impact as deep as 80 km inland or even more. The coastal regions are also exposed to the risk of progressive salinization of land due to processes like storms, cyclones, tidal surges, flooding etc.

d. Transport of salts in rivers: The salts brought down from the upstream by rivers to the plains and their deposition along with alluvial materials and weathering of rocks may also cause salinization.

8.7.2 Anthropogenic reasons of soil salinization (i.e., secondary salinization)

a. Land clearing for cultivation: Replacement of perennial vegetation with annual crops, may result into soil salinization due to saline seepage process. Change of land use from natural forest vegetation to annual food crops decreases evapotranspiration and increases leaching. The presence of impermeable/less permeable subsoil layers may intercept the percolating water passing through saline sediments resulting in lateral seepage, causing salinization in low lying areas.

b. Incorrect irrigation: Indiscriminate use of brackish and saline irrigation water, poor drainage conditions, rising water tables etc., lead to secondary salinization of land and water resources (Rao et al., 2014). Even irrigation with good quality water over a period of time in the absence of proper soil-water-crop management practices may cause salinization. Fall of civilizations like Mesopotamia, Nile Valley, Mohanzoadaro, and Indus Valley are glaring examples of imminent occurrence of salinity following irrigation (Dagar, 2005). Currently worldwide 310 million ha area is irrigated, out of which 20–33% area is estimated to be salt-affected. Irrigation with sea water causes salinization in coastal areas.

c. **Over extraction of groundwater:** It brings salts to soil surface where they get precipitated when water evaporates.

d. Canal water seepage: It is a serious problem leading to rise in water table and salinity development along the banks of canals. Water-logging and soil salinization in the Indira Gandhi Nahar Priyojna (IGNP) area in India is a glaring example of this process. Around 50% of the command area of IGNP has experienced water-logging (Tewari et al., 1997).

e. Over-use of agro-chemicals: Over-use of chemical fertilizers and soil amendments (lime and gypsum) may also lead to soil salinization.

f. Use of waste effluents: Use of sewage sludge and/or untreated sewage effluent, dumping of industrial brine onto the soil etc. may also cause soil salinization concerning to the entry of heavy metals into soils.

At several occasions the socio-economic and political considerations become extremely important in accelerating soil salinization processes. Many times, such factors are beyond the control of individual farmers. Some of such examples, especially in developing countries, may be the ill-conceived or poorly implemented irrigation schemes, intensive vs. extensive irrigation, over-irrigation due to zero water pricing, small and scattered land holdings etc. It is, therefore, the responsibility of respective governments to take appropriate policy decisions and corrective measures in order to keep a check on soil salinization.

8.8 Visual Indicators of Soil Salinity

Once soil salinity develops in irrigated agriculture fields, it is easy to see the effects on soil properties and plant growth. Visual indicators of soil salinization (Shahid and Rahman, 2011) include:

- White salt crusts
- Soil surface exhibits fluffy
- Salt stains on the dry soil surface
- Reduced or no seed germination
- Patchy crop establishment
- Reduced plant vigour

- Foliage damage – leaf burn
- Marked changes in leaf colour and shape occur
- The occurrence of naturally growing halophytes – indicator plants, increases
- Trees are either dead or dying
- Affected area worsens after a rainfall
- Waterlogging

8.9 Impact of Saline soil in Agriculture

The soil salinization has tremendous environmental, ecological, agricultural, and social impacts in terms of shrinkage of agricultural lands, low agricultural productivity, uncertain and unstable livelihood security, low economic returns, and poor quality of life.

Excess salts in soil affect the metabolism of soil flora and fauna, leading ultimately to the destruction of all soil life, transforming fertile and productive lands into barren and desert lands. Soils are rendered useless agriculturally as well as for several other purposes (e.g., construction work). The salt accumulation damages existing infrastructure, farm machinery, waterways, roads etc. History records that soil salinization were partly responsible for the collapse of ancient civilizations like Mesopotamia, Nile Valley, Mohanzoadaro, and Indus Valley (Dagar, 2005).

Salinity affects almost all aspects of plant development including germination, vegetative growth, and reproductive development due to drought and high soil salinity, and harsh environmental conditions. Plants in salt-affected environments experience two types of stress, the osmotic stress and nutrient stress. The osmotic stress is due to low osmotic potential of water in saline soils which adversely affects water absorption by plants. Nutrient stress is due to both toxicity (Na, Cl, B) and deficiency of plant nutrients (N, Ca, K, P, Fe, Zn). It also results in nutritional imbalances. Soil salinity significantly reduces phosphorus uptake by plants because phosphate ions precipitate with Ca ions. Gujarat and Uttar Pradesh have the largest salt-affected area (>50% of cultivated area) in the country. These two states alone share around 79% monetary losses in the country. All these states deserve policy attention for management of salt-affected areas to reduce the crop production and monetary loss. Peoples' living standard, daily life activities, and socio-economic conditions are adversely affected. Farmers in response to salinity problem are forced to shift their livelihood strategies. Farmers in salt affected areas are generally resource constrained and require financial and technical assistance to sustain their livelihood efforts. Such degraded ecosystems, nevertheless, offer immense opportunities to harness the productivity potential through appropriate technological interventions. Even marginal to modest gains in crop yields in such soils would mean dramatic improvements in the lives of thousands of poor farmers in salinity affected regions in a country facing many challenges in agriculture.

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Course Name	Problematic soils and their Management
Lesson 9	Reclamation and Management of Saline Soils
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Learning Objectives

- Recognize the constrained plant water relations, nature of salts, process for their removal from the root zone, crop selection and management interventions for sustainable agricultural production under saline conditions.
- Understand the soil water relations, nutrient relations, chemistry of saline soils and salinity parameters for characterization of saline soils.

Glossary of terms

1. **Bioremediation:** Bioremediation is a process used to treat contaminated media, including water, soil and subsurface material, by altering environmental conditions to stimulate growth of microorganisms and degrade the target pollutants.
2. **Drainage:** The removal of excess water either from the ground surface or from the root zone is called drainage. Excess water may be caused by rainfall or by using too much irrigation water, but may also have other origins such as canal seepage or floods.
3. **Leaching:** Means the loss of water-soluble plant nutrients from the soil; or applying a small amount of excess irrigation to avoid soil salinity.
4. **Gypsum Requirement (GR):** The quantity of gypsum or its equivalent required to reduce the exchangeable sodium fraction of a given amount of soil to an acceptable level where dispersion of soil colloids does not take place.

5. **Phytoremediation:** Phytoremediation is a bioremediation process that uses various types of plants to remove, transfer, stabilize, and/or destroy contaminants in the soil and groundwater.
6. **Soil Reclamation: Soil Reclamation** is the process of reclaiming the soil's quality like lost fertility, minerals, nutrients and moisture to make it fit for intensive use again. The reclamation of soil, its nutrients and fertility are done with an objective to increase further land use and enhance agricultural activities like cropping and irrigation.

9.1 Introduction

Saline lands can be converted to more productive croplands by preventing the influx of salt water through proper farm management practices, correcting soil toxicities and nutrient deficiencies, and leaching the salts out of the root zone. Leaching of soluble salts with ponded fresh water, sub-surface drainage, mulching between two irrigations and during fallow period, judicious irrigation management are some of the effective and well-known technological intervention to tackle the problems of water-logging and soil salinity (Arora and Sharma, 2017). The subsurface drainage technology has been successfully adopted in Haryana, Rajasthan, Gujarat, Punjab, Andhra Pradesh, Maharashtra, Madhya Pradesh, and Karnataka, restoring around 110,000 ha waterlogged saline soils (Sharma et al., 2014). The reclamation costs can be reduced by growing salt-tolerant cultivars. These practices are discussed below.

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9.2 Importance of reclamation of salt-affected soils and food security in India

It is estimated that due to soil salinization, India loses around Rs. 230.20 billion annually equivalent to the loss in crop production to the tune of 16.84 million tons (Mandal et al., 2018). The Indian Government, therefore, has attached highest priority to the policy planning for the reclamation of degraded lands, including salt affected soils in the country. The Indian Government is keen to restore 26 million ha of degraded lands by the year 2030 in order to ensure food security in the country. Significant research efforts have been made during the last 4 decades with encouraging results. The response of the farming community in salt-affected regions is overwhelming.

Sharma and Chaudhari (2012) reported reclamation of 1.5 million ha of salt-affected soils in the country, with addition of around 15 million tons of food grains to the national food basket annually. It provided additional income of around Rs. 13.5 billion per annum, and also generated 8.33 million man-days per year in terms of on-farm and off-farm rural employment opportunities. According to a recent publication of Mandal et al. (2018), around 2.18 million ha salt-affected soils (0.11 million ha saline soils and 2.07 million ha sodic soils) have been reclaimed in India. The reclamation has been achieved through gypsum technology in saline soils and sub-surface drainage technology in sodic soils. It has contributed an estimated 17.16 million tons of food-grains per annum (16.6 million tons from saline soils and 0.56 million tons from sodic soils) to the national food basket, with additional income of as high as Rs. 15.5 billion annually (Mandal et al., 2018).

The technological interventions on other aspects of salt affected soils such as alternate land-use systems, saline aquaculture, cultivation of salt tolerant crop varieties, agroforestry, phytoremediation, bioremediation etc. have proved their worth by positively influencing food and nutritional security, women empowerment, involvement of landless labourers and minimizing rural migration, besides restoration of the ecological balance by its positive impact on environment (Sharma and Chaudhari, 2012).

9.3 Various Reclamation Management techniques

a. Farm management practices

Salinity can be restricted by adopting the alternative farm management practices. Munns et al. (2002) proposed that irrigated agriculture could be sustained by better irrigation practices such as adoption of partial root zone drying methodology, and drip or micro-jet irrigation to optimize use of water. They suggested that, salinity could also be contained by reducing the amount of water passing beyond the roots by reintroducing deep rooted perennial plants that continue to grow and use water during the seasons that do not support annual crop plants. This may restore the balance between rainfall and water use, thus preventing rising water tables and the movement of salt to the soil surface. Deep-rooted perennial lucerne (Medicago sativa) has been found to lower the water table sufficiently to allow subsequent cropping. Such practices will rely on plants that have a high degree of salt tolerance. Salt tolerance in crops will also allow the more effective use of poor-quality irrigation water. Niknam and McComb (2000) suggested that trees could be planted to take up some of the excess salt since they have high water use and can lower water tables to reduce salt discharge into streams and prevent secondary salinization of the surrounding areas. However, it has not been proven to what extend the tree planting would assist in preventing salt stress in neighbouring fields.

b. Amelioration through fertilization

Salinity causes nutrient imbalances, mainly resulting in lower concentrations of the microelements (N, P, K and Ca) in plant tissues. Hence, the most direct way to recover the normal nutrient concentrations within the plant would be by raising their concentrations in the root zone on application of higher dosages of fertilizer. Many studies have shown that salt-stress can be alleviated by an increased supply of calcium to the growth medium. Depending on the concentration ratio, sodium and calcium can replace each other from the plasma membrane, and calcium might reduce salt toxicity. Increased Na^+ in the growth medium generally decreases the K^+ content, suggesting an antagonism between Na^+ and K^+. Addition of K^+ to the nutrient solution has been found to raise K^+ concentrations in the leaves and ameliorate salinity stress effects. The effect of salinity on P in plants depends on P concentration in the nutrient solution. At high P concentrations, leaf injury has been interpreted as P toxicity induced by salinity. However, at low P concentrations in the root medium, salinity was reported to inhibit P uptake by roots and translocation to the shoot. At low P concentration in the root medium, supplementary P applied to the saline growth medium enhanced the capacity of tomato plant to regulate Na^+, Cl^- and K^+ distribution, and improved plant growth. Under salt stress conditions, the uptake of N by plants is generally affected, and application of supplementary N has been found to ameliorate the deleterious effects of salinity. The approach of raising fertilizer dosages may work for irrigation with water at low salt concentrations. When water of high salinity is applied, however, the concentration of antagonistic ions required is so high that it causes a marked increase in the osmotic pressure of the soil solution, compounding the stress imposed by the salinity creating ions. Furthermore, in some species a very high concentration of nutrients, e.g. P, could interact negatively with salinity ions, resulting in severe toxic effects.

c. Leaching and Drainage

Leaching soils to remove soluble salts is the most effective method known to reclaim saline soils. This requires good permeability of the soil and good quality irrigation water. Removal of salts by leaching reduces salt hazard for plants but might cause permeability to decrease and pH to increase resulting in decomposition of roots as soil is changed from saline sodic to sodic. Although the best long-term solution to salinization is to provide adequate drainage, this process is expensive. Hence, many irrigation schemes, particularly in developing countries there is lacking of adequate drainage facilities. Provision of lateral and main drainage channels of 60 cm deep and 45 cm wide and leaching of salts could reclaim the soils. Sub-surface drainage is an effective tool for lowering the water table, removal of excess salts and prevention of secondary salinization of ions like chloride, sulphate, etc.

d. Uses of salt stress tolerant plants

Some areas have naturally occurring salinity and salt-tolerant crop plants may provide a better or perhaps the only means of utilizing these resources for food production. Salinity can possibly also be managed through biologically manipulating the plants. Identification of plant genotypes with tolerance to salt, and incorporation of desirable traits into economically useful crop plants, may reduce the effects of salinity on productivity (Table 1). Developing crop plants tolerant to salinity has the potential of making an important contribution to food production in many countries. This will permit the use of low-quality water and thereby reduce some of the demand for higher quality water. Great effort is, therefore, being directed toward the development of salt-tolerant crop genotypes through the use of plant-breeding strategies involving the introgression of the genetic background from salt-tolerant wild species into cultivated plants. However, it should be borne in mind that there is also the risk that the availability of salt tolerant genotypes will result in less effort to reclaim

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saline areas or to prevent salinization. In the longer term this will be counter-productive.

Table 1 Salt tolerant crop

Field crops		**Vegetables & Fruits**	
Plant species	**Threshold salinity (dSm^{-1})**	**Plant species**	**Threshold salinity (dSm^{-1})**
Barley	8.0	Sugarbeet	7.0
Cotton	7.7	Peas	3.4
Sorghum	6.8	Cucumber	2.5
Wheat	6.0	Tomato	2.5
Soybean	5.0	Cabbage	1.8
Sunflower	4.8	Potato	1.7
Groundnut	3.2	Onion, Radish	1.2
Rice	3.0	Carrot	1.0
Maize	1.7	Citrus	1.7
Sugarcane	1.7	Strawberry	1.0

e. Soil/cultural management

Planting the seed in the centre of the raised bed/ridge may affect the germination as it is the spot of greatest salt accumulation. A better salinity control can be achieved by using sloping beds with seeds planted on the sloping side just above the water line. Alternate furrow irrigation is advantageous as the salts can be displaced beyond the single seed row.

Application of straw mulch had been found to curtail the evaporation from soil surface resulting in the reduced salt concentration in the root zone profile within 30 days.

f. Irrigation management

Proportional mixing of good quality (if available) water with saline water and then using for irrigation reduces the effect of salinity. Alternate furrow irrigation favours growth of plant than flooding. Drip, sprinkler and pitcher irrigation have been found to be more efficient than the conventional flood irrigation method since relatively lesser amount of water is used under these improved methods.

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Course Name	Problematic soils and their Management
Lesson 10	Sodic Soils - Properties, Management & Reclamation
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University/College Name	Bihar Agricultural University, Bhagalpur
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Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
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Learning Objectives

- Understand the dispersive action and constrained infiltration profile with sodium salts, practices for improvement and sustained production from sodic soils
- Understand the concept of irrigation water quality, chemistry of sodic soils and parameters for characterization of soil sodicity

Glossary of terms

1. **Flushing:** Washing away the surface accumulated salts by flushing water over the surface is sometimes used to desalinize soils having surface salt crusts.
2. **Leaching requirement (LR):** It can be defined as "Fraction of irrigation water that must be leached through root zone to control soil salinity at any specific level."
3. **Phytoaccumulation:** Process by which plants remove excess salts from soil through root absorption and accumulate them in their biomass. Also termed as phyto-extraction
4. **Salt Balance:** A salt mass balance considers the amount of water plus salt entering a system and the amount of water plus salt leaving. When inputs and outputs are in balance, the system is said to be in equilibrium.
5. **Scraping:** Removing of the salts that have accumulated on the soil surface by mechanical means.
6. **Sodicity**: Soil sodicity is the accumulation of sodium salt relative to other types of salt cations, especially calcium. An increase in soil

pH and decreases in calcium and magnesium usually accompany this process.

7. **Surface Sealing:** Surface seal is defined as the orientation and packing of dispersed soil particles which have disintegrated from the soil aggregates due to the impact of rain drops. By definition, surface seals are formed at the very surface of the soil, rendering it relatively impermeable to water.
8. **Trenching:** It is the process of digging small pits on the field and taking the sub soil on the surface and vice versa in order to bury the saline soils.

10.1 Introduction

Sodicity is a measure of sodium ions in soil water, relative to calcium and magnesium ions. It is expressed either as sodium adsorption ratio (SAR) or as the exchangeable sodium percentage (ESP). If the SAR of the soil equals or is greater than 13 (mmoles $l^{-1})^{0.5}$, or the ESP equals or is greater than 15, the soil is termed sodic (USSL Staff 1954). Sodic soils (also called "non-saline sodic soils" or "alkali soils," or "solonetz") are high in exchangeable sodium compared to calcium and magnesium; sodium carbonate and sodium bicarbonate are the predominant salts; SAR >13; ESP >15; pH = 8.5–10.0; EC of saturation extract < 4 dS m^{-1}; black color; poor permeability for water and air; soils formed due to exchange of Ca^{2+} and Mg^{2+} ions by Na^{+} ions; sodium problems.

10.2 Visual Indicators of Soil Sodicity

Soil sodicity can be predicted visually in the field in the following ways

- Poorer vegetative growth than normal, with only a few plants surviving, or with many stunted plants or trees
- Variable heights of the plants
- Poor penetration of rain water – surface ponding
- Raindrop splash action – surface sealing and crusting (hard setting)
- Cloudy or turbid water in puddles
- Plants exhibit a shallow rooting depth
- Soil is often black in color due to the formation of a Na-humic substances complex
- High force is required for tillage (especially in fine textured soils)
- Difficult to get soil saturation extracts in laboratory due to a filter blockage with dispersed clay

10.3 Field Testing of Soil Sodicity

Field assessment of relative level of soil sodicity can be determined through the use of a turbidity test on soil: water (1:5) suspensions, with ratings:

- Clear suspension – non sodic
- Partly turbid or cloudy – medium sodicity
- Very turbid cloudy – high sodicity

The relative sodicity can be further assessed by placing a white plastic spoon in these suspensions, as below.

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- The spoon is clearly visible means non-sodic
- The spoon is partly visible means medium sodicity
- The spoon is not visible means high sodicity

10.4 Laboratory Assessment of Soil Sodicity

Accurate soil sodicity diagnostics can be made by analyzing soil samples in the laboratory. The standard presentation of soil sodicity is the exchangeable sodium percentage (ESP) derived from sodium adsorption ratio (SAR). Alternately, ESP can be determined through measurement of exchangeable sodium (ES) and cation exchange capacity (CEC), as below:

ESP = (ES/CEC) X 100

Where, ES and CEC are represented as meq100 g^{-1}soil. An ESP of 15 is the threshold for designating soil as being sodic (USSL Staff 1954). At this ESP level, the soil structure starts degrading and negative effects on plant growth appear.

10.5 Sodicity and Soil Structure

A lack of sufficient volumes of fresh water for irrigation use in arid and semi-arid regions often results in the need to use water with a relatively high salinity and high sodium ion levels. It has, generally, been recognized that the sodicity affects soil permeability appreciably. The swelling and dispersion of soil clays ultimately destroy the original soil structure – likely the most important physical property affecting plant growth. The soil bulk density (the weight of soil in a given volume) and porosity (open spaces

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between sand, silt and clay particles in a soil) are mainly used as parameters for the soil structure. The hydraulic conductivity (the ease with which water can move through the soil pore spaces) is the net result of the effect of physical properties in the soil and is markedly affected by soil structure development.

The effect of the sodicity of soil water on irrigated soils can be both a surface and subsurface phenomenon, causing surface sealing, as well as subsurface sealing respectively. In surface sealing, the soil water sodicity causes a breakdown and slaking of soil aggregates due to wetting. When the soil surface dries, a surface crust is formed. In subsurface sealing, the clay particles in the soil are dispersed and translocated to subsurface layers, where they are deposited on the surface of the voids, thereby reducing void volume and blocking the pores, thus restricting further water movement, e.g. yielding non-conducting pores. The surface sealing and crusting due to either water sodicity, or through combined effects of sodicity and raindrop splash action, have both positive and negative effects.

10.5.1 Negative Effects of Surface Sealing

- Increased runoff particularly on slopes leading to sheet and rill erosions
- Mechanical impedance of plant seedling emergence
- Lack of aeration just below the sealed structure
- Retardation of root development

- Increased mechanical force needed for tillage (cultivation) operations

10.5.2 Positive Effects of Surface Sealing

- Protection against wind erosion
- More economic distribution of irrigation water since longer furrows are possible
- Protection against excessive water losses from the subsoil

10.6 Sodic soil in relation to plant growth

The enhanced Na^+ absorption in sodic soils reduces K^+ absorption which adversely affects the enzymatic activities involved in metabolic processes like photosynthesis and protein synthesis, which is detrimental for plant growth. Reduced leaf area, chlorophyll content and stomatal conductance in salt-affected soils also affect photosynthesis. Apart from high ESP and nutrient deficiencies and toxicities, other constraints for plant growth in sodic soils include poor soil physical conditions, viz. low water and air permeability, high runoff, low water holding capacity, surface crusting, and hard setting and thus affecting plant root penetration, seedling emergence, and tillage operations.

10.7 Management and Reclamation

10.7.1 Mechanical/physical method: This is not actually removing sodium from exchange complex but improve physical condition of soil through improvement in infiltration and aeration. The commonly followed physical methods include;

a. Scraping of the salts – If the white salt concentrations are visible then they must be removed at once from the field with the help of domestic tools like khurpi.

b. Trenching – It is the process of digging small pits on the field and taking the sub soil on the surface and vice versa in order to bury the saline soils. Also, deep ploughing is adopted to break the hard pan developed at subsurface due to sodium and improving free-movement of water. This also helps in improvement of aeration.

c. Flooding and flushing of salts – Saline soils are first flooded with high-quality water (water which is free from salts) and after the water now containing the dissolved salts are flushed through drainage channels. This process reduces the concentration of salts at the surface layer and if repeated, gives better results. Scofield (1940) evolved a term salt balance which relates the quantity of dissolved salts carried into an area in irrigation water to the quantity of dissolved salts removed by drainage water. If salt input exceeds the salts output then salt balance is regulated as adverse. Drainage is also practiced to improve aeration and to remove further accumulation of salts at root zone.

d. Leaching of salts – Leaching means the removal of salts below the solum of the soil. Leaching of soluble salts from root zone is essential in irrigated soils. When there is no leaching then salt accumulation will occur

Concentration of salt in soil solution results due to water evaporation and transpiration. Depth of irrigation water (Diw) can be calculated which will create the salinity.

Leaching requirement (LR) – LR has been defined as that fraction of water that must be leached through the root zone to control soil salinity at a specified level. It depends on:

(i) Salt concentration of irrigation water.

(ii) Permissible limit of salt at root zone.

LR % (Leaching Requirement) = (EC_{iw}/EC_{dw})X 100

Here, EC_{iw}= EC of irrigation water in inches

EC_{dw} = EC of drainage water

e. Drainage –Salinity control depends upon the drainability of soil. The LR is only possible when required amount of water is passed through root zone. This may be improved by:

i) Improving drainage outlet facilities
ii) Improving soil permeability

f. Other measures are –

i) To check surface evaporation.
ii) To reduce water table.
iii) To break the hard layers and pans of calcium carbonate, clay soil etc.
iv) To use salt free water with short intervals of irrigation.

v) To provide better drainage conditions

vi) To grow crops which are salt resistant

10.7.2 Chemical methods: The technology package based on chemical amendments consists of the components such as land levelling, bunding, flushing, drainage for removal of excess water, good quality irrigation water, application of amendments, selection of crops and efficient nutrient management. Different chemical amendments used for the reclamation of sodic soils may be grouped into two categories: soluble calcium sources (e.g., gypsum, calcium chloride, and phospho-gypsum) and acids or acid formers (e.g., elemental sulfur, sulphuric acid, sulfates of iron and aluminium, pyrites and lime sulfur). Farmyard manure and pressmud are also used as amendments for reclaiming sodic soils. Chemical amendments require moisture (rainfall or irrigation) to activate the chemical processes that can reduce sodium levels or leach salts from the root zone. The organic amendments, on the other hand, are capable of alleviating problems associated with excessive salts or sodium without supplemental irrigation.

The amount and type of chemical amendments required for reclamation of sodic soils depend primarily on soil pH, EC, and ESP. Soluble calcium sources are recommended for use in non-calcareous soils while for calcareous soils, acids or acid-formers are recommended. Gypsum followed by pyrites has emerged as the most preferred and acceptable chemical amendment for sodic soils in India due to their easy availability and low. Pyrite was much less effective than gypsum. The pyrites to be effective for reclamation must contain at least 5–6% soluble S.

Gypsum requirement (GR) for restoring an alkali soil depends on the initial exchangeable sodium percentage (ESP), texture and mineralogy of soil, depth of soil to be reclaimed and tolerance of crops to sodicity. A good correlation exists between soil pH and gypsum requirement. Generally, 10–15 Mg ha^{-1} gypsum is required for the reclamation of alkali soils. The quantity of gypsum required to replace an initial level of exchangeable sodium (E_{Nai}) 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

Where, E_{Na} and CEC are in cmol(p^+) kg^{-1} soil

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

GR (kg/ha) = $1720 \times (E_{Nai}-E_{Naf})$ 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 addition of organic materials in conjunction with gypsum hastens the reclamation process and also reduces the gypsum requirement. Addition of organic material increases soil microbial biomass, while gypsum lowers soil pH. Industrial by-products such as phosphogypsum, pressmud, molasses, acid wash, and effluents from milk plants help in the reclamation of sodic soils by providing Ca directly or indirectly by dissolving soil lime. The equivalent amounts of other amendments relative to gypsum are given in **Table 1**.

Table 1 Equivalent quantity of some common amendments for sodic soil reclamation

Amendment	Relative quantity
Gypsum($CaSO_4.2H_2O$)	1.0
Calcium chloride($CaCl_2.2H_2O$)	0.85
Sulphuric acid(H_2SO_4)	0.57
Iron sulphate($FeSO_4.7H_2O$)	1.62
Aluminium sulphate [$Al_2(SO_4)_3.18H_2O$]	1.29
Sulphur (S*)	0.19
Pyrite (FeS_2*) (30% S)	0.63
Pressmud (Lime sulphur, 9% Ca, 24% S)	0.77

*Based on assumption of 100% oxidation of materials like sulphur or pyrite in order to be as effective as soluble calcium compounds. Since in practice this assumption is not fulfilled, their effectiveness is much lower than gypsum.

Source: Choudhary and Kharche (2018)

Chemical reaction of gypsum and other amendments:

a. Sodic soils containing lime

(i) Gypsum:

$2Na[X] + CaSO_4 \rightleftarrows Ca[X] + Na_2SO_4$

Where: [X] = Soil colloids

(ii) Sulphur:

$2S + 3O_2 \rightleftarrows 2SO_3$

$SO_3 + H_2O \rightleftarrows H_2SO_4$

$H_2SO_4 + CaCO_3 \rightleftarrows CaSO_4 + CO_2 + H_2O$

$2Na[X] + CaSO_4 \rightleftarrows Ca[X] + Na_2SO_4$

(iii) Sulphuric acid:

$H_2SO_4 + CaCO_3 \rightleftarrows CaSO_4 + CO_2 + H_2O$

$2Na[X] + CaSO_4 \rightleftarrows Ca[X] + Na_2SO_4$

(iv) Lime sulphur (Calcium polysulphide):

$CaS_5 + 8O_2 + 4H_2O \rightleftarrows CaSO_4 + 4H_2SO_4$

$H_2SO_4 + CaCO_3 \rightleftarrows CaSO_4 + CO_2 + H_2O$

$2Na[X] + CaSO_4 \rightleftarrows Ca[X] + Na_2SO_4$

(v) Iron sulphate:

$FeSO_4 + H_2O \rightleftharpoons H_2SO_4 + FeO$

$H_2SO_4 + CaCO_3 \rightleftharpoons CaSO_4 + H_2O + CO_2$

$2Na[X] + CaSO_4 \rightleftharpoons Ca[X] + Na_2SO_4$

(vi) Aluminium sulphate:

$Al_2(SO_4)_3 + 3H_2O \rightleftharpoons 3H_2SO_4 + Al_2O_3$

$H_2SO_4 + CaCO_3 \rightleftharpoons CaSO_4 + H_2O + CO_2$

$2Na[X] + CaSO_4 \rightleftharpoons Ca[X] + Na_2SO_4$

b. Sodic soils containing no lime

(i) Gypsum: Same as type 1

(ii) Sulphur:

$2S + 3O_2 \rightleftharpoons 2SO_3$

$SO_3 + H_2O \rightleftharpoons H_2SO_4$

$2Na[X] + CaSO_4 \rightleftharpoons Ca[X] + Na_2SO_4$

(iii) Lime sulphur:

$CaS_5 + 8O_2 + 4H_2O \rightleftharpoons CaSO_4 + 4H_2SO_4$

$2Na[X] + CaSO_4 \rightleftharpoons Ca[X] + Na_2SO_4$

(iv) Iron sulphate:

$FeSO_4 + H_2O \rightleftharpoons H_2SO_4 + FeO$

$2Na[X] + CaSO_4 \rightleftharpoons Ca[X] + Na_2SO_4$

10.7.3 Phytoremediation of Salt-Affected Soils

Phytoremediation of salt-affected soils refers to the processes of removing excess salts from soil by growing different type of plants. Growing of salt tolerant trees, shrubs, and grasses is a cost-effective and environmental-friendly way of restoring salt affected soils. Different species of salt tolerant trees, shrubs, and grasses have been identified and put to use (Table 2). Plants remove excess salts from soil through root absorption and accumulate them in their biomass, a process called phytoaccumulation or phyto-extraction. It decreases exchangeable sodium and soluble salt concentrations in soil. They also augment soil organic carbon and nutrient content thereby gradually improving physical (bulk density, porosity, infiltration, water holding capacity etc.), chemical (nutrient concentrations), and biological (microbial population) properties of soils and overall soil productivity.

Table 2 Soil ECe and SAR reduction through phytoremediation and chemical amendments using different plants ($_i$ initial, $_f$final).

Amendment/plant species	ECe_i (dSm^{-1})	ECe_f (dSm^{-1})	ECe reduction (%)	SAR_i	SAR_f	SAR reduction (%)	Remarks
Sesbania aculeata	7.5	5.5	27	55.6	43.5	22	

Leptochloa fusca	7.4	5.3	28	57.9	44.7	23	1^{st} year
Sorghum bicolor	7.8	6.4	18	62.3	55.1	12	
Gypsum	9.0	7.2	20	73.0	53.3	27	
Sesbania aculeate	5.5	4.4	20	43.5	30.1	31	2^{nd} year
Leptochloa fusca	5.3	4.9	8	44.7	32.5	27	
Sorghum bicolor	6.4	6.0	6	55.1	40.0	27	
Gypsum	7.2	6.8	6	53.3	24.7	54	

Source: Qadir et al. (1997)

10.7.4 Bio-Remediation

The bio-remediation approach, which involves plant-microbial interaction, has received increased attention worldwide for enhancing productivity of salt-affected soils. The microorganisms have the capability of rapid adjustment toward environmental changes and deterioration, and thus can play an important role in the maintenance and sustainability of any ecosystem. Microorganisms possess some unique properties such as salt stress tolerance, genetic diversity, synthesis of compatible solutes, production of plant growth promoting hormones, bio-control potential, and their interaction with crop plants. If these traits are suitably exploited, microorganisms can play a significant role in alleviating salt -effects on crop plants.

A low-cost microbial bio-formulation "CSR-BIO," a consortium of Bacillus pumilus, Bacillus thuringenesis, and Trichoderma harzianum, is rapidly becoming popular with the farmers in many states. This bio-formulation acts as a soil conditioner and nutrient mobilizer and has been found to increase the productivity of the high value crops such as banana, vegetables, and gladiolus in sodic and normal soils by 22–43%.

10.7.5 Cultivation of salt tolerant crops and crop varieties

Cultivation of salt tolerant crops and crop varieties is another way to address the problem of soil salinization. This technique is viable and cost effective and suits well to the small and marginal farmers who without financial support are unable to bear the high costs of chemical amendment-based reclamation technologies. Salt tolerant varieties of rice, wheat, mustard, and other crops, grasses, shrubs, fruit trees, and medicinal and aromatic plants have been developed/identified for commercial cultivation in salt-affected soils. The relative tolerance of some crops to total sodicity (ESP) is shown in Table 3.

Table 3 Relative tolerance of some crops to soil sodicity (ESP)

Tolerant (ESP= 35-50)	Moderately tolerant (ESP= 35-50)	Sensitive (ESP<15)
Karnal grass	Wheat	Gram/Chickpea
Rhodes grass	Barley	Mash
Para grass	Oat	Lentil
Bermuda grass	Shaftal	Soyabean
Dhaincha	Lucerne	Groundnut
Sugarbeet	Turnip	Sesamum
Teosinte	Sunflower	Mung
	Safflower	Pea
	Berseem	Cowpea
	Linseed	Maize
	Onion	Cotton
	Garlic	
	Pearl millet	

Source: Abrol and Bhumbla (1979)

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Course Name	Problematic soils and their Management
Lesson 11	Acid Soils - Properties, Types of acidity and its Impact
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Learning Objective

- Learn about pH of soil water suspension, sources of soil acidity and nutrient relations under acid soil conditions.

Glossary of terms

1. **Acid soils:** Acid soils, by definition, are those with pH below 7.0. The lower the pH, the more acid is the soil.
2. **Acid Rain:** Acid rain, or acid deposition, is a broad term that includes any form of precipitation with acidic components, such as sulphuric or nitric acid that fall to the ground from the atmosphere in wet or dry forms. This can include rain, snow, fog, hail or even dust that is acidic
3. **Active acidity:** Active acidity is the quantity of hydrogen ions that are present in the soil water solution. The active pool of hydrogen ions is in equilibrium with the exchangeable hydrogen ions that are held on the soil's cation exchange complex.
4. **Cation Exchange Capacity (CEC):** Cation Exchange Capacity (CEC) is the total capacity ofa soil to hold exchangeable cations. CEC is an inherent soil characteristic and is difficult to alter significantly. It influences the soil's ability to hold onto essential nutrients and provides a buffer against soil acidification.
5. **Exchangeable acidity:** Exchangeable acidity refers to the amount of acid cations, aluminium and hydrogen, occupied on the CEC. When the CEC of a soil is high but has a low base saturation, the soil

becomes more resistant to pH changes. As a result, it will require larger additions of lime to neutralize the acidity.

6. **Potential acidity/Reserve acidity:** Potential acidity is often referred to as the soil's buffer capacity or resistance to change in pH.

11.1 Occurrence

Acid soils occupy approximately 30% of the world's ice free land area and occur mainly in two global belts where they have developed under udic or ustic moisture regimes. The northern belt (cold and temperate climate) is dominated by Spodosols, Alfisols, Inceptisols and Histosols and the southern tropical belt consists largely of Ultisols and Oxisols.

Out of 328 million hectares of geographical area of India, nearly 145 million hectares is cultivated and a rough estimate indicate that 48 million hectare of soil is acidic out of which 25 million hectare of soil shows pH < 5.5 and are critically degraded acid lands with low productivity (Sharma and Sarkar, 2005) as shown in the map (Figure 1). In all those tracts of the country where rainfall and temperature are high, acid soils are predominantly found. The North-eastern region has the largest stretches of acid soils, followed by neighbouring states of West Bengal, Bihar and Orissa. In the coastal region of Kerala, not only high rainfall and temperature have contributed to the development of acid soils but rich organic deposits resulting information of peat and muck have also been found responsible for the extension of acid soil area in the state. Parts of Tamil Nadu, Andhra Pradesh, Karnataka, Madhya Pradesh, Uttar Pradesh, Bihar, Himachal Pradesh and Jammu & Kashmir also have acid soils.

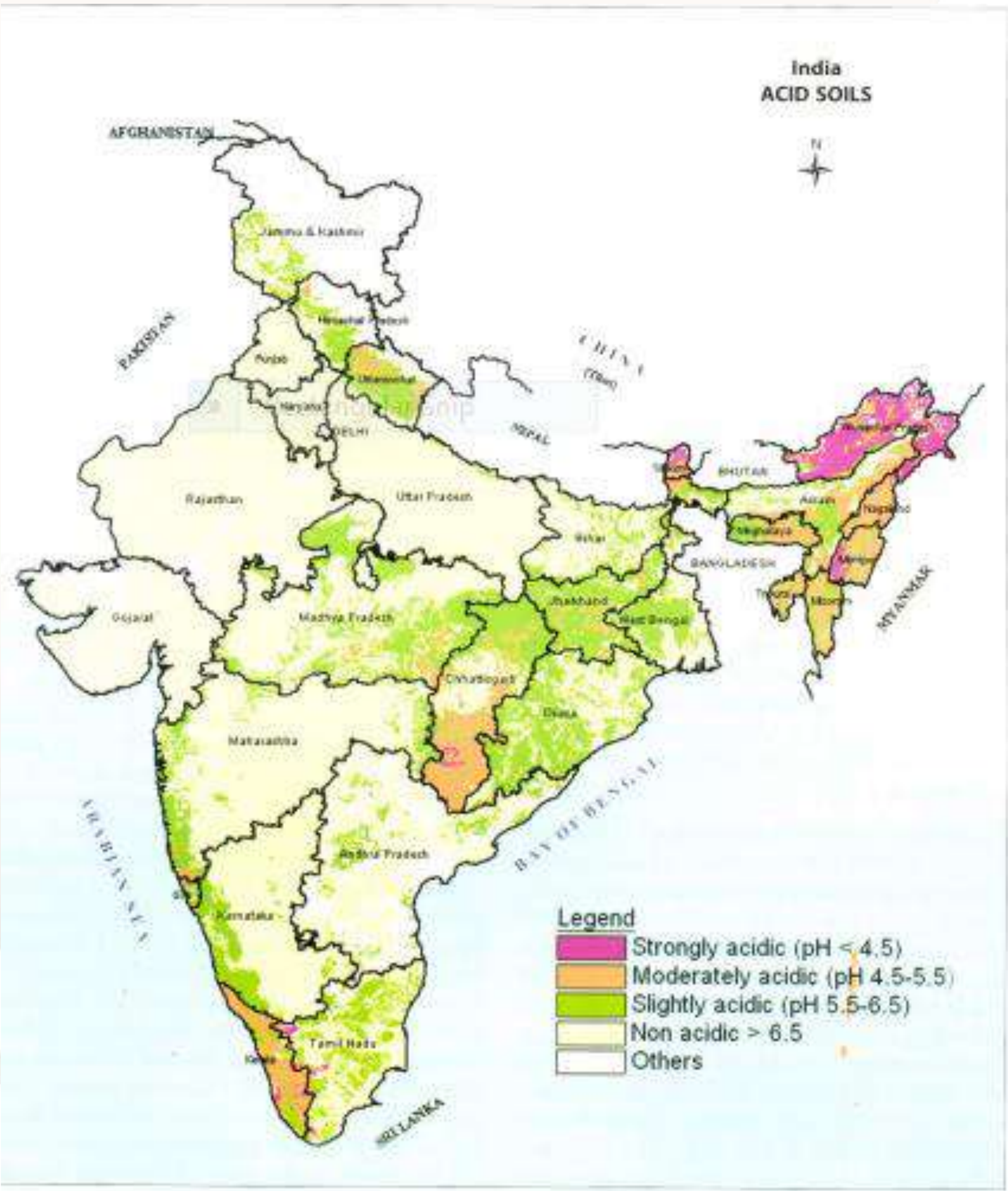

Figure 1 Distribution of Acid soil in India Source: Maji et al. (2012)

11.2 Genesis and Chemistry of Acid Soils

Soil acidity is determined by the amount of hydrogen ion (H) activity in soil solution and is influenced by edaphic, climatic, and biological factors. Soils that develop from granite parent materials acidify at a faster rate than soils developed from calcareous parent materials. Sandy soils acidify more rapidly due to their smaller reservoir of alkaline cations and higher leaching potential. High rainfall affects the rate of soil acidification depending on the rate of water percolation through the soil profile. Organic matter decaying to form carbonic acid and other weak acids also contributes to acidification.

11.2.1 Climate

As mentioned earlier, acid soils are mostly found in the areas of high rainfall. Rainfall is most effective in causing soils to become acidic if plenty of water moves through the soil rapidly. In acid soil regions (ASR), precipitation exceeds evapotranspiration and hence leaching is predominant causing loss of bases from soil. The iron and aluminium derivatives are relatively insoluble, seldom leached and contributes to surface acidity particularly in laterite soils. Since the effect of rainfall on acid soil development is very slow, it may take hundreds of years for new parent material to become acidic under high rainfall. When the process of weathering is drastic, the subsoil and in many cases the whole profile becomes acidic.

11.2.2 Organic Matter Decay

Decaying organic matter produces H ion which is responsible for acidity. The carbon dioxide (CO_2) produced by decaying organic matter reacts with water in the soil to form a weak acid called carbonic acid. This is the same acid that develops when CO_2 in the atmosphere reacts with rain to form acid rain naturally. Several organic acids are also produced by decaying organic matter, but they are also weak acids. Like rainfall, the contribution to acid soil development by decaying organic matter is generally very small.

11.2.3 Vegetation

Plants influence the earth surface through the uptake, transformation and redistribution of materials in the atmosphere, pedosphere and lithosphere. Although all plants leave such an imprint (e.g., input of organic matter and respired CO_2, enhancement of rock weathering, etc.), variations in size, growth rate, life span, allocation, tissue chemistry, and many other attributes affect cycling patterns and the properties of soils differently. In the regions of very low temperature the acid soils can develop easily. The foliage of coniferous trees which are most likely to grow in these regions is devoid of alkali elements. When the leaf litter of coniferous trees on ground is degraded, organic acids are released which gradually make the soil acidic. Vegetation of coastal zones and marshy places facilitates development of acidity. The places where excessive vegetation is accompanied by heavy rainfall and water pounding, soils are very acidic in reaction.

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11.2.4 Parent Material

Acidic parent materials (granites, rhyolites, diorites) are the basis for acidic soil formation. In these soils, predominant minerals are quartz, feldspar and oxides. Al and Fe are in soluble forms. Usually these soils are less fertile because of low content of nutrient elements like Mg, Ca, etc. and more risky for pollutants movement through the soil profile. Due to differences in chemical composition of parent materials, soils will become acidic after different lengths of time. Thus, soils that develop from granite material are likely to be more acidic than soils developed from calcareous shale or limestone. Some young soils exhibit acidic nature even in the areas of medium rainfall and vegetation. These soils still reflect the nature of rocks from which they have developed. Some rocks (parent material) are acidic in nature (e.g. igneous rocks). After weathering of these rocks, acidic constituents dominate the composition of soil.

Podzolization (or Podsolization) is complex soil formation process by which dissolved organic matter and ions of iron and aluminium, released through weathering of various minerals, form organo-mineral complexes (chelates) and are moved from the upper parts of the soil profile and deposit in the deeper parts of soil.

11.2.5 Topography

Topography has an influence on soil formation, most likely through hydrological processes. Increases in pH, $CaCO_3$, Ca and Mg, as well as base saturation are observed in down slope. Correlations between topography and soil chemistry were generally stronger for the O-horizon than for the

B-horizon, indicating that the organic layer is more exposed to topographic controls. Several studies have found a down-slope increase of pH, but have not quantified it against topography. Sloppy places with good drainage conditions are often acidic in nature.

11.2.6 Human interference

Excessive use of water or keeping the field submerged for a long time accompanied by improper drainage may lead to the development of acidity in the soil. Nitrogen and phosphorus fertilizers also contribute significantly to the formation of acid soils. Ammonium nitrogen can be a major factor in the acidification of sandy, low buffer-capacity soils. When ammonium is converted to nitrate by soil microbes, hydrogen ions are released. While it is less acidifying than ammonium, the monocalcium phosphate [$Ca(H_2PO_4)_2$], often used as one component of fertilizer, can also be a factor. It will react with water to form dicalcium phosphate ($CaHPO_4$) and phosphoric acid (H_3PO_4). Because of the tendency of H_3PO_4 to give up some of its hydrogen ions, very low pH values can occur in the band. This acidity will then gradually diffuse into the soil surrounding the band.

11.2.7 Presence of 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.

11.2.8 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.

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 amount 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)

11.3 Kinds of soil acidity

11.3.1 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.

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

11.3.3 Potential acidity/Reserve acidity: H^+ and Al^{+3} ions present inside the soil crystal lattice. Soil constituents capable of contributing H^+ ions to the

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soil solution through ionization, dissociation, hydrolysis, etc. It is the major contributor of soil acidity (Das, 2015).

Total acidity = (Reserve + Exchangeable) + Active Acidity

11.4. 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.

11.4.1 Direct effect

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

11.4.2 Indirect effects

- Availability of nutrients increases e.g. P, Cu, Zn
- 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.
- 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.
- Some disease causing agents (especially fungi) flourish well in acid soils. Incidence of disease is, therefore, increased.
- 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.

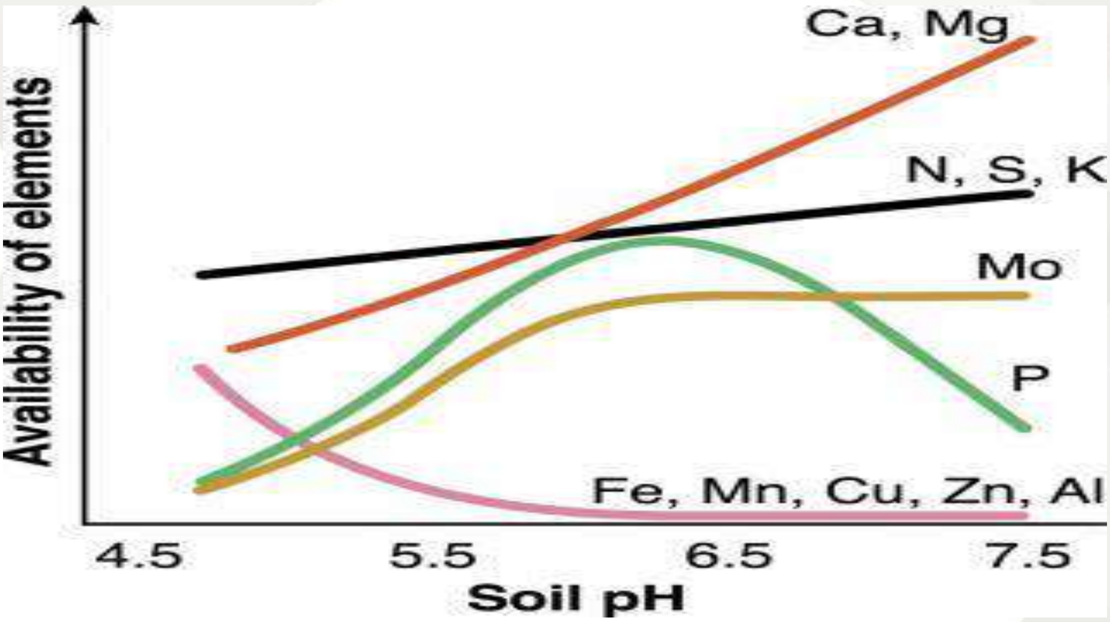

Figure 2 A representation of the relationship between soil pH and nutrient availability

11.4.3 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 (Figure 2).

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.

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Course Name	Problematic soils and their Management
Lesson 12	Management of Acid soils
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Learning Objective

- *Understand the concepts of liming, acidity tolerant plants and sub-soil acidity*

Glossary of terms

1. **Liming:** Liming is the application of calcium and magnesium-rich materials to soil in various forms, including marl, chalk, limestone, or hydrated lime. This neutralises soil acidity and increases activity of soil bacteria.
2. **Lime requirement (LR):** Lime requirement is defined as the amount of agricultural limestone or other basic material needed to increase the pH of the soil from an unacceptably acidic condition to a value that is considered optimum for the desired use of the soil.
3. **Liming factor:** The factor by which the actual amount of lime can be calculated from the estimated theoretical amount of lime or liming materials.
4. **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.

12.1 Introduction

The acid soils occur primarily in high rainfall, hilly/mountainous and coastal regions. The soils are under different land uses for growing of food crops, horticulture & plantation crops and forests. The highly leached soils are generally poor in fertility and water holding capacity. A substantial area with pH value less than 5.5 is more problematic with severe deficiencies of phosphorus, calcium, magnesium and molybdenum and toxicities of aluminium and iron. The average productivity of one tonne/ha of the soils is very low. The poor soil resource is one of the main factors of poverty and backwardness in the acid soil. The addition of lime to these soils neutralizes soil acidity and creates favorable environment for microbial activity, nutrients release and their availability to plants.

12.2 Methods for Management of Acid soils

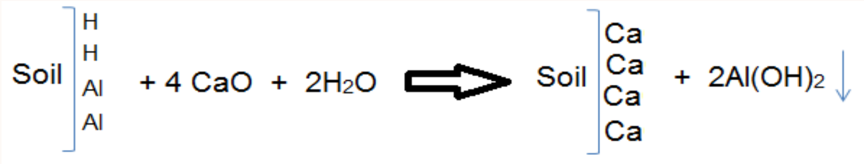
12.2.1. Liming

Liming is a widely accepted practice for ameliorating acid soils. It decreases exchange acidity and increases soil pH. It improves base saturation percent of soils, inactivates Al, Fe and Mn, reduces P fixation and stimulates microbial activity leading to the mineralization of organic nitrogen. Increased availability of major, secondary and micronutrients due to liming of acid soils has been reported. Among the naturally occurring lime sources, calcite, dolomite and stormatolitic lime stones are important. Since calcite and dolomite have industrial use, its application in agriculture is not economic

12.2.1.1 Reactions of liming materials in soil

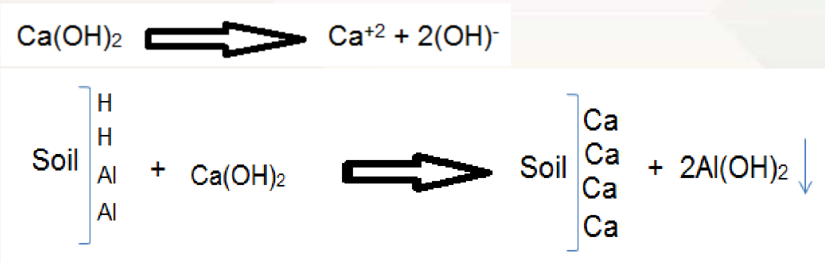
Reaction of CaO

This is also known as un-slaked lime or burnt limestone or quicklime. 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.



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



Dolomite (CaCO3, MgCO3)

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.

12.2.1.2 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 limestone solution, plant uptake and leaching during the reaction period.

Table 1 Lime requirement to bring the soil to desired level of pH indicated below (Das, 2015)

pH of soil buffer suspension	Lime required to bring the soil to indicated pH (tonnes 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 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).

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Table 2 Calcium Carbonate needed to increase the pH of a soil textural class by one unit.

Sl. No.	Soil texture	Lime in
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

12.2.1.3 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.

12.2.1.4 Benefits of liming

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.

12.2.1.5 Effects of liming

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

a. Physical effects

Liming improves physical condition of heavy soils; they become granular in structure and their water holding capacity is improved. Liming also encourages 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.

b. 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.

c. 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.

12.2.1.6 Adverse effects of over liming

- 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.
- Excess lime also interferes with the absorption of certain elements like potassium, phosphorus, boron, etc. by plants thus hindering their utilization.
- 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.

12.2.1.7 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.

i. 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.

Table 3 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

ii. Degree of fineness of material

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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.

iii. Purity of liming materials: The purer the liming material, the higher will be its effectiveness in amelioration of soil acidity.

12.2 Organic matter - loss and replenishment in acid soils

The role of organic matter in the productivity of mineral soils is still grossly underestimated and neglected in most of the tropical areas except China. There are nine major benefits of organic matter, the most important being increased available nutrient supply and CEC, reduced surface temperature, improved water relations (conservation, infiltration), and reduced soil erosion and surface water run-off. Organic matter additions as crop residues, and/or green manure crops in rotation or as intercrops (alleys) must be the key components of crop management systems for acid upland soils planted to food crops. They should be left on the soil surface as a mulch, incorporated into the soil, or, ideally, used both ways. Complexation of aluminium (Al) in soil solution by decomposition products of organic materials, particularly low molecular weight organic acids. The mechanism that best explained the neutralization reaction was found to be microbial decarboxylation of calcium-organic matter complex leading to the release and subsequent hydrolysis of calcium ions. The hydroxyl ions released in the hydrolytic reaction then reacts with both the exchangeable

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hydrogen and Aluminum ions to form water and insoluble Aluminum hydroxide [$Al(OH)_3$], respectively.

12.3 Phosphate management in acid soils

The fixation and immobility of P in acid soils of the tropics can be either major problems or blessings in disguise, depending on how soils and P fertilizers are managed. Phosphorus fixation is often high in Oxisols and Ultisols because they are most likely to have P-fixing clay minerals (amorphous and crystalline hydrous oxides of Fe and Al), high Fe and Al, and low pH, all of which are conducive to P fixation. When soil P concentration exceeds a certain level, P uptake by crops will actually be inhibited. Thus, highly concentrated bands of P fertilizer should be avoided. Because of strong interest in rock phosphates for direct application to tree crops in Southeast Asia, one must know that rock phosphates differ significantly in their reactivity. Because of their low cost, high Ca content, and residual effects, rock phosphates are especially well suited for amendment of acid soils poor in P and Ca.

Inherent soil properties and climate affect crop growth and how crops respond to applied P fertilizer, and regulate processes that limit P availability. Climatic and site conditions, such as rainfall and temperature, and moisture and soil aeration (oxygen levels), and salinity (salt content/electrical conductivity) affect the rate of P mineralization from organic matter decomposition. Organic matter decomposes releasing P more quickly in warm humid climates and slower in cool dry climates.

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Phosphorus is released faster when soil is well aerated (higher oxygen levels) and much slower on saturated wet soils. Soils with inherent pH values between 6 and 7.5 are ideal for P-availability, while pH values below 5.5 and between 7.5 and 8.5 limits P-availability to plants due to fixation by aluminum, iron, or calcium, often associated with soil parent materials.

12.4 Management of Secondary Nutrients in Acid Soils

Most of the acid soils are deficient in Ca, Mg and S except acid sulphate soils which contain high amount of S. Soils having Ca saturation less than 25% of the total cation exchange capacity requires Ca application to most of the crops. Deficiency of Ca and Mg can be corrected by using lime or liming materials @ 4-5 q/ha. Increasing usage of relatively pure, sulphur-free fertilizers, e.g. urea, TSP, ammonium phosphates, will lead to increasing S and trace element deficiencies as high crop yields increase removal.

12.5 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.

Table 4 Acid tolerant crops

Sl. No.	Slightly tolerant pH 6.0-6.8	Medium tolerant pH 5.5-6.8	Very tolerant pH 5.0-6.8
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	--

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Reference

Das, D. K. (2015). Introductory Soil Science. Kalyani Publishers. pp 500

Course Name	Problematic soils and their Management
Lesson 13	Acid Sulphate Soils - Properties, Management & Reclamation
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Learning Objectives

- Understanding the formation, mineralogy, properties and reclamation of acid sulphate soils.

Glossary of terms

1. **Acid Sulphate Soils:** 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.
2. **Potential acid sulphate soils:** Acid Sulphate Soils (ASS) which have not been oxidised by exposure to air are known as potential acid sulphate soils.
3. **Actual acid sulphate soils:** When potential acid sulphate soil is exposed to oxygen, the iron sulfides are oxidised to produce sulfuric acid and the soil becomes strongly acidic (usually below pH 4). These soils are then called actual acid sulphate soils.
4. **Liming: Liming** is the application (to soil) of calcium and magnesium-rich materials in various forms, including marl, chalk, limestone, burnt lime or hydrated lime. In acid soils, these materials react as a base and neutralize soil acidity.
5. **Leaching:** Leaching refers to the practice of applying a small amount of excess irrigation where the water has a high salt content to avoid salts from building up in the soil.

13.1 Introduction

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 jarosite.

13.2 Occurrence

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 acidity, 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.

The total area under acid sulphate soil is approximately 10-15 million hectare globally or about one percent of the total area of cultivated agricultural land. About half of the total area of acid sulphate soil is located in Asia. Major areas of acid sulphate soils occur in the coastal low lands of South East Asia, (Indonesia, Vietnam, Thailand), West Africa (Senegal, the Gambia, Guinea, Bissau, Sierra, Leone Liberia) & along the north eastern coast of South America (Venezuela, the Guyanas). 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.

13.3 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 very acidic when first drained in water.

Acid sulphate soils (ASS) are naturally occurring soils and sediments containing iron sulfides, most commonly pyrite. When Acid sulphate 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.

13.3.1 The Genesis and underlying chemistry of formation of Acid Sulphate Soils

The soils and sediments which are most prone to becoming acid sulphate soils are those which formed within the last 10,000 years after the major sea level rise. When the sea level rose and inundated the land, sulphate ($SO4^{2-}$) in sea water was mixed with land sediments containing iron oxides and organic matter. Under such anaerobic conditions, lithotrophic bacteria such as Thiobacillus ferrooxidans form iron sulphides (pyrite). For pyrite to form, it requires supply of sulphur (Seawater), anaerobic (O_2 free) condition, supply of energy for bacteria (usually rotting organic matter, e.g. mangrove leaves), system to remove reaction products (tidal flushing system, source of iron (most often from terrestrial sediments) and a temperature greater than 10 °C.

Acid sulphate soils are usually formed under waterlogged conditions. These soils contain iron sulphides minerals (predominantly as the mineral pyrite) or their oxidation products. In an undisturbed state below the water table, acid sulphate soils are benign. However if the soils are drained, excavated or exposed to air by a lowering of the water table, the sulphides will react with oxygen to form sulphuric acid.

$2FeS_2 + 9O_2 + 4H_2O \rightarrow 8H^+ + 4SO_4 + 2Fe(OH)_3$ **(solid)**

Under waterlogged anaerobic soils, sulphate derived from the sea water is reduced by anaerobic microorganisms.

$$SO_4^{2-} \xrightarrow[\textit{Desulfotomaculum}]{\textit{Desulfovibrio}} S^{2-} \xrightarrow[Fe^{2+}]{\text{Siltation}} FeS + FeS_2$$

13.4 Types of acid sulphate soils

13.4.1 Potential acid sulphate soils

Acid Sulphate Soils (ASS) which have not been oxidised by exposure to air are known as potential acid sulphate soils (PASS). They are neutral in pH (6.5–7.5) , contain unoxidised iron sulfides, are usually soft, sticky and saturated with water and are usually gel-like muds but can include wet sands and gravels have the potential to produce acid if exposed to oxygen. 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.

13.4.2 Actual acid sulphate soils

When PASS is exposed to oxygen, the iron sulfides are oxidised to produce sulfuric acid and the soil becomes strongly acidic (usually below pH 4). These soils are then called actual acid sulphate soils (AASS). They have a pH of less than 4, contain oxidised iron sulfides, vary in texture and often contain jarosite (a yellow mottle produced as a by- product of the oxidation process).

13.5 Appearance and physico-chemical properties of acid sulphate soils

Acid sulphate soils are often mid to dark grey to greenish grey in colour and soft and buttery with the consistency of clay. Pale yellow mottles are seen in the subsoil of acid sulphate soil and red coloration is found when acid sulphate soils are drained. Acid sulphate soils possess strong muddy odour due to presence of ferrous and hydrogen sulphide. The unique character which very often identifies an active acid sulphate soil is the presence of typical yellow mottles which resemble the mineral, jarosite. The available N and P contents are usually low while K and S contents are quite high. The salinity levels in acid sulphate soils are variable, due to seasonal changes and high EC values in the surface horizon of the soils may be due to the upward movements of salts by capillary action. Strongly acid sulphate soils result in toxicities of aluminum 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.

13.6 Problems

The growth of most dryland crops on acid sulphate soils is hampered by the toxic levels of aluminium and the low availability of phosphorus. Toxic levels of dissolved iron plus low phosphorus are the most important adverse factors for wetland rice. In the near-neutral potential acid sulphate soils (Sulfaquents, Sulfic Fluvaquents), high salinity, poor bearing capacity, uneven land surface, and the risk of strong acidification during droughts are the main disadvantages. Young acid sulphate soils (Sulfaquepts) in which the pyritic substratum occurs near the surface are often more acid than those soils (Sulfic Tropaquepts, Sulfic Haplaquets) in which this horizon is found at greater depths. Acid floodwater generated in large swamps with very acid Sulfaquepts, may adversely affect crops grown on adjacent better land.

13.7 Present land use

Most potential acid sulphate soils are under natural vegetation (mangrove swamps, tidal marshes) or are used for mangrove forestry (charcoal, nipa thatch, nipa sugar). Fishponds in potentially acid land can be fairly productive, provided that the pyritic substratum is not exposed and oxidized. In climates with a marked dry season, potentially acid swamps can be used for salt extraction. In some tidal swamps where the surface water is seasonally fresh, tidal swamp rice is grown on cleared mangrove land. Young, shallow, acid sulphate soils are commonly left uncultivated, although with good water management they can be used with some success for oil palm and rice. Older acid sulphate soils are used extensively for broadcast deep water rice, giving low to moderate yields. Droughts and sudden deep flooding, however, are probably at least as much to blame for lower rice yields on these older soils as are phosphorus deficiency and aluminium toxicity.

13.8 Reclamation Possibilities

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

13.8.1 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 sulphate soils are buried deepest, so the amount of acid sulphate soil removed is reduced
- Using construction methods and site management procedures that don't leave acid sulphate 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 sulphate soil layers but can still remove excess surface water efficiently.

The older, deeply developed acid sulphate soils require no specific reclamation measures, and can be greatly improved by good fertilizer application, moderate dressings of lime (1-5 ton/ha) and probably most important, good water management. In reclaiming or improving potential and young acid sulphate soils two diametrically opposite approaches are possible:

- Pyrite and soil acidity can be removed by leaching after drying and aeration, and

- Pyrite oxidation can be limited or stopped, and existing acidity inactivated by maintaining a high water-table.

13.8.2 Keeping the area flooded

The first method, combined with leaching by seawater has been used with some success in experiments, and these efforts have attracted considerable attention. The method can only be applied under specific conditions: close proximity to the sea, an appreciable tidal range and strongly contrasting wet and dry seasons. Even then, costly annual dressings of lime are still necessary, and no instances of a successful large-scale application have been reported. Most of the available experience from field and laboratory experiments shows that leaching is too slow to remove an appreciable and relatively immobile fraction of the soil acidity (mainly adsorbed aluminium, adsorbed sulphate and basic sulphate such as jarosite) from most of the soil within an acceptable time. However, leaching is often necessary to remove accumulations of soluble acid salts (Al-Fe-Mg sulphates) near the surface of rice fields on young acid sulphate soils after a dry fallow, and to remove acid surface water generated above flooded, reduced acid sulphate soils. This is usually done in the course of the growing season by lateral drainage of surface water after repeated wet tillage.

13.8.3 Controlling water table

The second reclamation method, maintaining a high water-table to stop pyrite oxidation and to inactivate existing soil acidity, has the advantage

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that its effects are usually noticeable within two years or so. This is especially true in young acid sulphate soils that are generally high in organic matter. Upon waterlogging, soil reduction caused by microbial decomposition of organic matter lowers acidity and may cause the pH to rise rapidly to near-neutral values. The method is particularly suitable with rice cultivation, but even in oil palm plantations, maintaining a shallow water-table has given far better results than deeper drainage with intensive leaching. The crucial factor is, of course, the availability of fresh water for irrigation. Large-scale engineering schemes for reclaiming potentially acid, and usually strongly saline, coastal swamp are rarely economic. In the areas, where patches of Sulfaquepts occur among better soils, improved water management and intensive irrigation have dramatically increased the productivity of these highly acid soils. So, unless sufficient fresh water is available and other prerequisites for good water management exist, potential acid sulphate soils and young, strongly acid sulphate soils should not be reclaimed, but are better left for other types of land use (conservation, forestry, fisheries and, sometimes, salt pans). If fishponds are constructed on such land, they should be kept shallow, because deep excavation will cause the water to turn toxic. The injudicious reclamation of seemingly suitable land in coastal swamps by excluding salt water through diking and by excavating fishponds has led to the destruction and abandonment of thousands upon thousands of hectares of mangrove land in southeast Asia. The less toxic and deeper developed older acid sulphate soils are moderately suitable for rice and can be improved by sound agronomic practices, such as growing adapted cultivars and applying phosphorus. By intensifying water and soil management, including dry season irrigation, the productivity of these soils for rice will increase and they can probably be made productive for a wide variety of annual and perennial dryland crops.

13.8.4 Liming and Leaching

If acid sulphate soil is disturbed, it must be treated. Additional liming and fertilization, especially with phosphorus, are usually necessary with either method. Liming alone, while technically and agronomically feasible, is always prohibitively expensive on these very acid soils. 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.

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Course Name	Problematic soils and their Management
Lesson 14	Eroded Soils – Types and factors responsible for soil erosion
Content Creator Name	Dr. SHWETA SHAMBHAVI
University/College Name	Bihar Agricultural University, Bhagalpur
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Learning Objective

- Understand various types of soil erosion and the geographic, meteorological and anthropogenic reasons for soil erosion.

Glossary of terms

1. **Accelerated Erosion:** If the rate of soil loss exceeds the rate of soil formation then it is called accelerated erosion.
2. **Erodibility:** It is considered as a dynamic property of the soil, which defined as resistance of soil to both detachment and transport of soil particle and depends on physical, chemical, mineralogical and biological property of soil . The resistance of soil to erosion include texture, structure, water retention and transmission properties and shear strength.
3. **Eutrophication:** Excessive richness of nutrients in a lake or other waterbody , frequently due to run-off from the land, which causes a dense growth of plant life.
4. **Deforestation:** Deforestation refers to the conversion of a forest into a non-forest use such as farmland, ranches, pasture, industrial complexes, and urban areas.
5. **Natural or geological erosion:** One in which rate of soil loss does not exceed the rate of soil formation.
6. **Sheet Erosion:** When a thin layer of soil is removed by raindrop impact and shallow surface flow from the whole slope, it is called sheet erosion.

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7. **Soil Erosion:** Soil erosion refers to the detachment and transportation of soil particles to another place by the agencies of water, wind or gravitational forces etc.
8. **Splash Erosion:** Splash erosion is the first stage of the erosion process. It occurs when raindrops hit bare soil. The explosive impact breaks up soil aggregates so that individual soil particles are 'splashed' onto the soil surface.
9. **Saltation:** As the wind speeds pick up, the surface particles start leaping off the surface into the air, this process is saltation.
10. **Suspension:** Movement of fine dust particles smaller than 0.1 mm diameter by floating in the air is known as suspension.
11. **Surface Creep:** A stage in the wind erosion process in which sand grains are moved along the ground surface by impact of other grains in saltation.

14.1 Introduction

Soil erosion refers to the detachment and transportation of soil particles to another place by the agencies of water, wind or gravitational forces etc. It is the most destructive phenomenon causing the loss of fertile soil, degrading the environment and reducing the storage capacity of water bodies. **Natural or geological erosion** is one in which rate of soil loss does not exceed the rate of soil formation and if the rate of soil loss exceeds the rate of soil formation then it is called **accelerated erosion**.

14.2 Types of Erosion

Based on the causal agents, soil erosion can be classified as **water erosion** when the detachment and transportation of soil particles takes place by the moving water; and **wind erosion** when the detachment and transportation of soil particles happens by the wind.

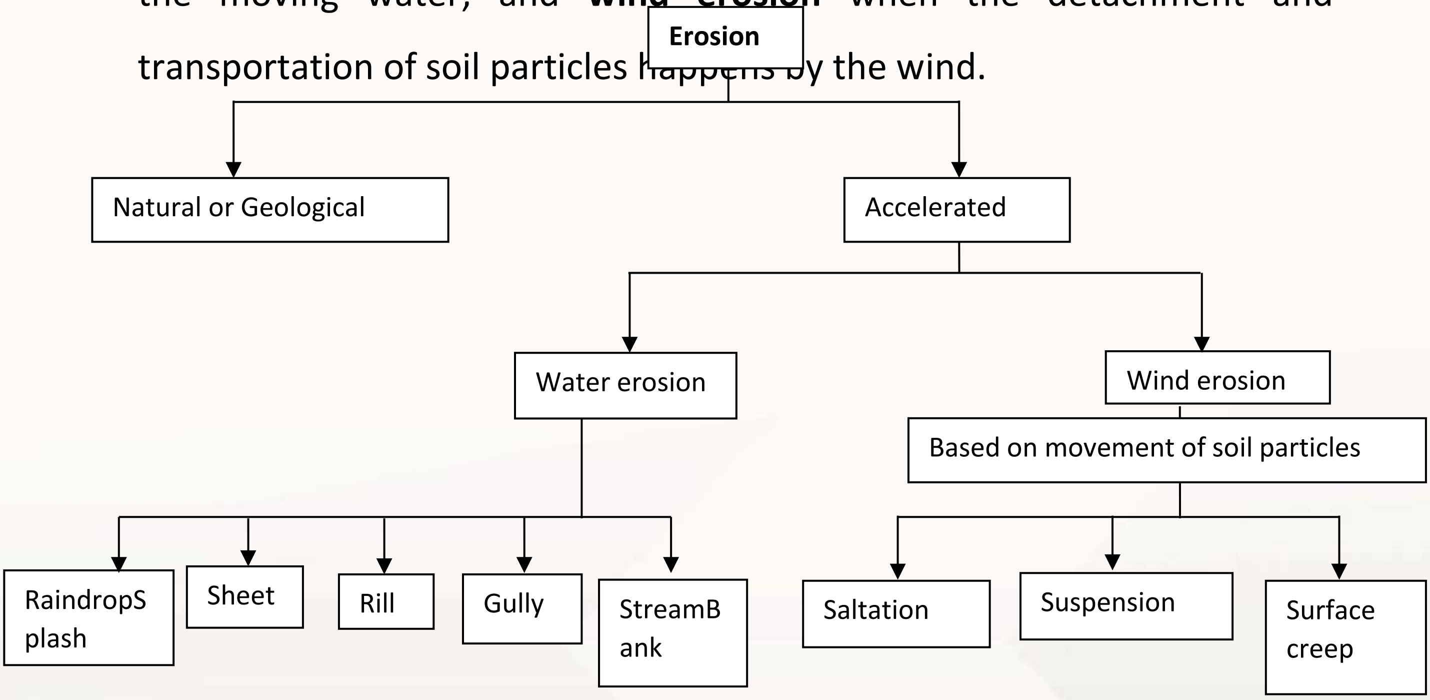

Figure 1 Schematic diagram for Soil Erosion

14.3 Soil Erosion by Water

14.3.1 Extent of Water erosion in India

Of the total degraded land in India, more than 80% is affected by soil erosion and out of it about 80% of it occurs by water. The annual water erosion rate value ranges from 5 t $ha^{-1}yr^{-1}$ (for dense forest, snow-clad cold deserts, and the arid regions of western Rajasthan) to more than 80 $ha^{-1}yr^{-1}$in the Shiwalik hills in northwest region with an average value of 16 t $ha^{-1}yr^{-1}$. The red soils, covering about 70 Mha, being shallow and have low intake capacity due to crusting, suffer from rapid surface runoff and erosion.

The flood plains of Ganga and its tributaries in Uttar Pradesh and Bihar transported about 30 Mt of eroded materials every year to the Bay of Bengal. Similarly, the Brahmaputra transported 10 Mt Yr^{-1} from the Brahmaputra valley to the Bay of Bengal (Das, 2015).

It has been also estimated that more than 1.5 Mha of forest land is cleared for shifting agriculture every year. The total area affected by shifting cultivation is estimated to be 4.5 Mha. Shifting agriculture, locally known as “jhumming” has caused severe soil erosion in the tribal areas of Assam, Meghalaya, Nagaland, Mizoram, Kerala, Andhra Pradesh, Orissa, Madhya Pradesh, Chhattisgarh etc.

14.3.2 Significance of Soil Erosion

a. Loss of fertile soil: The upper 15 cm soil layer (plough layer) lost as run-off consist of fertile soils and fresh or active organic matter. The fertile soil carries along with the essential plant nutrients leading to decreased fertility of eroded soils. An estimated loss of nutrient due to soil erosion by water in the country is to the extent of 5.4 to 8.4 Mt.

b. Loss of crop productivity: The consequences of fertile soil loss and deterioration of soil structure by water erosion led to reduction in the crop productivity.

c. Water pollution: The runoff water carries dissolved mobile nutrients like nitrogen whereas the eroded sediments in runoff water nutrient adsorbed on the soil particles. Nutrient-rich runoff-water causes '**eutrophication'** of water bodies.

d. Loss in reservoir capacity: The water reservoirs get silted up due to high sediment load of the runoff water entering in to these reservoirs, thus decreasing their storage capacity and minimising their useful life.

e. Flash floods and mudslides: The high intensity rain in the hilly regions in absence of sufficient vegetative cover led to high velocity runoff resulting in flash floods in the plains. The detachment of soil by rainwater coupled with gravitational forces leads to mud slides in the mountainous region.

14.3.3 Causes of Soil Erosion

a. Deforestation: Deforestation refers to the conversion of a forest into a non-forest use such as farmland, ranches, pasture, industrial complexes, and urban areas. Forest clearance exposes the bare soil to the scorching effect of the sun and the beating action of the rains. Due to elevated temperature, soil organic matter is decomposed at a faster rate, and soil aggregates are broken down by raindrop impact. Infiltration rate is reduced and more water runs off. The natural vegetation not only protects the soil surface from kinetic energy of raindrops, but also the soil particles are adhered strongly to the plant roots.

b. Overgrazing: Overgrazing is one of the most devastating causes of desertification in arid lands. The forage and overgrazing of livestock cause a chain of degradation, critically reducing vegetation cover and soil fertility, as well as increasing erosion. Domestic animals rapidly clear vegetation, placing stress on a land that already has a low vegetation cover. They also move in large groups and have sharp hooves that easily break up the soil, leaving it susceptible to erosion. These factors coupled with high temperatures destroy the rest of the natural vegetation and prepare the ground for large scale soil erosion with high intensity rainfall.

c. Inappropriate cultivation practices: Cultivation practices viz. up and down cultivation, cultivating sloping lands, unsafe disposal of excess runoff water, etc. lead to the accelerated soil erosion by water.

d. Intensive tillage: The intensive tillage of soils results in decrease in soil organic carbon, breakdown of particles aggregates into smaller particles, eases the soil detachment and transportation, and finally accelerates the rate of soil erosion by water.

e. Population pressure: The need to feed the ever-increasing population coupled with increasing urbanization has resulted in conservation of forest and grassland for agricultural practices.

14.3.4 Types of Soil Erosion

a. Splash Erosion: At the start of a rain event, falling raindrops beat the soil aggregates, break them, and detach soil particles. These particles clog the large soil pores and, thus, reduce the infiltration capacity of the soil. Water cannot enter the soil, and soon a thin film of water covers the ground. Further, raindrops beat the water and splash the suspended soil particles away. Soil particles are transported to some distance by the splashing. The splashed particles can rise as high 60 cm above the ground and move up to 1.5 m from the point of impact. Actually, splash erosion is the beginning of other types of soil erosion, particularly sheet erosion.

b. Sheet Erosion: When a thin layer of soil is removed by raindrop impact and shallow surface flow from the whole slope, it is called sheet erosion. It removes the finest fertile topsoil with plenty of nutrients and organic matter. It is the most dangerous type of soil erosion because it occurs gradually and almost silently leaving little or no signs of soil removal.

c. Rill Erosion: When rainfall exceeds the rate of infiltration, water accumulates on the surface, and if the land is sloping, it moves along the slope. On gently sloping lands, with standing crops or in fields that have been recently tilled, moving water concentrates along tiny channels called rills. Rills are less than 30 cm deep. The cutting action of flowing water detaches soil particles, and runoff water carries them away. The amount of soil loss may be high, but the small channels do not usually interfere with tillage implements. The rills may be levelled by normal tillage operations. Rill erosion is often the initial stage of gully erosion.

d. Gully Erosion: Gully erosion is an advanced stage of rill erosion where surface channels have eroded to the point where these cannot be obliterated by tillage operations. The channels with cross section area of 0.1 m^2 or more have been recently designated as gullies. Gullies are the most spectacular evidence of the destruction of soil as it permanently dissects the land. Gully erosion is responsible for removing amounts of soil irreversibly destroying farmlands, roads, and bridges and deteriorating the water quality by increasing the sediments load in the streams. Gullies not only transport the sediments but also contribute to these sediments due to erosion of sides and bottom of these channels.

e. Stream Bank Erosion: Stream/riverbank erosion occurs due to bank scour and mass failure. The direct removal of bank materials by the physical action of flowing water is called bank scour. It is often dominant in smaller streams and the upper reaches of larger streams and rivers. Mass failure occurs when large chunks of bank material become unstable and topple into the stream or river. Riverbank erosion can be accelerated by lowering streambed, inundation of bank soils followed by rapid drops in water flow, saturation of banks from off-stream sources, removal of protective vegetation from stream banks, poor drainage, readily erodible material within the bank profile, wave action generated by boats, excessive sand and gravel extraction, and intense rainfall.

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f. Mass movements and Land sliding: The downward and outward movement of a large block of soil and regolith caused by gravity are called landslides and landslips. Landslides are deep-seated mass movement, and soil slip is a shallow and rapid sliding or flowing movement of the soil. There are different forms of landslides, including mudflows, mudslides, debris flows, rock falls, and rockslides. Slides move in contact with the underlying surface. Flows are plastic or liquid movements in which land mass breaks up in water and flows during movement. Landslides are caused by unstable geological conditions, steep slopes, intense rainfall, weak soils, earthquakes, and human- induced changes of landforms. Human-induced causes are excavation, loading, deforestation, irrigation, mining, vibrations, and water impoundment.

14.3.5 Factors affecting Soil erosion

The major factors affecting soil erosion are: climate, soil, vegetation and topography

a. Climate: Climatic variables affecting soil erosion by water are precipitation, temperature, wind, humidity and solar radiation. It is rain and snow that play a major role in soil erosion. Temperature and wind are most evident through their effect on evaporation and transpiration; however, wind also changes raindrop velocities and angle of impact. Humidity and solar radiation are somewhat less indirectly involved as these are associated with temperature and rate of soil water depletion. Rainfall characteristic affecting soil erosion are amount, intensity, distribution, raindrop size etc.

b. Soil: The soil characteristic describes soil detachability and transportability, which when combined is designated as soil 'erodibility'. It is considered as a dynamic property of the soil, which is defined as resistance of soil to both detachment and transport of soil particle and depends on physical, chemical, mineralogical and biological property of soil that affect the resistance of soil to erosion including texture, structure, water retention and transmission properties and shear strength.

c. Vegetation: Vegetation act as protective layer or buffer between the atmosphere and the soil. The major effects of vegetation in reducing erosion include:

i. Interception of rainfall by absorbing the energy of raindrops and thus reducing surface sealing and runoff.
ii. Reducing of erosion by decreasing surface velocity
iii. Physical restraint of soil movement
iv. Improvement of aggregation and porosity of soil by roots and plant residues
v. Increased biological activity in soil
vi. Transpiration, which decreases soil water, resulting in increased strong capacity and less runoff.

d. Topography: Landform and slope of land play an important role in the origin of erosion, entailment, and deposition of entailed sediment.

Topographic feature that influences soil erosion are degree, shape and length of the slope, and size and shape of the watershed. Erosion expects to increase with increase in slope steepness and slope length as a result of increase in velocity and volume of surface runoff.

14.4. Soil Erosion by Wind

Wind erosion means detachment and transportation of soil particles by the forces generated by wind. Wind erosion takes place normally in arid and semi-arid regions devoid of vegetation, where the velocity of wind is high. The soil particles on the land surface are lifted and blown off as dust storms. When the velocity of the dust bearing wind is retarded, coarser soil particles are deposited in the form of dunes and thus fertile lands are rendered unfit for cultivation. In other place, fertile soil is blown away by winds and the subsoil is exposed, as a result the productive capacity of the soil is considerably reduced. Lifting and abrasive action of wind results in detachment of tiny soil particles from the granules or clods. The impact of these rapidly moving particles dislodges other particles from clods and aggregates. These dislodged particles are ready for movement. Movement of soil particles in wind erosion is initiated when the pressure by the wind against the surface soil grains overcomes the force of gravity on the grains.

14.4.1 Extent and Significance of Wind Erosion

Extent

About 13.5 M ha area, representing 4.1% of the total geographical area in the country is affected by wind erosion. Wind erosion is moderate to severe in the arid and semi-arid regions of north-west covering an area of 2.8 Mha, in states of Rajasthan, Gujarat, Haryana and Punjab. Out of this, 68% is covered by sand dunes and sandy plains. Rate of wind erosion is not measured in many geographic locations ,but, it may be as high as 0.5 mm yr^{-1}.

Significance

i. **Loss of soil fertility:** Soil fertility is reduced because of the loss of the plant nutrients that are concentrated on fine soil particles and organic matter in the topsoil. This reduces the soils' capacity to support productive pastures and sustain biodiversity.
ii. **Crop damage:** The strong soil particle laden-winds damage the young seedling, blowing away the recently sown seeds, exposing the roots. With the deposition of soil particles carried away by wind, the plant may be buried under. Weed seeds also spread from one field to another field, thereby reducing the crop productivity.
iii. **Pollution:** Dust particles can pollute water bodies and spread many disease pathogens. Air pollution caused by fine particles in suspension can affect people's health and cause other allergic problems.
iv. **Desertification:** Wind erosion is one of the major factors of desertification as deserts are expanding at the rate of 2 m yr^{-1}.

14.4.2 Causes of Wind Erosion

Wind erosion is a serious problem in the arid and semi-arid regions where vegetation is sparse, rainfall is low, and temperature is high. Potential evaporation is higher than precipitation for most of the year, which causes depletion of soil moisture, organic matter, and structure. Storms are regular events there, and in dry warm season, strong winds uplift small soil particles and carry them to distant places. Ecosystems in arid and semiarid regions are fragile by nature and are sensitive to human disturbances. Under population pressure and socio-economic backwardness, human actions cause stresses on all-natural resources. Land mismanagement, overgrazing, overcutting for fuel wood and deforestation, and misuse of water resources have been responsible for the loss of natural vegetative cover and hence accelerated wind erosion.

14.4.3 Types of Wind Erosion

Moving air has energy that can detach and transport soil particles. Detachment occurs when the energy exerted by wind exceeds the forces keeping the soil particles in place, such as weight and 'cohesion'. Detachment can also occur via the impact of particles already in motion dislodging other particles. Once detached, soil can be transported in one of three ways: suspension, saltation, or creep.

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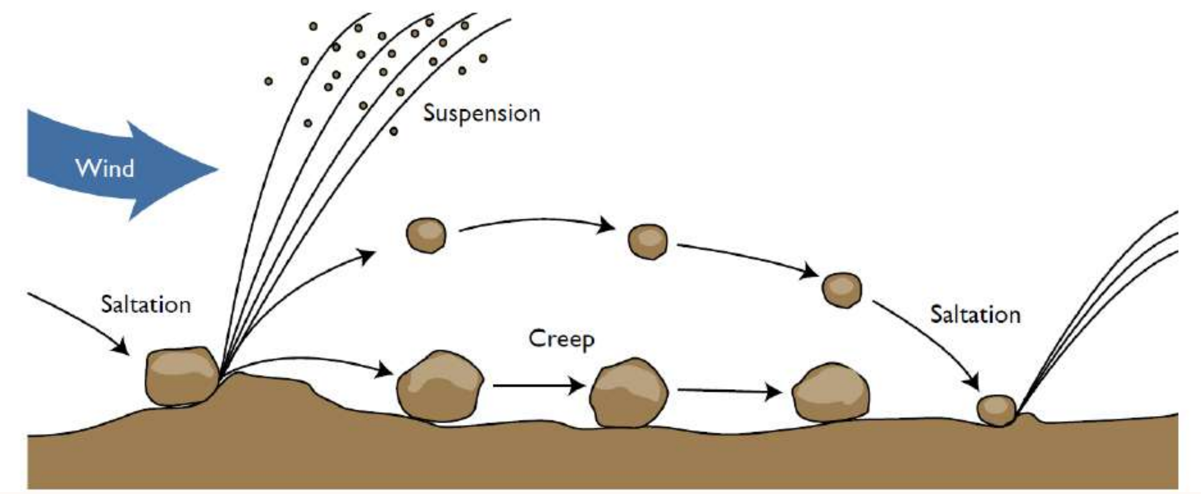

Figure 1 Different types of soil movement by wind. (From USDA, 1989)

i. **Suspension:** Movement of fine dust particles smaller than 0.1 mm diameter by floating in the air is known as suspension. Soil particles carried in suspension are deposited when the sedimentation force is greater than the force holding the particles in suspension. This occurs with decrease in wind velocity. Suspension usually may not account for more than 15% of total movement.

ii. **Saltation:** The major portion of soil carried by the wind is moved in a series of short bounces called "saltation." The soil carried in a saltation consists of fine particles ranging from 0.1 to 0.5 mm in diameter. About 50-75% of soil erosion by wind carried out by saltation. Saltation is caused by the direct pressure of wind on soil particles and their collision with other particles. After being pushed along the ground surface by the wind, the particles leap almost vertically in the first stages of saltation.

iii. **Surface creep:** Soil particles, larger than about 0.5 mm in diameter but smaller than 3.0 mm, are too heavy to be moved in saltation but rolled and sliding along the surface by the pressure of wind and hitting during saltation. About 5-25% of soil erosion carried out by surface creep. About 90% of the total soil movement in wind erosion is below the height of 30 cm and about 50% of it is within 5 cm of the ground level.

14.4.4 Factor affecting Wind Erosion

i. **Wind erosivity:** Wind characteristic like velocity, turbulence, frequency, duration seasonality are important parameters affecting erosion. Wind velocity is the most important wind factor affecting erosion; higher wind velocity equates to higher wind energy and erosivity. Wind speed of about 20 km hr^{-1} is required to initiate movement. At higher velocities the transport capacity of moving air increases with the cube of wind velocity.

ii. **Soil erodibility:** Soil erodibility refers to the ease of detachment and transport by wind. Soil characteristics that affect erodibility of soil due to wind are texture, structure, and water content. Texture is considered as the most dominant factor, and it is commonly agreed that particles smaller than 0.25 mm and larger than 0.08 mm are most easily eroded by wind. Soils with characteristics like fine sand particles having low organic matter contents, single grains to massive in arrangement, with friable and non-sticky consistence, etc. are more easily subjected to wind erosion.

The **soil erodibility factor** (K-factor) is a quantitative description of the inherent erodibility of a particular soil; it is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. For a particular soil, the soil erodibility factor is the rate of erosion per unit erosion index from a standard plot. The factor reflects the fact that different soils erode at different rates when the other factors that affect erosion (e.g., infiltration rate, permeability, total water capacity, dispersion, rain splash, and abrasion) are the same. Texture is the principal factor affecting K_{fact}, but structure, organic matter, and permeability also contribute. The soil erodibility factor ranges in value from 0.02 to 0.69.

iii. **Landform:** Features of landscape that affect wind erosion are the field length, exposed topographic location, field orientation, and shelter relative to erosive wind.

iv. **Cover:** Vegetative covers reduce the wind velocity at the soil surface and also generally decrease the soil erodibility. The relationship between vegetation coverage and wind erosion rate is an exponential function, i.e., with the increase of vegetation coverage the wind erosion rate decreases exponentially.

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Course Name	Problematic soils and their Management
Lesson 15	Monitoring, measuring and remediation of Eroded Soils
Content Creator Name	Dr. SHWETA SHAMBHAVI
University/College Name	Bihar Agricultural University, Bhagalpur
Course Reviewer Name	DIBYENDU MUKHOPADHYAY
University/college Name	Uttar Banga Krishi Viswavidyalaya, Coochbehar

Learning Objectives

- Understand the principles and techniques of soil loss measurements.
- Understand the biological, agronomic and engineering measures of soil conservation and management of ravinous and eroded lands.

Glossary of terms

1. **Agroforestry:** Agroforestry is a system of growing agricultural or horticultural crops or/and rearing livestock along with trees simultaneously or sequentially in the same piece of land.
2. **Alley Cropping:** In alley cropping, crops (grains, forages, vegetables, etc.) are grown between tree rows spaced widely enough to accommodate the mature size of the trees without interfering for light and moisture with the crops between the rows.
3. **Conservation Tillage:** Conservation tillage is any system that reduces the number of tillage operations, reduces the area of tilling in the field, and maintains residue cover on the soil surface.
4. **Contour cropping:** Ploughing and planting crop in the contour that is across the slope is called contour cropping or contour farming.
5. **Contour strip cropping:** Contour strip cropping is planting row crops in strips on the contour. It is more efficient in erosion control than contour farming and strip cropping alone because of the plant and crop diversity.
6. **Cover Crops:** Cover crops are close-growing crops that provide soil protection, seeding protection, and soil improvement between

periods of normal crop production or between trees in orchards and vines in vineyards.

7. **Grassed Waterways:** Grassed waterways are natural or constructed channels established at an appropriate place over the field for safe transport of concentrated water at a reduced velocity using adequate grass cover. They are generally broad and shallow drainways to transport surface water across farmland without causing soil erosion.
8. **Mulching:** A cover spread or laid over the surface to protect soil is called mulch.
9. **Rainfall Erosivity factor:** Rainfall erosivity is the kinetic energy of raindrop's impact and the rate of associated runoff. The R-factor is a multi-annual average index that measures rainfall's kinetic energy and intensity to describe the effect of rainfall on sheet and rill erosion
10. **Soil Loss Tolerance Value (T Value):** The soil loss tolerance value has been defined as an indication of how much erosion should be tolerated.
11. **Strip cropping:** In strip cropping, two or more crops are grown in alternate strips. Crops of different strips vary in their root/shoot characteristics and cultural requirements.
12. **Soil Erodibility Index:** It is defined as the potential soil loss in tonnes per hectare per year from a wide, unsheltered isolated field

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with a bare, smooth, non-crusted surface. This index is a function of soil aggregates greater than 0.84 mm in diameter.

15.1 Introduction

Estimating soil erosion is important for determining erosion severity and its influence on land use and management plans. Erosion is often best estimated with models, due to the number of variables involved. The most commonly used models are the Universal Soil Loss Equation (USLE), Revised Universal Soil Loss Equation (RUSLE), used to estimate water erosion, and the Wind Erosion Equation (WEQ). Both USLE and WEQ are defined by equations where a number of factors affecting erosion are taken into account to determine average annual erosion rates. Factors include climate, soil erodibility, surface roughness, length of field, vegetative cover, and in some scenarios, an erosion control practice.

15.2 Assessment of Soil Erosion by Water

15.2.1 Soil Loss Tolerance Value (T Value)

The soil loss tolerance value has been defined as an indication of how much erosion should be tolerated. The T value is the maximum soil erosion loss that does not cause significant loss in productivity. It depends on soil characteristics. For example, shallow soils over hard bedrock have small T values. More erosion loss can be tolerated for thick permeable soils on permeable unconsolidated parent materials. The T value is the maximum average annual soil loss that allows continuous cropping and maintains soil productivity without requiring additional management inputs. Many soils that have developed from thick sediments of loess are agriculturally productive. Where subsoils have physical properties unsuitable for rooting, erosion results in reductions in soil productivity that cannot be overcome with only fertilizer application. Such soils have low tolerance levels (small T value).

15.2.2 Soil Loss Equations (USLE and RUSLE)

Soil erosion is influenced by many different variables, the essence of the universal soil loss equation (USLE) is to isolate each variable and reduce its effect to a number, so that when these numbers are multiplied together, the answer is the amount of soil loss. The soil loss is an average erosion rate for the landscape profile. RUSLE uses the same factorial approach employed by the USLE:

$$A = R \times K \times LS \times C \times P$$

A – Potential long-term average annual soil loss in tons per acre per year (× 2.24 Mg ha $^{-1}$ year $^{-1}$). This is the amount that is compared to the “tolerable soil loss” limits.

R – Rainfall and runoff factor. The greater the intensity and duration of the rainfall, the higher the erosion potential.

K – Soil erodibility factor. K is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. Texture is the principal factor affecting K, but structure, organic matter, and permeability also contribute.

LS – Slope length and steepness factor. The LS factor represents a ratio of soil loss under given conditions. The steeper and longer the slope is, the higher is the risk for erosion. This is a very important factor in the overall erosion rate.

C – Crop management factor. It is used to determine the relative effectiveness of soil and crop management systems in terms of preventing soil loss. The C factor is a ratio comparing the soil loss from land under a specific crop and management system to the corresponding loss from continuously fallow and tilled land. The crop grown, type and timing of tillage, the use of winter cover, and the application of solid manure will all impact on the C factor.

P – Support practices factor. The P factor compares the soil losses from up- and downslope farming to losses that result from practices such as cross-slope cultivation, contour farming, and strip cropping.

In RUSLE, the factors have been updated with recent information, and new factor relationships have been derived based on modern erosion theory and data.

Major changes to the USLE incorporated into RUSLE include:

R factor: new and improved is erodent maps and erodibility index distributions for some areas

K factor: time-variant soil erodibility which reflects freeze – thaw in some geographic areas

LS factor: new equations to account for slope length and steepness

C factor: additional subfactors for evaluating the cover and management factor for cropland and rangeland

P factor: new conservation practice values for cropland and rangeland

a. Rainfall Erosivity Factor (R)

Generally, local variations in rainfall erosivity (+5 %) can be represented with a single R value. R values can be calculated for specific locations from rainfall intensity data. However, this is a very time- and labor-intensive process requiring erodibility index calculations for each storm event greater than 0.5 in. for each rain gauge over a period of years.

b. Soil Erodibility Factor (K)

The K factor represents both susceptibility of soil to erosion and the amount and rate of runoff. Soil texture, organic matter, structure, and permeability determine the erodibility of a particular soil. K values for various soil types are given below.

Soil type	Erodibility	K value range
Fine-textured; high in clay	Low	0.05–0.15

Coarse-textured; sandy	Low	0.05–0.20
Medium-textured; loams	Moderate	0.25–0.45
High silt content	High	0.45–0.65

b. Slope Length and Steepness Factor (LS)

The LS factor represents the combined effects of slope length and steepness relative to a standard unit plot on the erodibility. Slopes of non-uniform steepness require dividing the slope into segments. Usually, five segments comprised of slope length and steepness are sufficient to define a non-uniform slope profile. There are different equations for calculating LS factor for different slope conditions.

b. Cover and Management Factor (C)

The C factor represents the effect of plants, soil cover, belowground biomass, and soil-disturbing activities on soil erosion. Both time-variant (cropping/rotation scenario) and time-invariant (average annual values) modules have been constructed. The time-variant option is used when plant and/or soil conditions change enough to significantly affect erosion during the year, during a rotation cycle, or over an extended period. This option is typically applied to croplands; rangelands where cover changes significantly during the year such as from grazing, burning, or herbicide application. The time-invariant option is used where constant conditions can be assumed. The C factor depends on effective root mass in top 4" of soil, percent canopy, average fall height (ft), surface roughness value (index of average micro- elevation: generally ranges from 0.3 to 1.5), percent ground cover (rock + litter, excluding plant basal cover), and surface cover function expressed as B value (the relative effectiveness of surface cover for reducing soil loss). The choices of B value are based on the ratio of rill/inter rill erosion under bare soil conditions. Some typical B values are given below:

Field Conditions (B Value)

Flat and short slopes, where soil is resistant to erosion by flow, consolidated lands (e.g., pasture)	0.025
Moderate slopes and slope lengths with moderate disturbance	0.035
Steep and long slopes where soil is highly disturbed and where soil is susceptible to erosion by flow	0.045
Range lands, where runoff tends to be low and affected by cover	0.045
Long-term no-till cropping, especially where no-till significantly reduces runoff	0.050

15.3 Control of soil erosion by water is based on the following principles:

- Reducing raindrop impact: This can be achieved by providing a cover on the soil during the rainy season. Dense forest canopy, close-growing crops such as cover crops and mulches on the bare or cropped soils can provide necessary protection against raindrop impact.

• Stabilizing soil aggregates: Stable soil aggregates are obtained in soils supplied with sufficient organic matter. Aggregation improves porosity and infiltration and reduces runoff.

• Increasing infiltration and reducing runoff: Infiltration can be increased by mulching and by modification of the slope. Organic mulches soak water and allow water more time to infiltrate. Level lands have more infiltration capacity than sloping soils.

• Reducing velocity of runoff: Velocity of runoff can be reduced by modifying the degree and length of slope through terracing and contouring. Contour cropping, strip cropping, and contour strip cropping effectively reduce runoff velocity. When velocity of runoff is reduced, rate of infiltration increases.

• Minimum disturbance of soil: Tillage makes the soil more erodible. Conservation tillage systems, including no-tillage, minimum tillage, and subsoil tillage are efficient soil conservation practices.

• Preventing concentration of runoff water in channels: Levelling previously developed rills, growing crops closely, and keeping crop residues in field prevent concentration of runoff water.

• Carrying runoff water safely out of field: Runoff water can be driven safely out of the field by grassed waterways.

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• Integrating erosion control measures: Usually, no one method alone is sufficient for the control of soil erosion. For example, integrating mulching with no-tillagecan effectively reduce erosion.

• Regular maintenance of erosion control measures: Practices for erosion control need to be maintained regularly. Terraces may need mending and barriers may need reconstruction.

15.4 Control Measures for Water erosion

15.4.1 Amendments

Addition of manures and composts favours structure formation; increases aggregate stability, porosity, and infiltration; and thus, reduces runoff. Manuring can reduce water runoff by 70–90 % and sediment loss by 80–95 % as a result of increased organic matter content (Grande et al. 2005). Using manure in combination with other conservation practices, such as no-till may be an effective strategy for reducing soil erosion. However, indiscriminate use of manure may have detrimental impacts on water quality as well.

15.4.2 Cover Crops

According to the Soil Science Society of America, cover crops are close-growing crops that provide soil protection, seeding protection, and soil improvement between periods of normal crop production or between trees in orchards and vines in vineyards (SSSA 2008). Cover crops are presently used as an important companion practice to no-till, reduced tillage, alley cropping, agroforestry, and other conservation practices designed to reduce soil erosion and improve quality of soil and water resources. Retaining cover crops as mulch is more benefitting than ploughing under in soils where the erosion rate is high. Cover crop mulch on the soil surface increases soil organic matter content and suppresses weeds in addition to protection against erosion (Blanco and Lal, 2008).

Figure 1 Cover crops on a field in Black Hawk County, Iowa (Photo courtesy of USDA-NRCS)

15.4.3 Conservation Tillage

Conservation tillage is any system that reduces the number of tillage operations, reduces the area of tilling in the field, and maintains residue cover on the soil surface. The Soil Science Society of America (SSSA) defines conservation tillage as a tillage system that leaves at least 30 % of residue cover on the soil surface.

When combined with prudent management of crop residues, crop rotations, and cover crops, conservation tillage is a useful technology for protecting soil and sustaining crop production (Blanco and Lal, 2008).

Conservation tillage includes no-till and reduced or minimum tillage systems such as mulch tillage, strip tillage, and ridge tillage. Cropping with no-tillage or limited tillage is not as popular as with tillage. But for negative impacts of conventional tillage, including exposure of the soil surface to wind and water erosion, and loss of soil organic matter through oxidation, conservation tillage is gaining popularity. These management strategies have proved effective for controlling soil erosion and improving soil quality. In no-tillage, crops are planted directly in the residues of the previous crop with no prior tillage. For row crops, a slit is made in the soil in which the seed is sown. Minimum tillage involves the minimum manipulation of soil. It is actually a localized tillage. Minimum and no-tillage leave more residues on the soil surface than conventional tillage, resulting in enhanced infiltration and reduced runoff and soil erosion for which they are called conservation tillage. A strip 30–45 cm wide is tilled in the row between undisturbed spaces during strip tillage. Strip-till is less effective than no-till and subsoil systems, because bare soil exposed in the tilled strip is susceptible to erosion. It can be made effective by covering the exposed part with organic residues.

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Figure 2 Young soybean seedlings in a no-till field (Photo courtesy of USDA-NRCS)

Figure 3 Strawberries grown through reduced tillage (Photo courtesy of USDA-NRCS)

15.4.4 Mulching

A cover spread or laid over the surface to protect soil is called mulch. Organic mulches are efficient soil conservation measures. Organic mulches include compost, composted manure, grass clippings, newspaper, straw, and shredded leaves. They are natural and cheap, and along with protection, they improve soil fertility. Mulching has multiple advantages. It reduces the impact of solar radiation and raindrops. It protects soil aggregates from detachment by raindrops. It reduces evaporation and loss of soil moisture; it increases infiltration and reduces amount and velocity of runoff. It decreases surface sealing, crusting, and compaction. Stubble mulching is frequently recommended for reducing runoff and erosion. Residues of wheat or stalk of corn of the previous crop are retained during tilling the land for next crop without turning them under. Stubble mulch is a very efficient protector of wind erosion. Organic mulches release polysaccharides, polyuronides, and other cementing agents which improve soil structure. Mulched plants have more roots than plants that are not mulched. Inorganic mulches also provide many benefits to the landscape. Materials that can be used as inorganic mulches are crushed gravel and granite, river rock or small stones, lava or granite rock, decorative and colored stones, sand, crushed brick, crushed graded recycled glass, landscape fabric sometimes referred to as geo-textiles, plastic mulch, and aluminized mulch.

Figure 4 Soybean mulched with corn straw (Photo courtesy of USDA-NRCS)

15.4.5 Contour Cropping

Ploughing and planting crop in the contour that is across the slope is called contour cropping or contour farming. Contours are arbitrary lines drawn perpendicular to the direction of slope. So, contour farming is a cross-slope farming system. Contours reduce velocity of runoff, give accumulated water more time to infiltrate, and deposit detached soil particles along the contour lines. It retains sediments in the field. In contour farming, ridges and furrows are formed by tillage, planting, and other farming operations to change the direction of runoff from directly down slope to around the hill slope. Contour farming is most effective on slopes between 2 and 10 %. Contour farming is not well suited to rolling topography having a high degree of slope irregularity. Several factors influence the effectiveness of contour farming to reduce soil erosion. They are rainfall intensity, slope steepness, soil properties, ridge height, cover and roughness, and the critical slope length. Cover, roughness, and ridge height can be influenced by management. Spacing of contour lines is chosen on the basis of slope, soil, rainfall, and crop type. Annual and perennial crops are planted in the ridges or furrows of the contours. Contour farming can be combined with strip cropping.

Figure 5 Contour cropping (Photo courtesy of USDA-NRCS)

15.4.6 Strip Cropping

In strip cropping, two or more crops are grown in alternate strips. Crops of different strips vary in their root/shoot characteristics and cultural requirements. Crop strips break sloping landscapes in wide segments with diverse vegetative cover which intercepts runoff and promotes water infiltration, thereby reducing runoff and soil erosion. Sod-forming crops may be alternated with cereals, legumes with non-legumes, and root crops with vegetables. Strip cropping gives yields as good as monocropping. The width of the strips depends on soil slope, erosion potential, crop type, and equipment size. Narrow strips reduce flow lengths more effectively than wide strips. The width of strips must match the equipment turn or width for cultivation. On gentle slopes of up to 5 %, a strip width of about 30 m is recommended while on steeper slopes the width must be less than 20 m (Bravo and Silenzi, 2002). Strip cropping may be successfully combined with contour farming.

Figure 6 Strip cropping (Photo courtesy of USDA-NRCS)

15.4.7 Contour Strip Cropping

Contour strip cropping is planting row crops in strips on the contour. It is more efficient in erosion control than contour farming and strip cropping alone because of the plant and crop diversity. The grass, legumes, or small grains used in strips slow runoff and trap sediments leaving row crops. Permanent grass/legume strips must be maintained between strips in soils with severe erosion. These strips can be used as traffic lanes for cultural operations (Blanco and Lal, 2008).

Figure 8 Contour strip cropping (Photo courtesy of USDA-NRCS)

15.4.8 Sloping Agricultural Land Technology (SALT)

SALT is a technology package of soil conservation and food production that integrates several soil conservation measures (Tacio, 1993). It involves planting field crops and perennial crops in bands 3–5 m wide between double rows of nitrogen fixing shrubs and trees planted along the contour.

15.4.9 Agroforestry

Agroforestry is a system of growing agricultural or horticultural crops or/and rearing livestock along with trees simultaneously or sequentially in the same piece of land. The objectives of agroforestry include conserving soil, recycling nutrients, and enhancing crop yields, while producing fuelwood, fodder, grain, fruit, and timber. It involves the integration of trees, plants, and animals in conservative, long-term, productive systems. The positive interactions among all these components are exploited in carefully designed sustainable agroforestry systems (Sanchez, 1995) by (i) multiple use of land; (ii) improved utilization of land, labour, and resources; (iii) protection and improvement of soil by reducing erosion and providing soil organic matter; (iv) production of diverse food crops such as fruits, nuts, grains, and seeds; (v) production of feed for farm animals; (vi) long-term production of tree products; and (vii) enhanced productivity and net economic returns.

15.4.10 Alley Cropping

In alley cropping, crops (grains, forages, vegetables, etc.) are grown between tree rows spaced widely enough to accommodate the mature size of the trees without interfering for light and moisture with the crops between the rows. When light-demanding crops like corn (maize) will be grown, the alleyways need to be wide enough to let in plenty of light even when the trees have matured. Alternatively, the cropping sequence can be planned to change as the trees grow. For instance, soybeans or corn could

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be grown when the trees are very small; as the tree canopy closes, forages could be harvested for hay; and finally, when the trees are fully grown and the ground is more shaded, grazing livestock, or shade-tolerant crops like mushrooms or ornamental ferns could occupy the alleyways.

Figure 9 Alley cropping of cowpea with Leucaena (Photo courtesy of IITA)

15.4.11 Buffer Strips

Buffer strips are zones of permanent vegetation – trees, shrubs, and grasses – used for different purposes including reduction of erosion. Buffers reduce runoff by obstructing its way and cutting downslopes, filter sediments, and remove sediment borne chemicals and dissolved nutrients and agrochemicals. Buffer strips are generally established between agricultural lands and streams, rivers, and lakes. When placed perpendicular to the direction of water flow, buffers are effective measures for reducing sediment fluxes. Buffers are commonly used in sloping lands of developing regions where access to heavy equipment and construction of mechanical structures (terraces) can be unachievable. Benefits of buffers include yield of good quality water, enhanced agricultural production, secured wildlife habitat, and desired landscape aesthetics. Buffers can trap > 70 % of sediments and > 50 % of nutrients depending on the plant species, management, and climate (Blanco and Lal, 2008). Buffers are multifunctional systems. Above the surface, buffers reduce the runoff velocity and trap sediments and nutrients, and below the surface, they stabilize the soil in place, bind the soil aggregates, improves the structural characteristics, and increase soil organic matter content and water transmission characteristics.

15.4.12 Grassed Waterways

Grassed waterways are natural or constructed channels established at an appropriate place over the field for safe transport of concentrated water at a reduced velocity using adequate grass cover. They are generally broad and shallow drainways to transport surface water across farmland without causing soil erosion. Grassed waterways are used as outlets to prevent rill and gully formation. The grass cover slows the flow of water and minimizes channel erosion. Efficient grassed waterways can transport large water flows downslope without causing any harm. Grassed waterways also act as diversion channels. Grasses trap suspended sediments and absorb dissolved nutrients. It also traps dissolved nitrates, phosphates, herbicides, and pesticides and improves water quality of adjacent reservoirs.

Figure 10 Grassed waterways (Photo courtesy of USDA-NRCS)

15.4.13 Terracing

Terracing refers to the building of a mechanical structure, a channel and a bank or an earthen ridge or a stone wall on the land to reduce steepness of slope and divide the slope into short gently sloping sections. Terraces are created to encourage infiltration, to intercept surface runoff, or divert toward a pre-determined and protected safe outlet at a controlled velocity to avoid soil erosion. Terracing reduces runoff velocity below this threshold values. It is one of the oldest means of saving soil and water. Moreover, it is the most widely used soil conservation practice throughout the world. The **diversion terraces** are used to intercept runoff and channel it across the slope to a suitable outlet. The **retention terraces** are used when the objective is to conserve water by storing it on the hillside. These terraces are normally recommended only for permeable soil on slope of less than 4.5 ^{0}C. The **bench terraces** consist of series of alternating shelves and risers and are employed on steep slopes up to 30 ^{0}C.

Cut

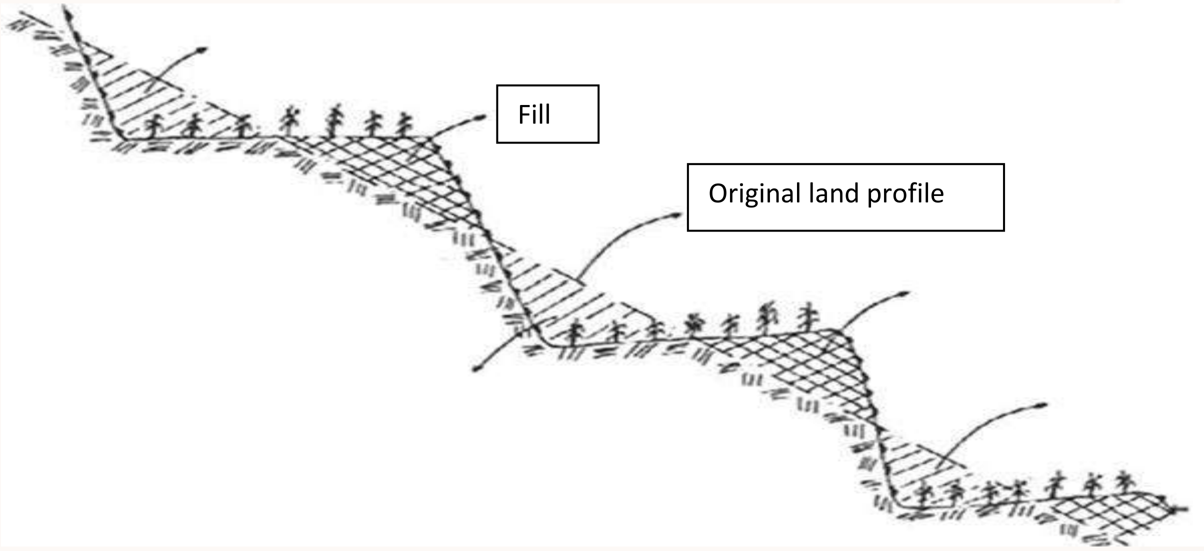

Figure 11 A sketch of a typical bench terrace (FAO 2000)

15.5 Assessment of Soil Erosion by Wind

Wind Erosion Equation

Several factors of wind erosion have been included in the wind erosion equation (WEQ), which is an erosion model designed to predict long-term average annual soil losses from a field having specific characteristics. The equation is shown as

E = f (IKCLV)

where

E = estimated average annual soil loss expressed in tons per hectare per year

I = soil erodibility index (t ha^{-1} yr^{-1}). It is defined as the potential soil loss in tonnes per hectare per year from a wide, unsheltered isolated field with a bare, smooth, non-crusted surface. This index is a function of soil aggregates greater than 0.84 mm in diameter.

K = soil ridge roughness factor is a measure of soil surface roughness other than that caused by clods or vegetation, i.e., it is the natural or artificial roughness of the soil surface in the form of ridges or small undulations. It can be determined from a linear measure of surface roughness.

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

L = equivalent unsheltered distance across the field along the prevailing wind erosion direction

V = equivalent vegetative cover factor which depends on standing line biomass, standing dead residue and flattened crop residue.

15.6 Principles of Wind Erosion Control

As early as in 1910, a USDA Farmers' Bulletin listed actions to control soil blowing as follows:

- Increase the water content of the soil.
- Increase the amount of humus (organic matter).
- Provide a cover of growing vegetation.
- Leave the stubble of the previous crop still standing on the land.
- Provide an artificial cover of straw and brush lines.
- Plant windbreaks to protect fields.
- Leave the soil surface in small clods instead of in a finely pulverized condition.

- Roughen the surface by proper cultivation at right angles to the direction of dangerous winds.

15.7 Wind Erosion Control Measures

Many conservation practices can be implemented to control wind erosion. Conservation practices are designed to either reduce the wind force at the soil surface or create a soil surface more resistant to wind forces. Some practices also trap saltating particles to reduce the abrasion of soil surfaces downwind.

15.7.1 Stabilization of Soil

Various soil stabilizers have been employed for the control of wind erosion. Many of these products successfully control wind erosion for a short time. However, easy and inexpensive stabilization may also be obtained by vegetative measures such as wheat straw anchored with a rolling disk packer. Often, chemical soil-stabilizing agents are used with varying success. The criteria for surface soil stabilizers according to Armbrust and Lyles (1975) are as follows: (1) 100 % of the soil must be covered, (2) the stabilizer must not adversely affect plant growth or emergence, (3) erosion must be prevented initially and reduced for the duration of the severe erosion hazard, usually for at least 2 months each season, (4) the stabilizer should apply easily and without special equipment, and (5) cost must be low enough for profitable use. They found five polymers and one resin-in-water emulsion that met all these requirements. These were Coherex, DCA-70, Petroset SB, Polyco 2460, Polyco 2605, and SBR Latex S-2 105.

These stabilizers may prevent wind erosion if applied to the total soil surface and at a sufficiently high rate, but their costs are prohibitive. For applying soil stabilizers in agricultural land, we need to develop (i) methods for applying large volumes rapidly, (ii) reliable pre-emergent weed control chemicals for use on coarse-textured soils, (iii) films strong enough to withstand raindrop impact and still allow water and plant penetration, and (iv) films that at have no adverse effects on the soil–water–air environment.

15.7.2 Cover Crops

Cover crop means plants or a green manure crop grown for seasonal soil protection or soil improvement. Cover crops help control soil movement and protect the soil surface between crops. Cover crop reduces wind erosion by shielding the soil with vegetation and anchoring the soil with roots. Green manuring cover crops are tilled into the ground in the spring, at least 1 month before planting the next crop. This provides additional nutrients to the crop, as the cover crop decomposes. The Dust Bowl (a period of severe dust storms causing major ecological and agricultural damage to American and Canadian prairie lands in the 1930s) has taught farmers the importance of planting cover crops for the control of wind erosion. Legumes, such as soybean or clover, are common choices for cover crops. Their vegetation reduces ground air pressure, and their roots hold the soil in place, in addition to their contribution to fixation of nitrogen.

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15.7.3 Ridging and Surface Roughening

Chepil and Milne (1941) observed that the initial intensity of drifting was always much less over a ridged than a smooth surface. Ridging cultivated soils reduces the severity of drifting. However, ridging highly erosive dune materials was less effective because the ridges disappeared rapidly. Experimental data showed that the rate of flow varied inversely with surface roughness. It is influenced by ridge spacing and ridge height, and it is defined relative to a 1:4 ridge height to ridge spacing ratio. A soil ridge roughness of 6 cm reduces wind erosion 50 %. Emergency tillage is most effective when done at right angles to the prevailing wind direction. Because clods eventually disintegrate (sometimes rapidly), emergency tillage offers, at best, only temporary wind erosion control (Woodruff et al. 1972).

15.7.4 Residue Management

Residues of the harvested crops protect soil against wind erosion. Standing crop residues provide non-erodible elements that absorb much of the shear stress in the boundary layer. When crop residues are sufficiently high and dense to prevent intervening soil, surface drag from exceeding threshold drag, soil will not erode. Standing stubble effectively protects the soil from wind erosion. Stubble mulching is a crop residue management system using tillage, generally without soil inversion and usually with blades or V-shaped sweeps. The goal is to leave a desirable quantity of plant residue on the surface of the soil at all times. Residue is needed for a period of time even after the crop is planted to protect the soil from erosion and to improve infiltration. The residue used is generally that remaining from a previous crop. Any crop residue, either grown in place or hauled in and spread, can control wind erosion. Last year's wheat or corn residues are uniformly spread over the field; they form effective cover mulch. However, residues must be spread and anchored to the soil surface by a packer or an anchoring agent such as cutback asphalt or asphalt emulsion. Depending on residue type, minimum amounts needed to control wind erosion are 5–10 t ha^{-1}.

15.7.5 Wind Barrier

Barriers reduces wind erosion by (1) reducing the field width, (2) reducing the distance that wind travels in crossing unprotected field strips, (3) decreasing wind velocity, and (4) trapping wind-blown and saltated soil. Use of wind barriers is an effective old wind erosion control measure. Different combinations of trees, shrubs, tall-growing crops, and grasses can reduce wind erosion. Besides the more conventional tree windbreak many other barrier systems are used to control wind erosion. They include annual crops like small grains, corn, sorghum, Sudan grass, sunflowers and tall wheat grass. Most barrier systems for controlling wind erosion, however, occupy space that could otherwise be used to produce crops. They are arranged usually perpendicular to the direction of the prevailing wind. They reduce the velocity of the wind at the ground level to a distance approximately ten times of the height of plants.

15.7.6 Strip Cropping

The practice of farming land in narrow strips on which the crops alternate with fallow is an effective aid in controlling wind erosion. Strips are most effective when they are at right angles to the prevailing wind erosion direction but also provide some protection from winds that are not perpendicular to the field strip. Strip cropping reduces erosion damage in the following ways: it reduces the distance the wind travels across exposed soil, localizes drifting that starts at a focal point, and reduces wind velocity across the fallow strip when adjacent fields are covered with tall stubble or crops.

15.7.7 Stabilization of Dunes

A dune is usually a low hill of sand built by the flow of wind or water. Dunes occur in different forms and sizes throughout the world, from coastal and lake shore plains to arid desert regions. In addition to the remarkable structure and patterns, they are habitats of a variety of life adapted to this unique environment. Most kinds of dunes are longer on the windward side where the sand is pushed up the dune and have a shorter slip face in the lee of the wind. Dunes are sensitive and unstable ecosystems. Dunes need to be stabilized, and for it, every effort should be made to protect the integrity of the natural dune ecology. Dune stabilization involves structural and vegetative measures. Vegetative measures are more effective to stabilize and rehabilitate the dunes. Vegetation establishment can be done by planting native grasses, trees, shrubs, or ground covers. Dune grasses can be effectively used for dune stabilization. Grass should be planted in a staggered or diamond pattern for maximum erosion control. Holes should be spaced 50 cm apart in areas where wind velocities and sand movement are high. Culm-to-culm distance should be 60 cm in areas not directly exposed to strong wind. The holes for plants should be between 15 and 25 cm deep to prevent the base of the stem from drying out and to prevent the entire plant from blowing out. Sand should be firm and moist around roots, with no air pockets near the base of the plants. Mulch should be applied between plants to protect plantings against rain and wind. Trees can be planted in beach grass after it has controlled sand movement, but before the grass becomes too dense. This may be done about 2 years after planting beach grass. Spacing of trees should be 2 × 2 m.

The mulch technique which consists of covering the dune uniformly with a natural or artificial protective cover to prevent saltation can be adopted on flat or reasonably even surfaces. The mulch can be made of various materials, such as straw, branches, stalks, plastic film or acrylic fiber, and mesh.

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Lesson 16	Compacted Soils
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Learning Objectives

- Understanding soil compaction in terms of reduced porosity, aeration, infiltration and increased bulk density.
- Understand the factors for soil compaction, mechanical impedance to root growth and management of compacted soils.

Glossary of terms

1. **Hardpan:** It is a hardened soil layer in the lower A or in the B horizon caused by cementation of soil particles with organic matter, silica, sesquioxides and calcium carbonate, etc. The hardness does not change appreciably with variation in soil moisture.
2. **Hydraulic conductivity:** Hydraulic conductivity is a measure of a material's capacity to transmit water. It is defined as a constant of proportionality relating the specific discharge of a porous medium under a unit hydraulic gradient in Darcy's law
3. **Infiltration:** Infiltration is the process by which water on the ground surface enters the soil. Infiltration is governed by two forces, gravity, and capillary action.
4. **Puddling:** Refers to breaking down soil aggregates at near saturation into ultimate soil particles.
5. **Soil compaction:** Compaction of soil is the compression of soil particles into a smaller volume, which reduces the size of pore space available for air and water.
6. **Soil porosity:** “Soil porosity” refers to the amount of pores, or open space, between soil particles. Pore spaces may be formed due to the

movement of roots, worms, and insects; expanding gases trapped within these spaces by groundwater; and/or the dissolution of the soil parent material.

16.1 Introduction

Soil compaction can be a serious and unnecessary form of soil degradation that can result in increased soil erosion and decreased crop production. Compaction of soil is the compression of soil particles into a smaller volume, which reduces the size of pore space available for air and water. Most soils are composed of about 50 per cent solids (sand, silt, clay and organic matter) and about 50 per cent pore spaces. Soil compaction occurs when soil particles are compressed together-especially when the soils are wet that destroy soil structure, reducing porosity, and leading to a more dense soil that is hard for crop roots and water to penetrate. Changes in agricultural practices, such as increased number of field operations and larger equipments, have made soil compaction more common on many fields. Field operations, such as silage crop harvest when the soil is wet, can lead to severe soil compaction. Grazing cattle on range and farmlands is very common in the Southwest, but compaction due to grazing is short-lived due to freeze/thaw cycles, and the total weight of grazing animals is often not sufficient to initiate deeper compaction (Baumhardt et al., 2011). However, soil puddling (trampling of soil by animals under very wet conditions) can occur due to overgrazing, resulting in structural breakdown at the soil surface and subsequent crust formation when the soil dries out. Soil compaction affects many agricultural fields and can lead to yield reductions if not properly managed.

16.2 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.

16.3 Types of soil compaction

Soil compaction can occur at the soil surface in the form of soil crusting, or it can occur in the subsoil. Soil compaction is sometimes blamed for reduced crop productivity, but it is important to correctly diagnose the cause or causes of reduced crop production. Poor plant growth can be caused by a number of factors, including soil compaction.

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Compaction of agricultural soils can be caused by various farming practices:

- Soil tillage that removes the protective residue from the soil surface, leaving the soil prone to natural environmental forces or excessive soil tillage that causes surface soil aggregates to break down or degrade, can lead to soil crusting, causing the surface soil layer to become hard, and compacted.
- Soil tillage implements can induce soil compaction just below the depth of tillage, particularly when soils are wet.
- The weight of large farm equipment (tractors, seed carts, combines, trucks, manure spreaders) can cause wheel traffic compaction to a considerable depth within the root zone. As soil moisture content increases, so too does the depth of soil compaction.

16.3.1 Surface soil crusting

Compaction by combination of soil tillage and raindrop or irrigation water impact

Soil tillage can bury much of the protective residue cover on the soil surface and degrade the granular structure of surface soils (mechanical crushing or breaking of larger soil aggregates). The impact energy of rainfall or irrigation droplets can also cause considerable degradation and breakdown of soil aggregates, causing soil particles to become suspended in water, flow together and then dry into a hard surface soil crust. The crusted soil can restrict water infiltration into soil and restrict the emergence of germinating crops.

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Surface soil crusting is the result of leaving bare soil exposed to the forces of precipitation or irrigation water. The best way to prevent soil crusting in fields is to both minimize tillage operations and ensure that a protective layer of residue remains on the soil surface to absorb the impact of water droplets before they strike and break down stable soil aggregates. This can be achieved by reduced tillage or, preferably, by using direct seeding practices. These methods leave greater amounts of residue on the soil surface to reduce soil crusting and increase soil organic matter levels, leading to improved surface soil structure.

Using crop management practices such as including forage in the crop rotation or using direct seeding practices to increase the levels of soil organic matter will aid in the development of a good granular-structured soil that has greater resistance to breakdown. In irrigated fields, it is also very important that water application is managed to ensure the infiltration rate of soil is not exceeded.

16.3.2 Subsurface compaction

Hardpan tillage-induced compaction

A tillage-induced compaction layer is sometimes referred to as a “hardpan,” or “plow pan” and occurs in the layer of soil just below the depth of tillage. It occurs when soils are cultivated repeatedly at the same depth. The weight of the tillage equipment, such as discs or cultivator shovels, can cause compression of the soil and smearing at the base of contact between the soil and tillage implement. Usually the compacted layer is about 2 to 3 cm thick. Compaction will increase when soil moisture conditions are wet at the time of tillage and/or if soils have a higher silt and clay content. In extreme cases, the compaction can be quite serious, affecting water and root penetration into the subsoil. However, with coarser textured soils, the hardpan tends to be weaker and more friable, and may not affect crop production. The clay may be hard when dry and softer when wet, but always impedes the flow of water, causing drainage problems. Fragipan is a layer of dense, compact cemented silt and fine sand. Like other pans, it impedes the movement of water. Fragipan is hard when dry, but brittle and fragile when wet.

To avoid the development of a tillage-induced hardpan, land should be direct seeded to minimize tillage of the soil. If soil must be tilled, great care is needed to ensure soils are not too moist to avoid tillage-induced compaction. Further, for soils that must be cultivated, the development of a hardpan can be reduced by varying the depth and direction of tillage for each cultivation. For land seeded to row or root crops, where tillage is required, soils should not be worked when wet.

16.3.3 Wheel traffic-induced compaction

Heavy farm equipments, including tractors, grain carts, combines, trucks, manure spreaders and wheels of pivot irrigation systems, can exert considerable weight onto the soil surface and, consequently, into the subsoil. The effect of equipment weight can penetrate down to 60 cm (24 inches) when soils are moist. The concern of wheel traffic compaction has increased in the past several decades due to the increasing size of farms, farm equipment and the time needed to complete farm operations at seeding and harvest. Tractor size and weight has increased to 15 to 20 tonnes for four-wheel drive tractors and fully loaded air seeder carts. The weight of a full combine can be in the range of 15 tonnes.

Wheel traffic-induced compaction can be managed using good agronomic practices, deep tillage or a combination of both. Ideally, it is best to use agronomic practices both to prevent and correct wheel traffic compaction. A good preventative management practice is to avoid having equipment repeatedly travel on the same wheel tracks. For example, avoid having grain trucks use the same path into and out of the field. Instead, shift over and drive on a new path each time in the field. Another suggestion is to load seeders and unload combines on the headlands of fields to reduce the traffic in the field. A good agronomic option is to plant a deep-rooted crop, such as alfalfa, to penetrate a compacted soil layer and utilize natural wetting-drying and freeze thaw cycles to mellow the soil. Great care is needed to avoid traffic on the land when soils are quite moist.

16.4 Effects of soil compaction

The various forces of soil compression by agricultural equipment can cause soil particles to become compacted closer together into a smaller volume. As particles are compressed together, the space between particles (pore space) is reduced, thereby reducing the space available in the soil for air and water. The compaction force may cause the crushing of soil aggregates, which has a negative effect on soil aggregate structure. Soil compaction can have a number of negative effects on soil quality and crop production including the following:

- causes soil pore spaces to become smaller
- reduces water infiltration rate into soil
- decreases the rate that water will penetrate into the soil root zone and subsoil
- increases the potential for surface water ponding, water runoff, surface soil waterlogging and soil erosion
- reduces the ability of a soil to hold water and air, which are necessary for plant root growth and function
- reduces crop emergence as a result of soil crusting
- impedes root growth and limits the volume of soil explored by roots
- limits soil exploration by roots and decreases the ability of crops to take up nutrients and water efficiently from soil
- reduces crop yield potential

Compacted soil will restrict root growth and penetration into subsoil. This situation can lead to stunted, drought stressed plants as a result of restricted water and nutrient uptake, which results in reduced crop yields. In wetter than normal years, soil compaction can decrease soil aeration and lead to the increased loss of nitrate nitrogen by denitrification, which is the conversion of plant available nitrate-nitrogen into gaseous nitrogen forms that are lost to the atmosphere. This process occurs when soils are in an anaerobic condition and soil pores are mostly filled with water. Reduced soil aeration can affect root growth and function, and lead to increased risk of crop disease. All these factors result in increased crop stress and yield loss.

16.5 Importance of soil porosity

Soils consist of organic matter, various-sized soil particles referred to as soil texture (proportion of solid particles including sand, silt and clay) and pore spaces that contain air and water. The connectivity of soil pores coupled with the size and number of pores is very important for water infiltration, water and nutrient movement within soil and the ability of the soil to hold water. Large, inter-connected soil pore spaces enhance several actions:

- water infiltration into soil
- water percolation into the root zone and subsoil
- air exchange with the atmosphere

Many important biological and chemical processes take place within soil pores that require both water and air. Reduced pore size and number will affect soil biological and chemical processes, such as the reduced cycling and release of plant available nutrients.

Soil compaction changes pore space size and distribution and will increase soil strength. One way to quantify the change is by measuring soil bulk density. This procedure is done by carefully taking a soil core and measuring the diameter and length to determine the volume of the core, then oven drying the core to determine the soil dry weight.

Soil bulk density is the dry weight of soil divided by the volume of the soil. It is usually expressed in grams per cubic centimeter (g/cm^3). As the pore space is decreased within a soil, the soil bulk density is increased.

Normally, loam to clay loam soils have a bulk density of about 1.3 to 1.4 g/cm3, and sandy loam to loamy sand soils have a bulk density of 1.4 to 1.6 g/cm^3. Naturally dense horizons in a Solonetzic soil will have bulk densities of 1.6 g/cm^3 or greater, and root growth will be hindered. Disced or cultivated surface soils will have bulk densities in the range of 1.0 to 1.2 g/cm^3.

Heavily compacted soils contain few large pores and have a reduced rate of water penetration through the compacted layer. Large soil pores are the most effective in moving water through the soil. When large pores are absent, the hydraulic conductivity of soil (rate water will move through soil) will be greatly reduced.

In addition, the exchange of gases in soil with the atmosphere slows down in compacted soils, causing an increase in the likelihood of aeration-related problems. Soil compaction increases soil strength, which means plant roots must exert greater force to penetrate the compacted layer.

16.6 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.

Soil compaction can impair water infiltration into soil, crop emergence, root penetration and crop nutrient and water uptake, all of which result in depressed crop yield. Human-induced compaction of agricultural soil can be the result of using tillage equipment during soil cultivation or result from the heavy weight of field equipment. Compacted soils can also be the result of natural soil forming processes. Solonetzic soils are an example of natural soil compaction.

- 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.
- 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.
- Compacted soil requires more horsepower (and fuel) to cultivate. Planting implements are less effective in compacted soil and poor germination is the result.
- Fertiliser efficiency is also reduced as the large blocks of compacted soil provide few surfaces to retain and release fertiliser for crop growth.
- 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.

16.7 Management Strategies

Nature has built-in processes that reduce soil compaction, including cycles of wetting and drying, freezing and thawing, as well as plant growth and microbial activity. In the last 30 to 40 years, farming practices have

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changed drastically, creating situations where natural rejuvenation of the soil environment by wet-dry and freeze-thaw cycles is inadequate to maintain optimum conditions for crops. Performing field operations on wet soils, using multiple field operations for crop production, eliminating perennial crops from crop rotations, and using heavy equipment contribute to more extensive and deeper compaction.

Soil compaction problems can be reduced or eliminated through use of proper management practices.

16.7.1 Stay off Wet Soils

Soil is most susceptible to compaction when soil water in the 3- to 6-inch soil depth is near field capacity or wetter. Under such moisture conditions, the potential for compaction increases as soil clay content increases and soil organic matter decreases.

The water content of a soil can be determined using the feel-and-appearance method, or by molding soil from the 3- to 6-inch depth and dropping the soil ball onto a hard surface; if it does not break or crack on impact, it is too wet for field operations. Perform field operations in your driest fields first to allow more drying time for wetter fields. If field operations need to be conducted when the soil is near field capacity to remain timely, minimize the axle load and increase tire size to reduce deep compaction. Larger tires will compact more of the soil surface, but with less pressure on the soil and less penetration of compactive forces.

16.7.2 Reduce Tillage

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Tilled soils are more susceptible to compaction than no-till soils. Tillage contributes to the breakdown of soil structure by compressing and breaking soil aggregates, which are necessary for good air and water movement and good root growth. Tillage also results in the loss of soil organic matter which is important to soil aggregate stability. Reduced tillage systems leave greater amounts of plant residue on the soil surface which helps prevent surface sealing, a form of compaction, by intercepting raindrops before they hit the soil surface.

Tillage affects microbial activity in the soil. Reduced tillage causes fungal decomposers of organic matter to increase relative to bacterial decomposers. Fungal, as compared to bacterial, decomposers aid aggregate formation and stability on fine-textured soils.

16.7.3 Build Soil Organic Matter

Organic matter promotes the development of good soil structure and decreases soil bulk density. It helps bind soil particles together as aggregates, so they are not as easily cracked, split, or compressed by tillage or wheel traffic. Root derived organic matter is especially effective in aggregate formation. Building soil organic matter also increases soil nutrient mineralization and availability for crop growth, especially for nitrogen, phosphorus, sulfur, and trace elements. Organic matter can be added to the soil in the form of animal manure, municipal biosolids, or green manure crops, and by leaving crop residues in the field. Tillage generally accelerates the decomposition of soil organic matter.

16.7.4 Rotations with Perennial Crops

When crop rotations include alfalfa, clover, or grass, soils usually are less compact than soils in fields without these rotations. This is true as 1) there generally is no tillage for several years after seeding, 2) trips across the field tend to be associated with hay harvesting when the soil is dry and less susceptible to compaction, 3) the deeper rooting depth and large taproot of alfalfa and clover keeps the soil more porous and 4) these crops remove large amounts of water which helps dry the soil and increase cracking in some soil types.

16.7.5 Crop rotations with others

Using diverse crop rotations, which include forage, cereal, oilseed and pulse crops that vary in rooting depth and type (fibrous versus taproot), combined with good agronomic management practices, such as direct seeding will help reduce soil compaction issues. Good cropping practices will help in several ways:

- promote plant roots to grow through and break up compacted soils
- increase soil organic matter
- improve soil structure, improve water infiltration and penetration into soil
- promote biological diversity

A biologically healthy soil will be more resistant to soil compaction.

16.7.6 Alter the Tillage Depth

If you till the soil, vary tillage depth to minimize the development of a "tillage pan" or compacted zone where the tillage implements shears the soil. Till deeper in dry years when soil fracturing is greatest. Keep tillage shallow in wet years to avoid formation of a deep tillage pan. Shallow pans can be easily fractured with tillage when the soil is dry.

16.7.7 Control Wheel Traffic

Compaction will be intense but localized if all equipment wheel traffic is restricted to "tracks" or traffic lanes in the field, while the non traffic areas are protected from compaction. The area in traffic lanes is minimized when the operating widths and wheel bases of various implements are well matched. Farm implements have different wheel widths making it difficult to confine traffic. Traffic control is easier with fewer operations such as with ridge plant and no-till systems. Planning is required in equipment purchase or hires to reduce the variability in wheel track requirements. Infield operation on moist soils, such as with grain carts, may be reduced to minimize compaction.

16.7.8 Deep Tillage

Compaction causes reduced yields and may worsen other problems that reduce yields, such as disease and low nutrient supply because of reduced root distribution. Assessment of the severity of compaction problems is best done by inspection of crop roots. If root growth is restricted due to compaction, deep tillage such as subsoiling may be warranted.

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The depth of yield-limiting soil compaction will determine the required depth of tillage and tillage tool selection. If compaction occurs in the top 6 to 8 inches of the soil, tillage tools such as a chisel plow or moldboardplow can be used to shatter the compacted layer. However, if compaction is below 8 to 10 inches, tillage tools such as a subsoiler, ripper, or paraplow may be needed. Sub-soiling tillage is often best performed in the late summer or fall but can be done whenever the soil is dry enough. The relative success of subsoiling will vary with soil type, soil water content, soil texture and bulk density, and the shape of the subsoiler shank.

"Slot ripping" allows roots and water to penetrate into the soil, especially if the rows of the next crop follow the slots. Parabolic shanked subsoilers heave the soil surface too much to allow slot planting of the next crop. Secondary tillage may be used in the spring to level the field prior to seeding but sub-soiled fields can redevelop a compacted layer if the loosened soil is worked when wet or if wheel traffic is not controlled.

16.7.8.1 Adverse effects of deep tillage

Use deep tillage with great caution**.** Although deep tillage can be beneficial under specific soil conditions, its use can also have very serious negative effects on soil quality. Therefore, the use of deep tillage must be considered carefully. Some potential concerns:

- Some rippers cause greater mixing of surface soil with subsoil, which results in the deterioration of soil structure, reduction in soil organic matter, reduced soil fertility and increased potential for surface soil crusting. These conditions can be much worse than minor soil compaction problems.

- Loss of plant available moisture can occur.
- Soluble salts in subsoil can be intermixed with surface soil, increasing salt levels and reducing crop yield potential.
- Subsoiling can make the ground surface rough and lumpy and can pull rocks to the surface. This potential outcome includes implements that claim to cause lower surface soil disturbance.
- A sub-soiled field will often have a poor seedbed the following year due to an uneven and soft surface soil and reduced soil moisture conditions.
- If high or excessive amounts of moisture are received after subsoiling, the fractured soil zones can become waterlogged and unmanageable until dry.

16.8 Summary

Soil compaction is not considered a widespread, serious problem. However, soil compaction can be a serious and unnecessary form of soil degradation. Preventing soil compaction is far better than trying to correct a compaction problem after it occurs. A number of management options can be implemented to minimize the risk of soil compaction:

- Keep protective residue covers on the soil surface to reduce the negative effects of rain or irrigation water causing soil crusting.
- Minimize or eliminate soil tillage to prevent soil aggregate breakdown and induce the development of a tillage “hardpan” – this

goal can be achieved by direct seeding and the elimination of soil cultivation.

- As far as possible, avoid field traffic when soils are wet; this is more easily said than done, for example, when harvest schedules dictate the crop must come off despite wet field conditions.
- Reduce the wheel traffic load on the soil, which can be done by keeping axel loads to a minimum. Use radial tires at low inflation pressures to create a larger footprint.
- Minimize the field traffic areas on fields. Load wagons or trucks on a road (if it can be done safely) or on headlands.
- Improve soil organic matter and soil structure and increase biological activity in soil by using best agronomic management practices.

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Course Name	Problematic soils and their Management
Lesson 17	Flooded Soils – Concepts and Properties
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Learning Objectives

- Understanding soil compaction in terms of reduced porosity, aeration, infiltration and increased bulk density.
- Understand the factors for soil compaction, mechanical impedance to root growth and management of compacted soils.

Glossary of terms

1. **Hardpan:** It is a hardened soil layer in the lower A or in the B horizon caused by cementation of soil particles with organic matter, silica, sesquioxides and calcium carbonate, etc. The hardness does not change appreciably with variation in soil moisture.
2. **Hydraulic conductivity:** Hydraulic conductivity is a measure of a material's capacity to transmit water. It is defined as a constant of proportionality relating the specific discharge of a porous medium under a unit hydraulic gradient in Darcy's law
3. **Infiltration:** Infiltration is the process by which water on the ground surface enters the soil. Infiltration is governed by two forces, gravity, and capillary action.
4. **Puddling:** Refers to breaking down soil aggregates at near saturation into ultimate soil particles.
5. **Soil compaction:** Compaction of soil is the compression of soil particles into a smaller volume, which reduces the size of pore space available for air and water.
6. **Soil porosity:** "Soil porosity" refers to the amount of pores, or open space, between soil particles. Pore spaces may be formed due to the

movement of roots, worms, and insects; expanding gases trapped within these spaces by groundwater; and/or the dissolution of the soil parent material.

16.1 Introduction

Soil compaction can be a serious and unnecessary form of soil degradation that can result in increased soil erosion and decreased crop production. Compaction of soil is the compression of soil particles into a smaller volume, which reduces the size of pore space available for air and water. Most soils are composed of about 50 per cent solids (sand, silt, clay and organic matter) and about 50 per cent pore spaces. Soil compaction occurs when soil particles are compressed together-especially when the soils are wet that destroy soil structure, reducing porosity, and leading to a more dense soil that is hard for crop roots and water to penetrate. Changes in agricultural practices, such as increased number of field operations and larger equipments, have made soil compaction more common on many fields. Field operations, such as silage crop harvest when the soil is wet, can lead to severe soil compaction. Grazing cattle on range and farmlands is very common in the Southwest, but compaction due to grazing is short-lived due to freeze/thaw cycles, and the total weight of grazing animals is often not sufficient to initiate deeper compaction (Baumhardt et al., 2011). However, soil puddling (trampling of soil by animals under very wet conditions) can occur due to overgrazing, resulting in structural breakdown at the soil surface and subsequent crust formation when the soil dries out. Soil compaction affects many agricultural fields and can lead to yield reductions if not properly managed.

16.2 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.

16.3 Types of soil compaction

Soil compaction can occur at the soil surface in the form of soil crusting, or it can occur in the subsoil. Soil compaction is sometimes blamed for reduced crop productivity, but it is important to correctly diagnose the cause or causes of reduced crop production. Poor plant growth can be caused by a number of factors, including soil compaction.

Compaction of agricultural soils can be caused by various farming practices:

- Soil tillage that removes the protective residue from the soil surface, leaving the soil prone to natural environmental forces or excessive soil tillage that causes surface soil aggregates to break down or degrade, can lead to soil crusting, causing the surface soil layer to become hard, and compacted.
- Soil tillage implements can induce soil compaction just below the depth of tillage, particularly when soils are wet.
- The weight of large farm equipment (tractors, seed carts, combines, trucks, manure spreaders) can cause wheel traffic compaction to a considerable depth within the root zone. As soil moisture content increases, so too does the depth of soil compaction.

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Using crop management practices such as including forage in the crop rotation or using direct seeding practices to increase the levels of soil organic matter will aid in the development of a good granular-structured soil that has greater resistance to breakdown. In irrigated fields, it is also very important that water application is managed to ensure the infiltration rate of soil is not exceeded.

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16.6 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.

Soil compaction can impair water infiltration into soil, crop emergence, root penetration and crop nutrient and water uptake, all of which result in depressed crop yield. Human-induced compaction of agricultural soil can be the result of using tillage equipment during soil cultivation or result from the heavy weight of field equipment. Compacted soils can also be the result of natural soil forming processes. Solonetzic soils are an example of natural soil compaction.

- 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.
- 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.
- Compacted soil requires more horsepower (and fuel) to cultivate. Planting implements are less effective in compacted soil and poor germination is the result.
- Fertiliser efficiency is also reduced as the large blocks of compacted soil provide few surfaces to retain and release fertiliser for crop growth.
- 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.

16.7 Management Strategies

Nature has built-in processes that reduce soil compaction, including cycles of wetting and drying, freezing and thawing, as well as plant growth and microbial activity. In the last 30 to 40 years, farming practices have changed drastically, creating situations where natural rejuvenation of the soil environment by wet-dry and freeze-thaw cycles is inadequate to maintain optimum conditions for crops. Performing field operations on wet soils, using multiple field operations for crop production, eliminating perennial crops from crop rotations, and using heavy equipment contribute to more extensive and deeper compaction.

Soil compaction problems can be reduced or eliminated through use of proper management practices.

16.7.1 Stay off Wet Soils

Soil is most susceptible to compaction when soil water in the 3- to 6-inch soil depth is near field capacity or wetter. Under such moisture conditions, the potential for compaction increases as soil clay content increases and soil organic matter decreases.

The water content of a soil can be determined using the feel-and-appearance method, or by molding soil from the 3- to 6-inch depth and dropping the soil ball onto a hard surface; if it does not break or crack on impact, it is too wet for field operations. Perform field operations in your driest fields first to allow more drying time for wetter fields. If field operations need to be conducted when the soil is near field capacity to remain timely, minimize the axle load and increase tire size to reduce deep compaction. Larger tires will compact more of the soil surface, but with less pressure on the soil and less penetration of compactive forces.

16.7.2 Reduce Tillage

Tilled soils are more susceptible to compaction than no-till soils. Tillage contributes to the breakdown of soil structure by compressing and breaking soil aggregates, which are necessary for good air and water movement and good root growth. Tillage also results in the loss of soil organic matter which is important to soil aggregate stability. Reduced tillage systems leave greater amounts of plant residue on the soil surface which helps prevent surface sealing, a form of compaction, by intercepting raindrops before they hit the soil surface.

Tillage affects microbial activity in the soil. Reduced tillage causes fungal decomposers of organic matter to increase relative to bacterial decomposers. Fungal, as compared to bacterial, decomposers aid aggregate formation and stability on fine-textured soils.

16.7.3 Build Soil Organic Matter

Organic matter promotes the development of good soil structure and decreases soil bulk density. It helps bind soil particles together as aggregates, so they are not as easily cracked, split, or compressed by tillage or wheel traffic. Root derived organic matter is especially effective in aggregate formation. Building soil organic matter also increases soil nutrient mineralization and availability for crop growth, especially for nitrogen, phosphorus, sulfur, and trace elements. Organic matter can be added to the soil in the form of animal manure, municipal biosolids, or green manure crops, and by leaving crop residues in the field. Tillage generally accelerates the decomposition of soil organic matter.

16.7.4 Rotations with Perennial Crops

When crop rotations include alfalfa, clover, or grass, soils usually are less compact than soils in fields without these rotations. This is true as 1) there generally is no tillage for several years after seeding, 2) trips across the field tend to be associated with hay harvesting when the soil is dry and less susceptible to compaction, 3) the deeper rooting depth and large taproot of alfalfa and clover keeps the soil more porous and 4) these crops remove large amounts of water which helps dry the soil and increase cracking in some soil types.

16.7.5 Crop rotations with others

Using diverse crop rotations, which include forage, cereal, oilseed and pulse crops that vary in rooting depth and type (fibrous versus taproot), combined with good agronomic management practices, such as direct seeding will help reduce soil compaction issues. Good cropping practices will help in several ways:

- promote plant roots to grow through and break up compacted soils
- increase soil organic matter
- improve soil structure, improve water infiltration and penetration into soil
- promote biological diversity

A biologically healthy soil will be more resistant to soil compaction.

16.7.6 Alter the Tillage Depth

If you till the soil, vary tillage depth to minimize the development of a “tillage pan” or compacted zone where the tillage implements shears the soil. Till deeper in dry years when soil fracturing is greatest. Keep tillage shallow in wet years to avoid formation of a deep tillage pan. Shallow pans can be easily fractured with tillage when the soil is dry.

16.7.7 Control Wheel Traffic

Compaction will be intense but localized if all equipment wheel traffic is restricted to “tracks” or traffic lanes in the field, while the non traffic areas are protected from compaction. The area in traffic lanes is minimized when the operating widths and wheel bases of various implements are well matched. Farm implements have different wheel widths making it difficult to confine traffic. Traffic control is easier with fewer operations such as with ridge plant and no-till systems. Planning is required in equipment purchase or hires to reduce the variability in wheel track requirements. Infield operation on moist soils, such as with grain carts, may be reduced to minimize compaction.

16.7.8 Deep Tillage

Compaction causes reduced yields and may worsen other problems that reduce yields, such as disease and low nutrient supply because of reduced root distribution. Assessment of the severity of compaction problems is best done by inspection of crop roots. If root growth is restricted due to compaction, deep tillage such as subsoiling may be warranted.

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The depth of yield-limiting soil compaction will determine the required depth of tillage and tillage tool selection. If compaction occurs in the top 6 to 8 inches of the soil, tillage tools such as a chisel plow or moldboardplow can be used to shatter the compacted layer. However, if compaction is below 8 to 10 inches, tillage tools such as a subsoiler, ripper, or paraplow may be needed. Sub-soiling tillage is often best performed in the late summer or fall but can be done whenever the soil is dry enough. The relative success of subsoiling will vary with soil type, soil water content, soil texture and bulk density, and the shape of the subsoiler shank.

“Slot ripping” allows roots and water to penetrate into the soil, especially if the rows of the next crop follow the slots. Parabolic shanked subsoilers heave the soil surface too much to allow slot planting of the next crop. Secondary tillage may be used in the spring to level the field prior to seeding but sub-soiled fields can redevelop a compacted layer if the loosened soil is worked when wet or if wheel traffic is not controlled.

16.7.8.1 Adverse effects of deep tillage

Use deep tillage with great caution**.** Although deep tillage can be beneficial under specific soil conditions, its use can also have very serious negative effects on soil quality. Therefore, the use of deep tillage must be considered carefully. Some potential concerns:

- Some rippers cause greater mixing of surface soil with subsoil, which results in the deterioration of soil structure, reduction in soil organic matter, reduced soil fertility and increased potential for surface soil crusting. These conditions can be much worse than minor soil compaction problems.

- Loss of plant available moisture can occur.
- Soluble salts in subsoil can be intermixed with surface soil, increasing salt levels and reducing crop yield potential.
- Subsoiling can make the ground surface rough and lumpy and can pull rocks to the surface. This potential outcome includes implements that claim to cause lower surface soil disturbance.
- A sub-soiled field will often have a poor seedbed the following year due to an uneven and soft surface soil and reduced soil moisture conditions.
- If high or excessive amounts of moisture are received after subsoiling, the fractured soil zones can become waterlogged and unmanageable until dry.

16.8 Summary

Soil compaction is not considered a widespread, serious problem. However, soil compaction can be a serious and unnecessary form of soil degradation. Preventing soil compaction is far better than trying to correct a compaction problem after it occurs. A number of management options can be implemented to minimize the risk of soil compaction:

- Keep protective residue covers on the soil surface to reduce the negative effects of rain or irrigation water causing soil crusting.
- Minimize or eliminate soil tillage to prevent soil aggregate breakdown and induce the development of a tillage “hardpan” – this

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goal can be achieved by direct seeding and the elimination of soil cultivation.

- As far as possible, avoid field traffic when soils are wet; this is more easily said than done, for example, when harvest schedules dictate the crop must come off despite wet field conditions.
- Reduce the wheel traffic load on the soil, which can be done by keeping axel loads to a minimum. Use radial tires at low inflation pressures to create a larger footprint.
- Minimize the field traffic areas on fields. Load wagons or trucks on a road (if it can be done safely) or on headlands.
- Improve soil organic matter and soil structure and increase biological activity in soil by using best agronomic management practices.

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Course Name	Problematic soils and their Management
Lesson 18	Nutrient transformation under flooded soils
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Learning Objective

- Understanding the chemistry of waterlogged soils

Glossary of terms

1. **Denitrification:** Denitrification is defined as the "microbial reduction of nitrate or nitrite coupled to electron transport phosphorylation resulting in gaseous N either as molecular N_2 or as an oxide of N." The key to denitrification as defined is the availability of the N oxides, nitrite (NO_2^{-}) or nitrates (NO_3^-), which are formed from the autotrophic nitrification pathway substrate, ammonia (NH_3), which is derived from ammonium (NH_4^+).
2. **Mineralization:** Mineralization is the decomposition (i.e., oxidation) of the chemical compounds in organic matter, by which the nutrients in those compounds are released in soluble inorganic forms that may be available to plants.
3. **Immobilization:** Immobilization is the conversion of inorganic compounds to organic compounds by micro-organisms or plants, by which it is prevented from being accessible to plants.
4. **Oxidation:** Oxidation is the loss of electrons during a reaction by a molecule, atom or ion. Oxidation occurs when the oxidation state of a molecule, atom or ion is increased.
5. **Reduction:** Reduction is a chemical reaction that involves the gaining of electrons by one of the atoms involved in the reaction between two chemicals. The term refers to the element that accepts

electrons, as the oxidation state of the element that gains electrons is lowered.

18.1 Nutrient Transformation

The most important change in the soil as a result of flooding is the conversion of the root zone of the soil from an aerobic environment to an anaerobic or near-anaerobic environment where oxygen is absent or limiting (Patrick and Mahapatra, 1968). Oxygen deficiency or exclusion in submerged soils can occur within a day after flooding. The oxygen movement through the flooding water is usually much slower than the rate at which oxygen can be reduced in the soil. This situation may result in the formation of two distinctly different layers being formed in a waterlogged soil. On the top is an oxidized or aerobic surface layer where oxygen is present, with a reduced or anaerobic layer underneath in which no free oxygen is present. A thin oxidized layer (usually 1 to 20 mm in thickness) normally found at the interface between water and soil (Bouldin, 1986). In addition, flooding also has major effects on the availability of macro and micronutrients. Some nutrients are increased in availability to the crop, whereas others are subject to greater fixation or loss from the soil as a result of flooding (Patrick and Mikkelsen, 1971).

Table 1 Changes in organic matter and availability of plant nutrients in soils following their submergence under water

Chemical property	**Change(s) following soil submergence**
pH	Favours convergence to neutral pH
Organic matter	Favours accumulation of organic C and N
Ammonium-N	Release and accumulation of ammonium favoured
P	Improves P availability, especially in soils high in Fe and Al oxides
K	K availability improves through exchange of K
Ca, Mg, Na	Favours release of Ca, Mg and Na in solution
S	Sulphate reduction may reduce sulphur availability
Fe	Iron availability improves in alkali and calcareous soils, but Fe toxicity may occur in acidic soils high in reducible Fe
Al	Al toxicity is generally absent, except perhaps in acid sulphate soils
Cu, Zn, Mo	Improves availability of Cu and Mo but not of Zn
Reduction products	Production of sulphide and organic acids, especially in degraded soils may cause toxicity or injurious effects to growing plants

Source: Sahrawat (2005)

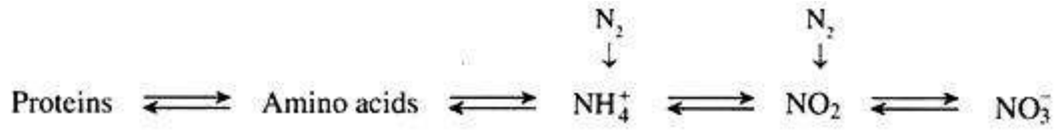
18.2 Nitrogen

Nitrogen occurs in soils mainly as complex organic substances, ammonia, molecular nitrogen, nitrite and nitrate. The transformations of nitrogen are largely micro-biological inter-conversions regulated by the physical and chemical environment of the soil. In submerged soils, the main transformations are accumulation of ammonia, volatilization loss of ammonia, denitrification, nitrogen fixation and leaching losses of nitrogen. These transformations have an important bearing on the nutrition of rice. It is evident that nitrogen is deficient in rice soils because of conditions favourable for rapid transformations and losses of nitrogen from the soil.

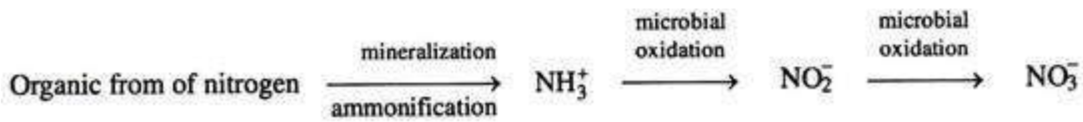
18.2.1 Mineralization of Nitrogen and Accumulation of Ammonia

In aerated soils NO_3^- is the inorganic form and all of the nitrogen reactions that follow the composition of organic matter proceed towards the production of NO_3^-. Thus organic form of nitrogen undergoes mineralization to NH_4^+, oxidation of NH_4^+ to NO_2^- and oxidation of NO_2^- to NO_3^-.

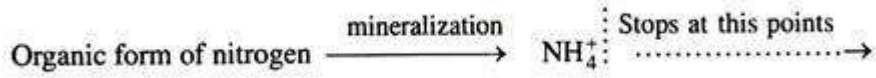
The main inter-conversions are shown below:



In aerobic soils



But in anaerobic soils the absence of O_2 inhibits the activity of the Nitrosomonas micro-organisms that oxidises NH_4^+ and therefore, nitrogen mineralization stops at the NH_4^+ form. **In submerged soil**



The accumulation of ammonia in submerged soils is, therefore, a good index of the capacity of a soil to meet up the demand for nitrogen to the rice crop. The transformation of nitrogen occurs in the aerobic and anaerobic layers of a submerged soil.

In the aerobic surface layer, conditions are similar to those of a well-drained soil and nitrogen mineralization proceeds to the NO_3^- form. The presence of an aerobic layer above the anaerobic layer is the major cause of instability of nitrogen in submerged soils and results in considerable loss of nitrogen through nitrification-denitrification reactions.

Nitrate is stable and not subject to denitrification as long as it remains in the surface aerobic layer, but it readily diffuses downward into the anaerobic layer and undergoes denitrification as a result of a gradient in the NO_3^- concentration between the aerobic layer and the anaerobic layer. This process can proceed as long as NO_3^- is formed in the aerobic layer, and that can readily happen if there is a sources of NH_4^+ in the aerobic layer that can be nitrified (NO_3^-). The removal of NH_4^+ in that layer by nitrification creates a concentration gradient that causes NH_4^+ to diffuse upward form the anaerobic layer (Figure 1).

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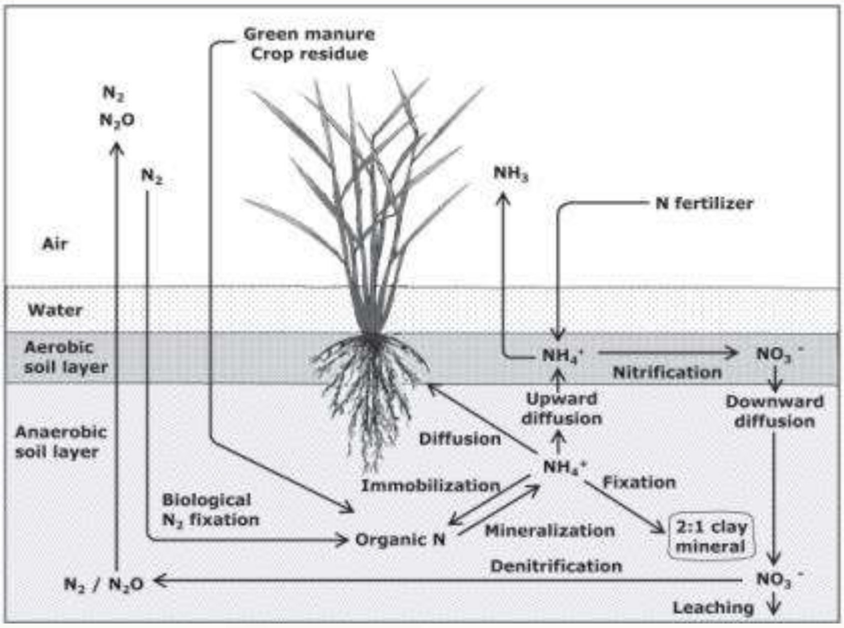


Figure1: Schematic diagram of N transformation in submerged soil

18.3 Phosphorus

Soil flooding is known to influence the transformation and availability of both native and applied phosphorus. P is not directly involved in oxidation-reduction reactions in redox potential change encountered in submerged soils, but because of its reactivity with a number of redox elements, its behavior is significantly affected by waterlogging (Figure 2). P chemistry is linked with iron and Ca/Mg – phosphates formed depending upon the pH of the soils. The increase in P availability on submergence may be attributed to the following mechanisms:

1. Release of P from the mineralization of organic residues
2. Reduction of $FePO_4.2H_2O$ to more soluble $Fe_3(PO_4)_2.8H_2O$ and increase in solubility of $FePO_4.2H_2O$ and $AlPO_4.2H_2O$ caused by increase in pH coupled with reduction of acid soils.

3. Release of occluded phosphorus due to reduction of ferric oxyhydroxide
4. Displacement of P from ferric and aluminium phosphates by organic anions
5. Increase in solubility of calcium phosphates ($CaHPO_4.2H_2O$, $Ca_4H(PO_4)_3.3H_2O$, $Ca_{10}(PO_4)_6(OH)_2$, $Ca_{10}(PO_4)_6CO_3$ and $Ca_{10}(PO_4)_6F_2$) associated with the decrease in pH caused by the liberation of CO_2 in the calcareous soils.
6. The release of P due to anion exchange reactions between clay and phosphate or organic anions and phosphate. The decrease in the concentration of available P at the later period of submergence may be due to the fixation (through adsorption) of released phosphorus by clay colloids (kaolinite, montmorillonite and hydrous oxides of Fe and Al).

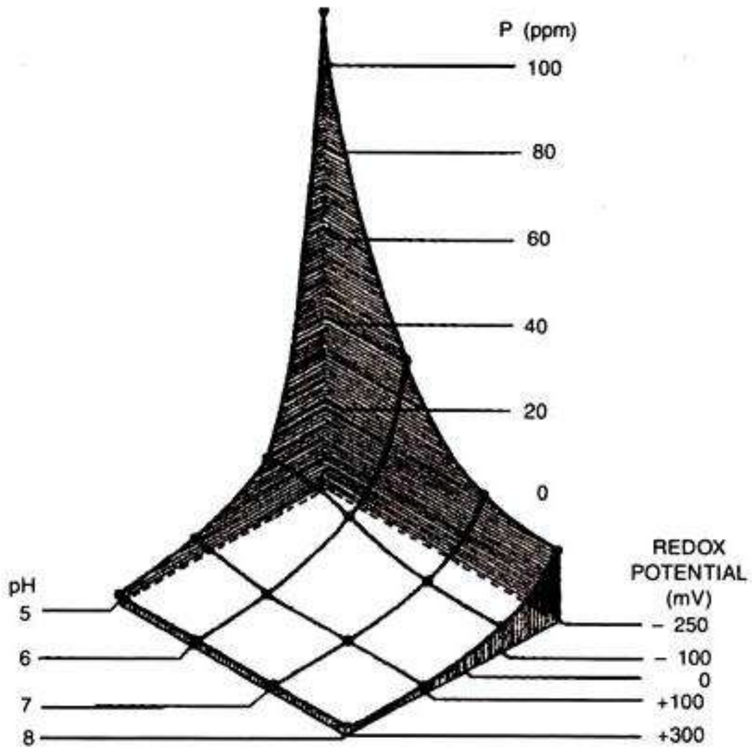


Figure 2: Solubility of phosphorus in relation to various redox potential-pH combinations in submerged soils

18.4 Potassium

A net mobilization of K from reserve pools to the different forms is observed due to submergence of the soils. These have arisen from a higher level of soluble phosphate in the submerged soils and the residual soil acidity, both acting jointly on the mineral K in the soils. The combined effect of soluble phosphate and proton plays an important role on the alteration of K-bearing minerals and, hence increasing its availability. With submergence, soluble Fe^{2+} and Mn^{2+} ions increase and exchangeable K^{+} is then displaced into the soil solution. It has been also reported that the availability of applied potassium decreases in submerged soils due to formation of Fe-K sparingly soluble complexes (Figure 3).

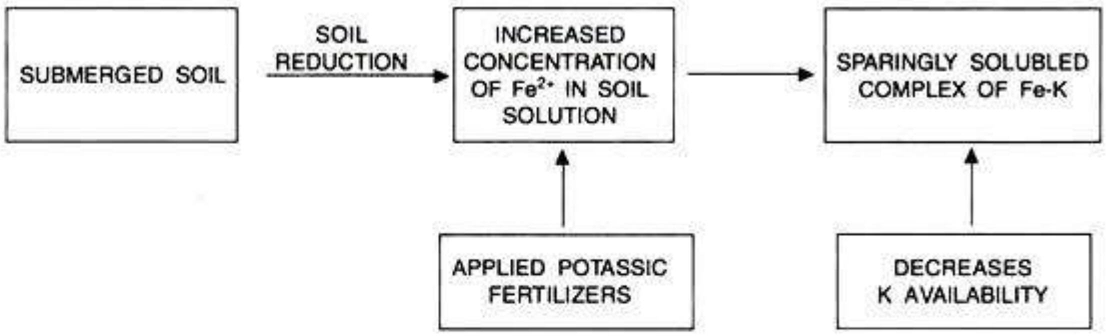
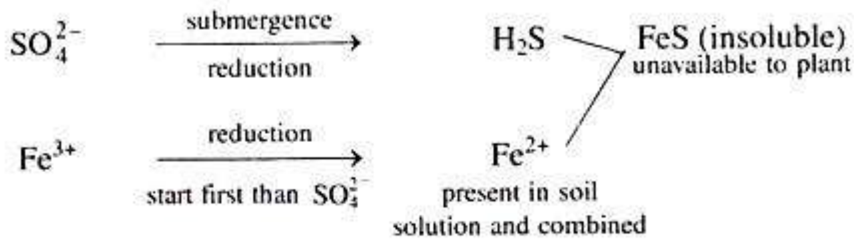


Figure 3 A schematic representations for the transformation of potassium in submerged soil

18.5 Sulfur

In aerated soils the main transformations of Sulfur are (a) the oxidation of elemental sulfur, sulfides, and organic sulfur compounds to sulfate, and (b) the reduction of SO_4^{2-} and incorporation of sulfur into plant and microbial tissues. In anaerobic media, the main changes are the reduction of SO_4^{2-} to sulfide and the dissimilation of the amino acids, cysteine, cystine, and methionine (derived from the hydrolysis of proteins) to H_2S, thiols, ammonia, and fatty acids. The reduction of sulfate is brought about by a small group of obligate anaerobic bacteria of the genus Desulfovibrio, which use as the terminal electron acceptor in respiration. The reduction of sulfate in submerged soils has three implications for rice cultivation: the sulfur supply may become insufficient, zinc and copper may be immobilized, and H_2S toxicity may arise in soils low in iron.

In submerged soil



The reduction of SO_4^{2-} has three implications:

(i) Sulphur supply may become insufficient

(ii) Zinc and copper may be immobilized

(iii) H_2S toxicity may arise in soils low in iron.

18.6 Iron

The most important chemical change that takes place when a soil is submerged is the reduction of iron and the accompanying increase in its solubility. Rice benefits from the increase in availability of iron but may suffer, in acid soils, from an excess. Five to 50% of the free iron oxides present in a soil may be reduced within a few weeks of submergence depending on the temperature, the organic matter content, and the crystallinity of the oxides. The lower the degree of crystallinity, the higher is the reduction percentage. The increase in concentration of water-soluble iron can, in most soils, be related to the potential and pH of the $Fe(OH)_3$-Fe^{2+}system (Figure 4). Water-soluble Fe^{2+} diffusing to the oxygenated soil-water interface and moving by mass flow and diffusion from the surface of rice roots and to the oxidized zone below the plow sole is deposited as mottles, tubules, and nodules, respectively.

The initial increase in the concentration of ferrous iron (Fe^{2+}) on soil submergence is caused by the reductions that are shown below:

$$\underset{\text{(Insolule)}}{Fe(OH)_3} + e^- \xrightleftharpoons{\text{Reduction}} \underset{\text{(Soluble)}}{Fe^{2+}} + 3OH^-$$

The decrease in the concentration of Fe^{2+} following the peak rise is caused by the precipitation of Fe^{2+} as $FeCO_3$ in the early stages where high partial pressure of CO_2 prevails and as $Fe_3(OH)_8$ due to decrease in the partial pressure of $CO_2(pCO_2)$

$$\underset{\text{(Soluble)}}{2Fe^{2+}} + 3CO_2^+ \longrightarrow \underset{\text{(Insoluble)}}{2FeCO_3}$$

Rice benefits from the increase in availability of iron but may suffer in acid soils, from an excess.

The reduction of iron has some important consequences:

i. The concentration of water soluble iron increases,
ii. pH increases,
iii. Cations are displaced from exchange sites,
iv. The solubility of P and Si increases and
v. New minerals are formed.

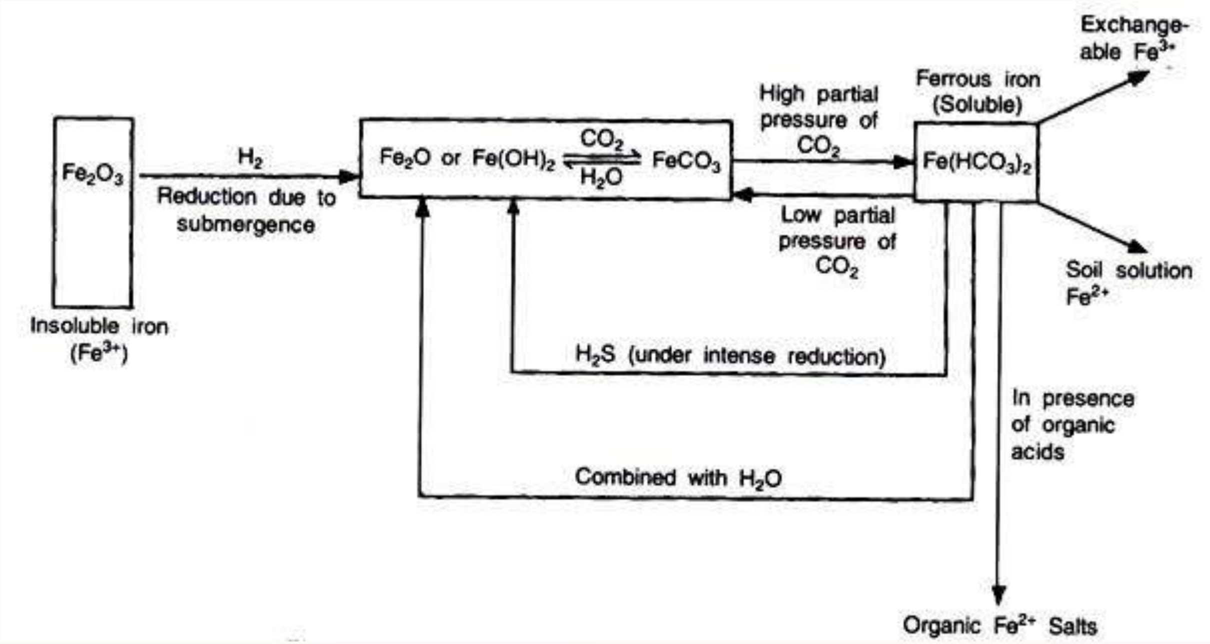


Figure 4 A schematic representations for the transformation of iron in submerged soil

18.7 Manganese

The main transformations of manganese in submerged soils are the reduction of manganic (Mn^{4+}) to manganous (Mn^{2+}) and almost similar to that of iron transformation. Like iron, the transformation for Mn is also governed by the redox equilibria system.

In submerged soils, the transformation of Mn results an increase in the concentration of water soluble Mn^{2+}, precipitation of manganous carbonate ($MnCO_3$), and re-oxidation of Mn^{2+} diffusing or moving by mass flow to oxygenated interfaces in the soil (Figure 5).

When an aerobic laterite soil is submerged the reduction of manganic manganese (Mn^{4+}) occurs almost concurrently with the nitrate (NO_3^-) reduction, but this reduction precedes that of Fe reduction. The concentration of Mn^{2+} (water soluble) increases initially and thereafter declines with the period of soil submergence that is shown in Figure 5.

$$MnO_2 + 4H^+ + 2e^- \underset{}{\overset{\text{reduction}}{\rightleftharpoons}} \underset{\text{(Water soluble)}}{Mn^{2+}} + 2H_2O$$

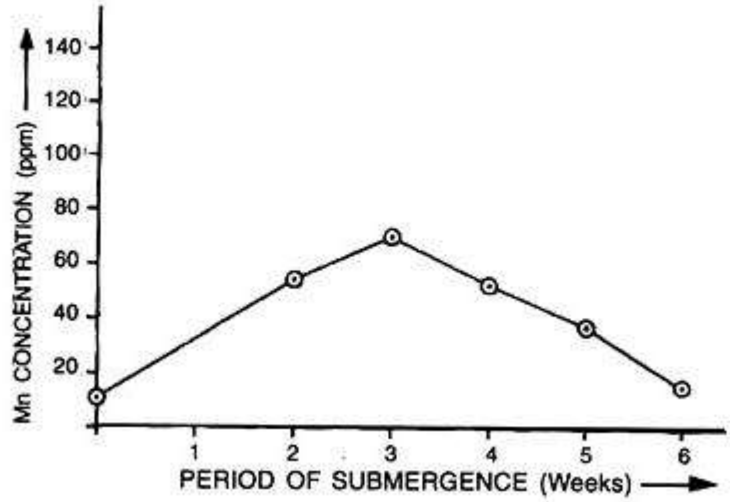


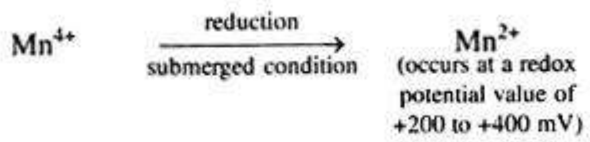
Figure 5 Effect of submergence on the release of Mn^{2+} in soil solution

The initial increase in the concentration of Mn^{2+} may be due to the reduction of soil as well as Mn^{4+} and the decrease of the same of the later period may be due to the precipitation of Mn^{2+} on $MnCO_3$ and $Mn(OH)_2$ in the soil solution.

The kinetics of manganese reduction varies markedly from soil to soil. The changes in water soluble Mn^{2+} concentration depend upon the pH, organic matter content and active Mn content of the soils. The mobilization of Mn in soils is markedly increased after submergence due to the reduction of manganic compounds to more soluble forms as a consequence of the anaerobic metabolism of soil bacteria.

Acid lateritic soils high in active Mn regardless of organic matter content will give higher peak of water soluble Mn^{2+} concentration sharply and low organic matter content delayed the peak. Strongly acid soils with relatively low Mn content will also give lower peaks. The smallest peak will produce in slightly alkali soils and in soils very low in Mn content.

We know that the transformation of Mn in submerged soils largely depends on the oxidation-reduction reactions and the reduction of Mn^{4+} occurs when the redox potential value is within a range from +200 to +400 mV.



It is evident that organic matter influences the manganese transformation in soils through the following ways:

(i) The production of complexing agents that effectively reduces the activity of free iron in solution.

(ii) The decrease in the oxidation-reduction potential of the soil either directly or indirectly through microbial activity.

(iii) The stimulation of microbial activity that results in the incorporation of Mn in biological tissue

18.8 Zinc

The transformation of zinc in submerged soils is not involved in the oxidation-reduction process like that of iron and manganese. However, the reduction of hydrous oxides of iron and manganese, changes in soil pH, partial pressure of CO_2, formation insoluble sulphide compound etc. In soil on submergence is likely to influence the solubility of Zn in soil either favorably or adversely and consequently the Zn nutrition of low and rice.

The reduction of hydrous oxides of iron and manganese, formation of organic complexing agents, and the decrease in pH of alkaline and calcareous soils on submergence are found to favour the solubility of Zn, whereas the formation of hydroxides, carbonates, sulphides may lower the solubility of Zn in submerged soils. Zinc deficiency in submerged rice soils is very common owing to the combined effect of increased pH, HCO_3^- and S_2^- formation.

The solubility of native forms of Zn in soils is highly pH dependent and decreases by a factor of 10^2 for each unit increase in soil pH. The activity of Zn-pH relationship has been defined as follow:

$$\text{Soil} + Zn^{2+} \Longleftrightarrow \text{Soil} - Zn + 2H^+$$

The pK value for the above reaction with the solid phase of soils is 6.0. This equation holds good for submerged soils.

Some equations relating to solubility of Zn in submerged soils governed by various meta-stable compounds are given below (Table 2):

Table 2 equations relating to solubility of Zn in submerged soils governed by various meta-stable compounds

$3Zn^{2+} + 2PO_4^{3-}$	$\rightleftharpoons$	$Zn_3(PO_4)_2$	$pK_2 = 32.0$
$Zn^{2+} + NH_4^+ + PO_4^{3-}$	$\rightleftharpoons$	$ZnNH_4PO_4$	$pK_s = 16.0$
$Si(HO)_4 + Zn^{2+}$	$\rightleftharpoons$	$Zn(OH)_2 + SiO_2 + 2H^+$	$pK_2 \geq 17.5$
$Zn^{2+} + S^{2-}$	$\rightleftharpoons$	ZnS	$pK_2 = 22.8$
$Zn^{2+} + 2OH^-$	$\rightleftharpoons$	$Zn(OH)_2$	$pK_s = 17.5$
$Zn^{2+} + CO_3^{2-}$	$\rightleftharpoons$	$ZnCO_3$	$pK_s = 16.5$

Many of these compounds are meta-stable intermediate reaction products and varying mean residence time in submerged soils. Applied Zn tends to approach the solubility of the native forms instead of having residual effect in the former Zn forms.

When an aerobic soil is submerged, the availability of native as well as applied Zn decreases and the magnitude of such decrease vary with the soil properties. The transformation of Zn in soils was found to be greatly influenced by the depth of submerged and application of organic matter.

If an acid soil is submerged, the pH of the soil will increase and thereby the availability of Zn will decrease. On the other hand, if an alkali soil is submerged, the pH of the soil will decrease and as a result the solubility of Zn will generally increase.

The availability of Zn decreases due to submergence may be attributed to the following reasons:

(i) Formation of insoluble franklinite ($ZnFe_2O_4$) compound in submerged soils.

$$Zn^{2+} + 2Fe^{2+} + 4H_2O \underset{\text{reduction}}{\rightleftharpoons} ZnFe_2O_4 \text{ (Franklinite)}$$

(ii) Formation of very insoluble compounds of Zn as ZnS under intense reducing conditions,

$$Zn^{2+} + S^{2-} \rightleftharpoons \underset{\text{(Very insoluble in water)}}{ZnS \text{ (Sphalerite)}}$$

(iii) Formation of insoluble compounds of Zn as $ZnCO_3$ at the later period of soil submergence owing to high partial pressure of CO_2(pCO_2) arising from the decomposition of organic matter,

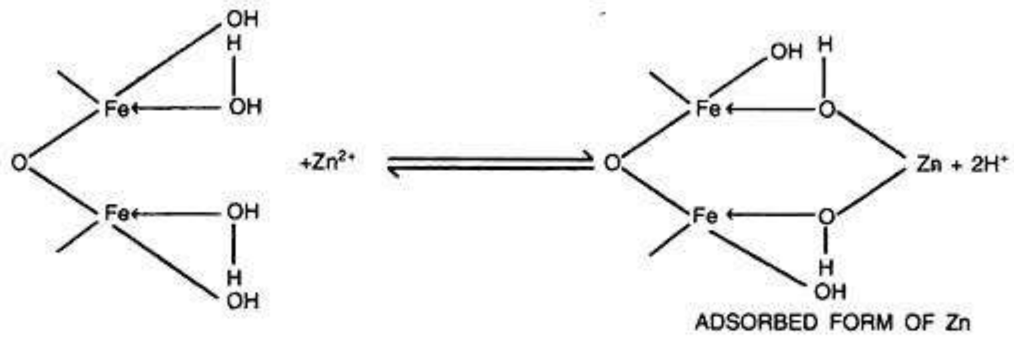
$$Zn^{2+} + 2HO^{-} \rightleftharpoons \underset{\text{(Insoluble)}}{Zn(OH)_2}$$

(iv) Formation of $Zn(OH)_2$ at a relatively higher pH which decreases the availability of

$$Zn^{2+} + 2HO^{-} \rightleftharpoons \underset{\text{(Insoluble)}}{Zn(OH)_2}$$

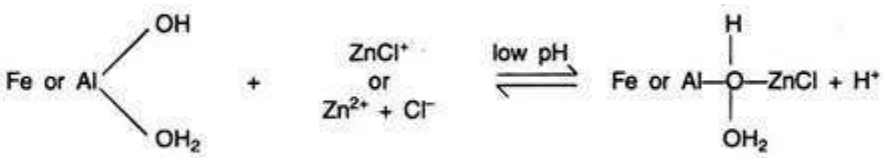
(v) Adsorption of soluble Zn^{2+} by oxide minerals e.g. sesquioxides, carbonates, soil organic matter and clay minerals etc. decreases the availability of Zn, the possible mechanism of Zn adsorption by oxide minerals is shown below:

Mechanism I:



In mechanism I, Zn^{2+} adsorption occurs as bridging between two neutral sites, but in addition to this mechanism, Zn^{2+} could also be adsorbed to two positive sites or to a positive and neutral site.

Mechanism II:



This mechanism occurs at low pH and results non-specific adsorption of Zn^{2+}. In this way Zn^{2+} is retained and rendered unavailable to plants.

(vi) Formation of various other insoluble zinc compounds which decreases the availability of Zn in submerged soil e.g. high phosphatic fertilizer induces the decreased availability of Zn^{2+},

$$Zn^{2+} + PO_4^{3-} \longrightarrow \underset{\text{(Insoluble)}}{Zn_3(PO_4)_2}$$

A simplified diagram illustrating dynamic equilibria of Zn in submerged soils is shown in Figure 6.

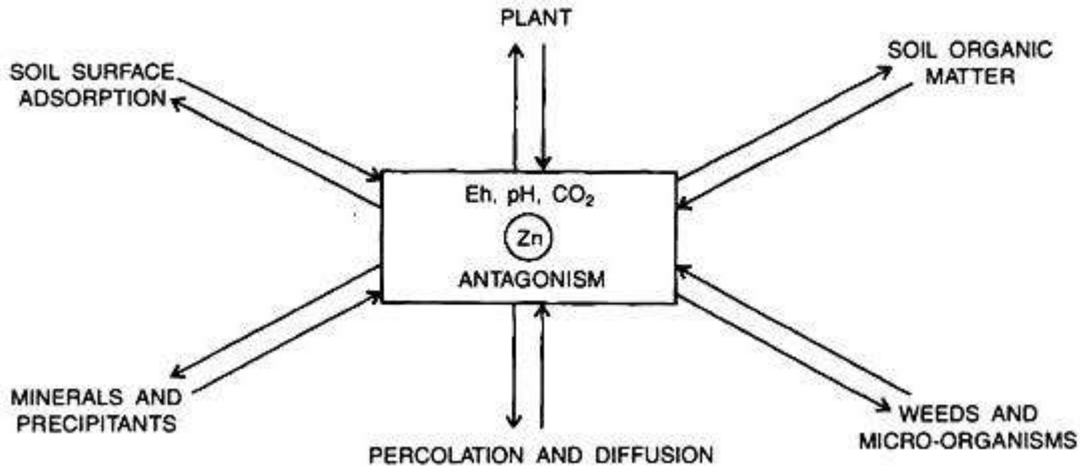


Figure 6 Dynamic equilibria of Zn in submerged soils

It shows that rice receives Zn from the soil solution and the exchangeable and adsorbed solid phase including the soil organic fractions.

Zinc sulphide (ZnS, Sphalerite) in the presence of traces of hydrogen sulphide (H_2S) in submerged soils may control the solubility of Zn. Zinc is stable in submerged soils. So it can be concluded that higher the pH and poorer the aeration, the greater is the likelihood of Zn deficiency if the soil solution Zn activity is controlled by sphalerite (ZnS).

Therefore, a variety of chemical reactions in soils influence the availability of Zn to rice. For example, high manganese concentration antagonises Zn absorption and translocation. Calcium and magnesium may also affect Zn uptake.

The reversible pH change of the submerged soils, where the pH tends to increase in acid soil and decrease in alkaline soils, undoubtedly modify the Zn equilibrium concentration in the soil solution. Because the solubility of Zn minerals and Zn sobered by soil colloids is pH dependent (higher at higher pH), an increase in the pH of an acid soil when submerged will tend to decrease the Zn concentration in the soil solution.

In alkaline soil, however initially Zn uptake increases as the pH decreases after submergence. Submerged alkali or calcareous soils possess all the essential characteristics for the formation of high amount of bicarbonate (HCO^{3-}) ions which helps Zn^{2+} rendering unavailable to plants by forming insoluble $ZnCO_3$ compound.

18.9 Copper

Most of the copper in soils is very insoluble and can only be extracted by strong chemical treatments which dissolve various mineral structures of solubilize organic matter. The concentration of copper in soil solutions is usually very low. At pH values below 6.9, divalent Cu^{2+} is the dominant species. Above pH 6.9, $Cu(OH)_2^0$ is the principal solution species and $CuOH^+$ at pH 7.0.

Hydrolysis reactions of copper ions are shown below:

$$Cu^{2+} + H_2O \rightleftharpoons CuOH^+ + H^+$$
$$CuOH^+ + H_2O \rightleftharpoons Cu(OH)_2^0 + H^+$$

The complexes $CuSO_4^0$ and $CuCO_3^0$ are also important forms of copper. Solubility of copper is very pH dependent and it increases several times (approx. 100 times) for each unit decrease in soil pH. The transformation of copper in submerged soils is not involved in oxidation-reduction reactions; its behaviour is influenced by simple submergence in soils.

It is evident that copper exists in soils as different discrete chemical pools which are as follows:

i. Water soluble plus exchangeable Cu
ii. Copper associated with clay minerals
iii. Organically bound Cu
iv. Copper associated with different oxides in soils
v. Residual copper

The amount of each form of copper in soils depends on soil pH, amount of organic matter, clay content, oxides of Fe and Mn etc. All these above forms of Cu are in dynamic equilibrium in soils.

In submerged soils, copper comes into the soil solution or available pool and becomes available to the plant as follows:

$$\text{Soil } Cu^{2+} + H^+ \rightleftharpoons \underset{\text{(soluble)}}{Cu^{2+}}$$

$$\underset{\text{(Malachite, and abundant source of Cu in submerged soils)}}{Cu_2(OH)_2CO_3} + 4H^+ \rightleftharpoons \underset{\text{(soluble)}}{Cu^{2+}} + CO_2 + 3H_2O$$

The chemical equilibria of Cu in submerged rice soils are similar to those of Zn. The mechanism for removal of Cu from soil solutions in submerged soils is so pronounced that copper is apparently removed from chelating agents that is capable of keeping the element is solution phase in upland soils.

When an acid soil is submerged, the release of copper decreases due to increase in soil pH, whereas submerging an alkali and calcareous soils, the amount of copper in soil solution increases to a lesser degree. However, in most of the soils, submergence decreases the availability of copper and thereby creates deficiency to plants.

The possible explanations for the increase in the concentration of copper in submerged soils are formation of organic complexes and decreased soil pH (alkali soil). On the other hand, the decrease in the amount of copper may be due to the insoluble precipitation as CuS, $CuCO_3$ and $Cu(OH)_2$ since the production of sulphide, carbonate, bicarbonate and hydroxide is more in submerged soils resulting from the reduction of soils.

Again submerging a soil high in organic matter, the amount of extractable Cu either decreases or increases and it is contradictory. The decrease may be due to the microbiological immobilization and the antagonistic effect of increased concentration of iron, manganese and phosphorus forming insoluble copper complexes in soils.

It is also evident that the higher concentration of phosphorus in submerged soil decreased the availability of copper. The possible mechanism for enhanced copper retention on allophane and oxides, in which phosphate coordinates to the axial position of a surface bound copper (Cu^{2+}) ion, thereby produces a ternary surface copper complex.

Evidently due to application of organic matter in submerged soils the amount of available copper increases. The increase may be due to the reduction of coating of hydrous oxides of Fe^{3+} and Mn^{4+} on the copper compounds and also for the production of soluble Cu-organic chelates and thus increases its solubility.

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Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Course Name	Problematic soils and their Management
Lesson 19	Polluted Soils – Sources, Extent and Impact
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Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
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Learning Objective

- Awareness about soil pollutants, point and non-point sources of pollution, reasons for soil pollution and effects on growth and development of crop plants and natural flora and fauna

Glossary of terms

1. **Pollutant:** A pollutant is something which adversely interferes with health, comfort, property or environment of the people.
2. **Pollution:** Pollution may be defined as an undesirable change in the physical, chemical and biological characteristics of air, water and soil which affect human life, lives of other useful living plants and animals, industrial progress, living conditions and cultural assets.
3. **Emerging pollutants (EPs):** Refers to a large number of synthetic or naturally occurring chemicals that have recently appeared in the environment and are not commonly monitored.
4. **Microplastics:** Microplastics are very small pieces of plastic that pollute the environment. They are not a specific kind of plastic, but rather any type of plastic fragment that is less than 5 mm in length.
5. **Persistent Organic Pollutants (POP):** Are a group of chemicals which are intentionally or inadvertently produced and introduced into the environment.
6. **Phytotoxicity:** Phytotoxicity is a toxic effect by a compound on plant growth. Such damage may be caused by a wide variety of

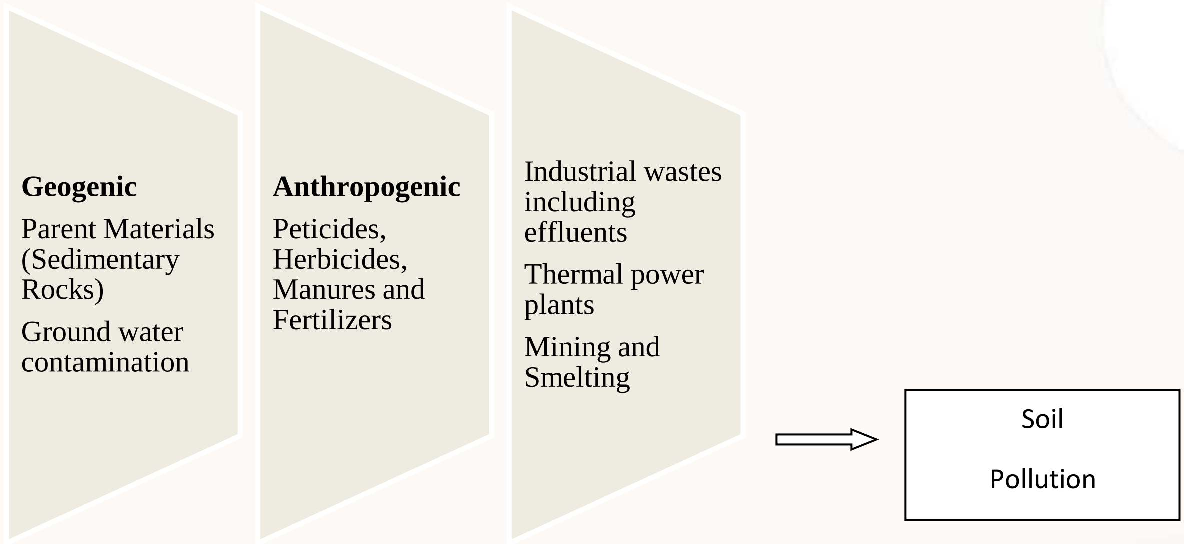
compounds, including trace metals, salinity, pesticides, phytotoxins or allelochemicals.

7. **Soil Pollution:** Soil pollution is defined as the build-up of pollutants in soils like persistent toxic compounds, chemicals, salts, radioactive materials etc with adverse effects on plant growth and human health.

19.1 Introduction

Pollution may be defined as an undesirable change in the physical, chemical and biological characteristics of air, water and soil which affect human life, lives of other useful living plants and animals, industrial progress, living conditions and cultural assets. A pollutant is something which adversely interferes with health, comfort, property or environment of the people. Generally, most pollutants are introduced in the environment by sewage, waste, accidental discharge or else they are by-products or residues from the production of something useful. Due to this our precious natural resources like air, water and soil are getting polluted.

Soil pollution is defined as the build-up of pollutants in soils like persistent toxic compounds, chemicals, salts, radioactive materials etc. with adverse effects on plant growth and human health. The various sources of soil pollution can be schematically represented as follows:



19.2 Types of Pollutants

19.2.1 Inorganic toxic compounds

Inorganic residues in industrial waste cause serious problems as regards their disposal. They contain metals which have high potential for toxicity. Industrial activity also emits large amounts of arsenic fluorides and sulphur dioxide (SO_2). Fluorides are found in the atmosphere from superphosphate, phosphoric acid, aluminium, steel and ceramic industries. Sulphur dioxide emitted by factories and thermal plants may make soils very acidic. These metals cause leaf injury and destroy vegetation. Copper, mercury, cadmium, lead, nickel, arsenic are the elements which can accumulate in the soil, if they get entry either through sewage, industrial waste or mine washings. Some of the fungicides containing copper and mercury also add to soil pollution. Smokes from automobiles contain lead which gets adsorbed by soil particles and is toxic to plants. The toxicity can be minimized by building up soil organic matter, adding lime to soils and keeping the soil alkaline.

19.2.2 Organic wastes

Organic wastes of various types cause pollution hazards. Domestic garbage, municipal sewage and industrial wastes when left in heaps or improperly disposed seriously affect health of human beings, plants and animals. Organic wastes contain borates, phosphates, detergents in large amounts. If untreated they will affect the vegetative growth of plants. The main organic contaminants are phenols and coal. Asbestos, combustible materials, gases like methane, carbon dioxide, hydrogen sulphide, carbon monoxide, sulphur dioxide, petrol are also contaminants. The radioactive materials like uranium, thorium, strontium etc. also cause soil pollution. Fallout of strontium mostly remains on the soil and is concentrated in the sediments.

19.2.3 Sewage and sewage- sludge

Soil pollution is often caused by the uncontrolled disposal of sewage and other liquid wastes resulting from domestic uses of water, industrial wastes containing a variety of pollutants, agricultural effluents from animal husbandry and drainage of irrigation water and urban runoff. Irrigation with sewage water causes profound changes in the irrigated soils. Amongst various changes that are brought about in the soil as an outlet of sewage irrigation include physical changes like leaching, changes in humus content, and porosity etc., chemical changes like soil reaction, base exchange status, salinity, quantity and availability of nutrients like nitrogen, potash, phosphorus, etc. Sewage sludges pollute the soil by accumulating the metals like lead, nickel, zinc, cadmium, etc. This may lead to the phytotoxicity of plants.

19.2.4 Heavy Metals

What is heavy metals?

The build-up of heavy metals in cultivated fields are mainly from the sources like, industrial effluents, sewage, sludge, contaminated ground water and river water. It is of rising apprehension as it induces detrimental effects on soil biota which in turn is a potential risk to human and animal health. Transfer of metals to the palatable portion of crops grown in contaminated soils often renders the food crops unfit for human and animal consumption. Excessive intake of metals and metalloids due to ingestion of food stuffs grown in contaminated soil may resulted into different physiological and metabolic disorders in human and animal. All the micronutrient cations viz. zinc (Zn), copper (Cu), manganese (Mn), iron (Fe) and nickel (Ni), which are indispensable for plant growth termed as metal (atomic number > 20 and sp. gravity > 5.0). Based on the concentrations, they exhibit both deficiency and toxicity in the plants/organisms. Lead (Pb), cadmium (Cd), chromium (Cr), mercury (Hg), selenium (Se), arsenic (As) and fluorine (F) are other metal, metalloid and non-metal of concern, which can cause toxicity to the plant/organisms, when present at an elevated level.

19.2.5 Pesticides

Pesticides are quite frequently used tocontrol several types of pests now-a-days. Pesticides may exert harmful effects to micro-organisms, as a result of which plant growth may be affected. Pesticides which are not rapidly decomposed may create such problems. Accumulation is residues of pesticides in higher concentrations are toxic. Pesticides persistence in soil and movement into water streams may also lead to their entry into food chain and create health hazards. Pesticides particularly aromatic organic compounds are not degraded rapidly and therefore, have a long persistence time.

19.2.6 Persistent Organic Pollutants

Persistent organic pollutants (POPs) are a group of chemicals which are intentionally or inadvertently produced and introduced into the environment. Due to their stability and transport properties, they are now widely distributed around the world, found even in the most unlikely places such as the arctic regions.

19.2.7 Microplastics

Microplastics are very small pieces of plastic that pollute the environment. Microplastics are not a specific kind of plastic, but rather any type of plastic fragment that is less than 5 mm in length according to the U.S. National

Oceanic and Atmospheric Administration (NOAA) and the European Chemicals Agency. They enter natural ecosystems from a variety of sources, including cosmetics, clothing, and industrial processes.

19.2.8 Emerging Pollutants

Emerging pollutants (EPs) refers to a large number of synthetic or naturally occurring chemicals that have recently appeared in the environment and are not commonly monitored. They have the potential to enter the environment and to cause known or suspected adverse ecological and/or human health effects. Emerging pollutants may well become pollutants of emerging concern, as new facts or information have demonstrated that they are posing a risk to the environment and human health. Emerging pollutants encompass chemicals such as pharmaceuticals, endocrine disruptors, hormones and toxins, among others, and biological pollutants, such as micropollutants in soils, which include bacteria and viruses. Other major groups of emerging contaminants are manmade nanoparticles (MNPs) and treatment by-products.

19.3 Extent of Soil Pollution

The Status of the World's Soil Resources Report (SWSR) identified soil pollution as one of the main soil threats affecting global soils and the ecosystems services provided by them. Concerns about soil pollution are growing in every region. Recently, the United Nations Environmental Assembly (UNEA-3) adopted a resolution calling for accelerated actions and collaboration to address and manage soil pollution. This consensus, achieved by more than 170 countries, is a clear sign of the global relevance of soil pollution and of the willingness of these countries to develop concrete solutions to address the causes and impacts of this major threat. The anthropogenic production of chemicals has experienced a rapid growth globally since the 1970s. In the European Union in 2016, the chemical industry produced 319 million tonnes of hazardous and non-hazardous chemicals. Of these, 117 million tonnes were deemed to be hazardous to the environment (EUROSTAT, 2018). Global production is projected to increase annually by approximately 3.4 percent until 2030, and non-OECD countries will be much greater contributors to this production in the future (OECD, 2008). Production and use of hazardous chemicals have been reduced over the last ten years; however, the uncertainties that still remain and the lack of information from many developing countries make it impossible to conclude that risks to the environment and human health have been successfully reduced. As the global population increases, so does the generation of waste. In developing and least developed countries, high rates of population growth and increasing waste and sludge production, combined with lack of municipal services that deal with waste management, create a dangerous situation. According to a World Bank report, the global production of municipal solid waste was estimated to be 1.3 billion tonnes per year in 2012, varying from 0.45 kg per person and per day in sub-Saharan Africa to 2.2 kg per capita annually in the Organisation for Economic Co-operation and Development

(OECD) countries. Future predictions are worrying, however, as waste production is expected to rise to 2.2 billion tonnes by 2025.

Although, surge in India's economic growth aided by higher levels of industrialization has remained a subject of pride, there is also a huge concern for the environmental degradation that slowly but loudly being voiced out. Central Pollution Control Board (CPCB) identified critically polluted industrial areas and clusters or potential impact zone based on its Comprehensive Environmental Pollution Index (CEPI) rating. Forty three critically polluted zones were reported in the 16 states which have CEPI rating more than 70. Among the 43 sites, 21 sites exist in only four states namely Gujarat, Uttar Pradesh, Maharashtra and Tamil Nadu. Information on soil pollution has been generated by research organizations in several of these critically polluted areas and such information is unevenly distributed. In some areas having very high CEPI rating like Haldia, Bhiwadi, Chandrapur, Singrauli, Bhiwadi, published information on the soil pollution in nearby agricultural areas is practically absent.

Industries, particularly those associated with chlor-alkali, textiles, glass, rubber production, animal hide processing and leather tanning, metal processing, pharmaceuticals, oil and gas drilling, pigment manufacture, ceramic manufacture, soap & detergent production are the major consumers of salts (mainly NaCl) produced in the world today. When released into the environment, salt ions present in the industrial effluents percolate through the soil profile and contaminate the ground- water due to their high mobility in the matrix. Most of the effluent treatment plants don't remove salts from the effluent water. As a result of this, salinity of groundwater has been found elevated in and around many industrial clusters of India; deteriorating drinking and irrigation water quality.

Table 1 Heavy metals accumulated in soil under different industrial areas are as follows:

Location	**Name of the industries**	**Heavy Metals accumulated**
Pithampur (Dhar), Madhya Pradesh	Automobile manufacturing, food processing, chemical processing, distilleries, textile industries and other manufacturing industries	Cr, Zn, Co
Debari (Udaipur), Rajasthan	Zinc smelter	Zn, Cd, Pb
Korba, Chhattisgarh	Thermal power plant, Metallurgical (Al), Textiles, Engineering workshops, Tyre rethreading, and others	Cd, Cr
Coimbatore, Tamil Nadu	Electroplating, Textile, Dye	Ni, Pb, Cd, Cr
Kanpur-Unnao (UP)	Textile, leather tanning, fertilizer, miscellaneous small scale chemical factories	Ni, Zn, Cr, Sn

(Panwar et al., 2010)

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**
As	75
Cd	85
Cr	3000
Cu	4300
Hg	57
Mo	75
Ni	420
Pb	840
Se	100
Zn	7500

USPEA = US environmental protection agency (1993)

19.3.1 Arsenic (As)

Arsenic (As) contamination in groundwater in the Ganga-Brahmaputra fluvial plains in India and Padma-Meghna fluvial plains in Bangladesh and its consequences to the human health have been reported as one of the world's biggest natural groundwater calamities to the mankind. In India, seven states namely- West Bengal, Jharkhand, Bihar, Uttar Pradesh in the flood plain of the Ganga River; Assam and Manipur in the flood plain of the Brahamaputra and Imphal rivers and Rajnandgaon village in Chhattisgarh state have so far been reported to be affected by Arsenic contamination in groundwater above the permissible limit of 10 µg/L. People in these affected states have chronically been exposed to drinking Arsenic- contaminated hand tube-wells water. With every new survey, more Arsenic affected villages and people suffering from Arsenic related diseases are being reported, and the issues are getting complicated by a number of unknown factors. These fluvial plains represent Holocene aquifers of recent alluvial sediments and have the routes originated from the Himalayan region. Arsenic groundwater contamination has far-reaching consequences including its ingestion through food chain which are in the form of social disorders, health hazards and socio-economic dissolution besides its sprawling with movement, and exploitation of groundwater. Arsenic contamination is understood to be of geogenic origin released from soil under conditions conducive to dissolution of Arsenic from solid phase on soil grains to liquid phase in water, and percolation of fertilizer residues might have played a modifying role in its further exaggeration. The toxicity of arsenic compounds in groundwater/soil environment follows the order: Arsine [AsH3; valence state of arsenic: 3] > organo-arsine compounds > arsenites and oxides (trivalent arsenic form) > arsenates (pentavalent arsenic form) > arsonium metals (monovalent arsenic form) > native arsenic metal. There are a number of hypotheses about the source of Arsenic and probable reasons of occurrence in groundwater. Over the last 25 years since the groundwater Arsenic contamination was first surfaced in the year 1983, a number of restorative and precautionary measures coupled with action plans focusing mainly on detailed investigations to understand the physiochemical process and mechanism, alternate arrangement to supply Arsenic free water to the affected populace and development of devices for Arsenic removal and their implementation at the field, etc. have been initiated mainly in West Bengal while in other States, they are meagre. The organo-arsenic complexation can increase the stability of the complex and thus mitigate the entry in the food chain to some extend (Mukhopadhyay and Sanyal,2004). Despite a number of corrective and precautionary measures, the spread of Arsenic contamination in groundwater continued to grow and more new areas have been added to the list of contaminated area. While drinking water is considered as the most important source for arsenic exposure, food is equally important exposure route and most important route of exposure in areas with safe drinking water. Food gets contaminated mainly due to application of contaminated irrigation water resulting in soil-crop-food transfer. According to World Health

Organization (WHO), maximum permissible limit of As concentration in rice grain is 1.0 mg kg^{-1}, which is more stringent in case of United States Department of Agriculture (0.15 mg kg^{-1}) and European Union (0.5 mg kg^{-1}). However, these permissible limits do not have much practical significance as there exist diversity from region to region with respect to the amount and type of food being consumed.

19.3.2 Selenium (Se)

Selenium (Se), a component of the enzyme glutathione peroxidase may be beneficial or toxic to plants, animals and humans depending upon its concentration. It is also an inorganic carcinogenic agent at elevated levels. The recommended human intake of Se is between 50 and 200 ppb Se day^{-1} according to World Health Organization. Geogenic-driven Se toxicity has been reported from some pockets of Punjab where as high as 2.41 mg Se kg^{-1} soil has been obtained. More than 1000 ha of such seleniferous soils exist in the North Eastern Punjab, where toxic Se sites are located at the terminal ends of the seasonal rivulets. The soils are alkaline in reaction, calcareous, silty loam to silty clay loam in texture and are well drained. Irrigation with groundwater in seleniferous region has led to the accumulation and toxicity of Se in soils of Punjab. During wheat season (upland conditions) 14% of the total Se in surface soil was present as selenate-Se (Si^{6+}) form. In contrast under submerged rice conditions, only 2.5% of the total Se was present as Si^{6+} whereas the remaining amount was predominantly present as selenite-Se (Si^{4+}) form. Se in water is an important criterion for determining its suitability for different purposes. According to United States Environment Protection Agency (USEPA) the maximum concentration level (MCL) of Se in water for drinking purpose is 10 ppb and the maximum permissible level (MPL) for water used for irrigation purpose is 20 ppb.

19.3.3 Fluoride (F)

The presence of Fluoride (F) in water is essential for protection against the dental caries and weakening of the bones, but excess F^- may lead to dental or skeletal fluorosis. In India the problem has been assumed alarming proportion in at least 17 states of the country, mostly from the geogenic-driven causes, rather than from industrial emissions. Indeed the groundwater of around 50-100 % districts are thus affected by fluoride toxicity in erstwhile, Andhra Pradesh, Tamil Nadu, Uttar Pradesh, Gujarat and Rajasthan; 30-35% districts are fluoride toxic in Bihar, Haryana, Karnataka, Maharashtra, Madhya Pradesh, Punjab, Orissa and West Bengal. Fluoride occurs exclusively as the F^- ion in soils, where it complexes strongly with metal ions such as Al^{3+} and Fe^{3+} ions. It may be present as the structural component of hydrous minerals, isomorphously substituting for structural OH. In acid soils solubility and mobility of F could be enhanced due to formation of soluble Al-F cationic and anionic complexes. In calcareous soils its solubility and mobility is limited by its incorporation into insoluble Ca-minerals.

19.4 Impacts of soil pollution

The predicted world's population of over nine billion by 2050 will require the provision of enough good quality food and water. FAO's latest projections indicate that global food production will increase by 60 percent between 2005/07 and 2050 under its baseline scenario. This represents a downward revision, based on updated data and information, from the 70 percent increase projected for the same period in 2009. (World Agriculture Towards 2030/2050: The 2012 revision ESA E Working Paper No. 12-03 http://www.fao.org/economic/esa/esag/en/). The quantity and nutritional quality of food supports human health, and 95 percent of food production depends on soils (FAO, 2015). Only healthy soils can provide the needed ecosystem services and secure supplies of more food and fibre. The provision of ecosystem services has received considerable attention and can be defined as "the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly" (Groot, 1992). Food security is defined as "the availability, access, utilization and stability of food supply." Soil pollution reduces food security both by reducing crop yields due to toxic levels of contaminants and by causing the produced crops to be unsafe for consumption (FAO and ITPS, 2015). Some major effects of Soil pollution are as follows:

19.4.1 Effects on Plants and Animals

If a contaminant is highly toxic to plants at low concentrations and is not easily translocated to shoots, fruits or tubers to pose a hazard to animals

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and humans, it is unlikely to enter the food chain and become a hazard. This concept was termed the “Soil-Plant Barrier” by Chaney almost 40 years ago for metals and metalloids. Since soil pollution is often accompanied by a decrease in the availability of nutrients, plant life ceases to thrive in such soils. Soils contaminated with inorganic aluminium can prove toxic to plants. Also, this type of pollution often increases the salinity of the soil, making it inhospitable for the growth of plant life. Plants that are grown in polluted soil may accumulate high concentrations of soil pollutants through a process known as bioaccumulation. When these plants are consumed by herbivores, all the accumulated pollutants are passed up the food chain. This can result in the loss/extinction of many desirable animal species. Also, these pollutants can eventually make their way to the top of the food chain and manifest as diseases in human beings.

19.4.2 Effects on the Ecosystem

Since the volatile contaminants in the soil can be carried away into the atmosphere by winds or can seep into underground water reserves, soil pollution can be a direct contributor to air and water pollution. It can also contribute towards acid rain (by releasing huge quantities of ammonia into the atmosphere). Acidic soils are inhospitable to several microorganisms that improve soil texture and help in the decomposition of organic matter. Thus, the negative effects of soil pollution also impact soil quality and texture. Crop yield is greatly affected by this form of pollution. In China, over 12 million tons of grain (worth approximately 2.6 billion USD) is found to be unfit for human consumption due to contamination with heavy metals (as per studies conducted by the China Dialogue).

19.4.3 Effect on the human

Soil contaminants can exist in all three phases (solid, liquid, and gaseous). Therefore, these contaminants can find their way into the human body via several channels such as direct contact with the skin or through the inhalation of contaminated soil dust.

The short term effects of human exposure to polluted soil include: a) Headaches, nausea, and vomiting b) Coughing, pain in the chest, and wheezing c) Irritation of the skin and the eyes d) Fatigue and weakness.

A variety of long-term ailments have been linked to soil pollution. Some such diseases are listed below.

a) Exposure to high levels of lead can result in permanent damage to the nervous system. Children are particularly vulnerable to lead.

b) Depression of the CNS (Central Nervous System).

c) Damage to vital organs such as the kidney and the liver.

d) Higher risk of developing cancer.

It can be noted that many soil pollutants such as petroleum hydrocarbons and industrial solvents have been linked to congenital disorders in humans. Thus, soil pollution can have several negative effects on human health.

Table 4 Effect of metal toxicity on human health

Element	Impact on human health due to toxicity
Arsenic	Skin cancer, hyperkeratosis, hyperpigmentation, black foot, rashes, cancer of internal organs
Cadmium	Renal tubular dysfunction, proteinuria, glucosuria, aminoaciduria, itai-itai disease
Chromium	Renal dysfunction, lung cancer
Fluoride	Calcification of the ligaments, osteosclerosis, endochondral ossification, thickening of the flat bones, osteomalacia and osteoporosis
Copper	Wilson's disease and cirrosis, haemolysis, hepatic necrosis, renal damage and salivary gland swelling
Lead	Encephalopathy (damage to brain), failure in reproduction, metabolic disorder, neurophysical deficit in children, affects the haematologic and renal system
Mercury	Neurological defects, depression, irritability, confusion, tremor, visual and auditory defects
Selenium	Persistent, adverse clinical signs developed with as high as 50% morbidity
Zinc	Interferes with reproduction, impair the growth of embryo

(Golui et.al., 2019)

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Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

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Course Name	Problematic soils and their Management
Lesson 20	Remediation Technique for Polluted soils
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Learning Objective

- Understanding various physical, chemical and biological methods as remediation techniques for polluted soils

Glossary of terms

1. **Soil washing:** This is an ex-situ technique of transferring metals from soil matrix to washing fluids (mostly acids, e.g. HCl) followed by precipitation of metals as metal salts and revert of unpolluted soil residue to the site.
2. **Soil replacement:** It is the process of using unpolluted soil to swap or partially replenish the polluted soil with the objective of diluting metal intensity.
3. **Thermal treatment:** It is the technique of heating contaminated soils using steam, microwave, IR radiation to make the pollutant (e.g. Hg, As) unstable and collecting unstable metals using void negative pressure or carrier gas for the abstraction of metals and metalloids from the soil.
4. **Electrokinetic remediation:** This technique of remediation is centred on the principles of electrochemistry, which involves application of direct current (DC) electricity via electrodes injected in the contaminated soil for facilitating the migration of cations to the cathode and negatively charged ions to the anode under a recognized electric field.
5. **Phytostabilization:** It refers to the immobilization of metals and metalloids in soil by plant roots.

20.1 Remediation approaches for polluted soils

Nathanail referred to sustainable remediation as “remediation that eliminates and/ or controls unacceptable risks in a safe and timely manner, and which maximizes the overall environmental, social and economic benefits of the remediation work” (Nathanail, 2011). Sustainable management requires the incorporation of the best available techniques, not only during the remediation process itself, but for the whole process, including risk assessment and risk reduction. Best management practices (BMPs) are individual or combinations of management, cultural and structural practices that researchers (academic or governmental) have identified as the most effective and economical way of reducing damage to the environment. Remediation is commonly done on a site-by-site basis, since for every combination of pollutant, soil property, land use, property and liability regimes and technical and economic reality of the site or area, a different technique or combination of techniques may be more appropriate.

The remediation of the soils contaminated with metals and metalloids, although challenging, can be achieved following physico-chemical and biological approaches. The physical approach involves removal of soil from contaminated site, decontamination of soil, and return of clean soil residue to the site (in some cases). In the chemical approach, heavy metals in contaminated soil are mostly immobilized or fixed through alteration of soil chemistry and facilitating the formation of insoluble chemical species using amendments or additives. The biological approach involves use of plants or microbes to trim down the level of contamination in soils. Mostly, the physical approach of remediation is based on the principle of ex-situ techniques. However, chemical and biological approaches of remediation are mostly based on the principles of in-situ techniques. Ex-situ techniques involve exclusion of contaminated soils for treatment on- or off site, and in-situ techniques involve remediation without excavation of polluted soils. Usually, remediation of metal polluted soils encompasses physical removal (decontamination) or immobilization of metals, rather degradation of metals.

20.2 Physical Approach

(i) Excavation and land-filling: It involves bulk digging out of contaminated soil and burial (land-filling) at a hazardous waste site.

ii) Soil washing: This is an ex-situ technique of transferring metals from soil matrix to washing fluids (mostly acids, e.g. HCl) followed by precipitation of metals as metal salts and revert of unpolluted soil residue to the site. Although chemical extractants (washing fluids) are used in this method, it does not detoxify or considerably revise the contaminants

(iii) Soil replacement: It is the process of using unpolluted soil to swap or partially replenish the polluted soil with the objective of diluting metal intensity.

(iv) Thermal treatment: It is the technique of heating contaminated soils using steam, microwave, IR radiation to make the pollutant (e.g. Hg, As) unstable and collecting unstable metals using void negative pressure or carrier gas for the abstraction of metals and metalloids from the soil.

20.3 Chemical Approach

(i) Immobilization (stabilization) of metals: The technique involves addition of reagents or amendments to the polluted soil to yield more chemically durable components. Immobilization of metals and metalloids is achieved mainly through chemical adsorption, precipitation of the metals, and complexation/chelation reactions which cause in the reallocation of contaminants from the soil solution phase to solid phase, and thereby reducing their bioavailability. The effectiveness of different amendments, viz. phosphate compounds, liming materials, organic ameliorant and metal oxides in immobilization of metals and metalloids has been attributed to sound chemical reactions in soil by various authors.

Phosphate compounds immobilize metals and metalloids in soils due to direct adsorption/substitution of heavy metals by phosphorus compounds, phosphorus anion-induced metal adsorption, and precipitation of metals and metalloids with solution phosphorus as metal and metalloid-phosphates.

Liming, a technique to ameliorate the acid soils, its usefulness to check the movement of metals in contaminated soil as reported. Liming causes the rise of soil pH which results in precipitation of the metals as their hydroxides and carbonates and hence reduces its bioavailability.

In chemical immobilization (stabilization) technique, soil ecological conditions such as pH, redox potential (Eh), cation exchange capacity (CEC) and soil organic matter content can affect the substantial release of immobilized heavy metals and metalloids in soil solution (Table 1).

Table 1: 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

(ii) Vitrification: It involves high-temperature (1400-2000^{0}C) treatment of the contaminated soil to transform into glass like solids. Heavy metals are encapsulated in to glass like solid materials. Vitrified substances with particular traits may be attained by using sand, clay, and/or native soil. In-situ vitrification is favoured over ex-situ technique due to lower energy requirement and cost.

(iii) Electrokinetic remediation: This technique of remediation is centred on the principles of electrochemistry, which involves application of direct current (DC) electricity via electrodes injected in the contaminated soil for facilitating the migration of cations to the cathode and negatively charged ions to the anode under a recognized electric field. Under a DC electric field the metal ions migrate which is primarily via electroosmosis, electromigration (movement of ions to the counterpart electrode), electrophoresis and diffusion due to gradient force.

20.4 Biological Approach

(i) Phytoremediation: Phytoremediation is an in-situ remediation, involving employment of plants to extract metals from contaminated soil or stabilize them in soil. In general, reduction in metal(loid) contamination in soil is achieved through phytoextraction (removal technology) and phytostabilization (containment technology). Phytoextraction denotes the uptake of metals and metalloids by plant roots into the aerial parts of plants. Phytostabilization refers to the immobilization of metals and metalloids in soil by plant roots. For being potentially suitable for phytostabilization, plants must have high root biomass. Agrostis tenuis, Festuca rubra, Gentiana pennelliana, Hyparrhenia hirta, Zygophyllum fabago, and Vossia cuspidate are some important plant species for phytostabilizing soils contaminated by Pb, Zn, Cr, and Cu. Phytoremediation of As can be done by Pteris vittata, Eleocharis acicularis, Hibiscus sabdariffa L., Hibiscus cannabinus L., Corchorus capsularis L., Cladophora sp, Chlorodesmis sp., Himetainubie, BR-29 rice, Chotoshama, Zinnia elegans, Gomphrena globose and Brassica juncea

(ii) Bioremediation: This technique involves the use of microorganisms for remediation purpose. The mechanisms by which microorganisms detoxify metal(loid)s include intracellular accumulation, extracellular chemical precipitation, oxidation-reduction reaction, sorption on microbial cell surface and volatilization. For example, Bacillus circulans and Bacillus megaterium have been reported to be potential bacterial strains for biosorption and bioaccumulation of hexavalent (VI) chromium.

20.5 Applicability of remediation techniques

The applicability and assortment of any remediation technique is depended on the nature and source of contamination, contamination level, cost-effectiveness, long-term permanence, general acceptance, remediation goal, time requirement and ease in implementation. All these criteria are important for selection of remediation technique based on site-specific issues. In developing countries like India with limited funds allocated for environmental restitution, cost-effective and ecologically viable alternatives are required for restoration of metal(loid) contaminated soils in order to diminish associated health risk and enhance food and nutritional security. The ex-situ remediation technologies, due to involvement of high cost, are usually not preferred. Chemical immobilization and phytoremediation are the encouraging tools for remediation of soil polluted by metal(loid)s in developing countries. Chemical immobilization and phytoremediation can be followed for highly contaminated and low to moderately contaminated soils, respectively. In excessively-high contaminated soils, e.g. mining and smelting sites, chemical immobilization technique can be practiced to minimize the toxicity due to high-accumulation of metal(loid)s in soil for establishing plants, followed by phytoremediation to restore the contaminated site gradually in long-run. For successful implementation of any remediation technology, proper planning in view of the merits and demerits of the proposed techniques is of immense importance.

20.6 Mechanisms of Heavy Metal Uptake by Plant

Contaminant uptake by plants and its mechanisms have been being explored by several researchers. It could be used to optimize the factors to improve the performance of plant uptake. The plants act both as “accumulators” and “excluders”. Accumulators survive despite concentrating contaminants in their aerial tissues. They biodegrade or biotransform the contaminants into inert forms in their tissues. The excluders restrict contaminant uptake into their biomass.

Plants have evolved highly specific and very efficient mechanisms to obtain essential micronutrients from the environment, even when present at low ppm levels. Plant roots, aided by plant-produced chelating agents and plant-induced pH changes and redox reactions, are able to solubilize and take up micronutrients from very low levels in the soil, even from nearly insoluble precipitates. Plants have also evolved highly specific mechanisms to translocate and store micronutrients. These same mechanisms are also involved in the uptake, translocation, and storage of toxic elements, whose chemical properties simulate those of essential elements. Thus, micronutrient uptake mechanisms are of great interest to phytoremediation.

The range of known transport mechanisms or specialized proteins embedded in the plant cell plasma membrane involved in ion uptake and translocation include (1) proton pumps (″-ATPases that consume energy and generate electrochemical gradients), (2) co- and antitransporters (proteins that use the electrochemical gradients generated by ″-ATPases to drive the active uptake of ions), and (3) channels (proteins that facilitate the transport of ions into the cell). Each transport mechanism is likely to take up a range of ions. A basic problem is the interaction of ionic species during uptake of various heavy metal contaminants. After uptake by roots, translocation into shoots is desirable because the harvest of root biomass is generally not feasible. Little is known regarding the forms in which metal ions are transported from the roots to the shoots.

Plant uptake-translocation mechanisms are likely to be closely regulated. Plants generally do not accumulate trace elements beyond near-term metabolic needs. And these requirements are small ranging from 10 to 15 ppm of most trace elements suffice for most needs. The exceptions are “hyperaccumulator” plants, which can take up toxic metal ions at levels in the thousands of ppm. Another issue is the form in which toxic metal ions are stored in plants, particularly in hyperaccumulating plants, and how these plants avoid metal toxicity. Multiple mechanisms are involved. Storage in the vacuole appears to be a major one.

Water, evaporating from plant leaves, serves as a pump to absorb nutrients and other soil substances into plant roots. This process, termed evapotranspiration, is responsible for moving contamination into the plant shoots as well. Since contamination is translocated from roots to the shoots, which are harvested, contamination is removed while leaving the original soil undisturbed. Some plants that are used in phytoextraction strategies are termed “hyperaccumulators.” They are plants that achieve a shoot-to-root metal-concentration ratio greater than one. Nonaccumulating plants typically have a shoot-to-root ratio considerably less than one. Ideally, hyperaccumulators should thrive in toxic environments, require little maintenance and produce high biomass, although few plants perfectly fulfill these requirements.

Metal accumulating plant species can concentrate heavy metals like Cd, Zn, Co, Mn, Ni, and Pb up to 100 or 1000 times those taken up by nonaccumulator (excluder) plants. In most cases, microorganisms bacteria and fungi, living in the rhizosphere closely associated with plants, may contribute to mobilize metal ions, increasing the bioavailable fraction. Their role in eliminating organic contaminants is even more significant than that in case of inorganic compounds.

Heavy metal uptake by plant through phytoremediation technologies is using these mechanisms of phytoextraction, phytostabilisation, rhizofiltration, and phytovolatilization as shown in Figure 1.

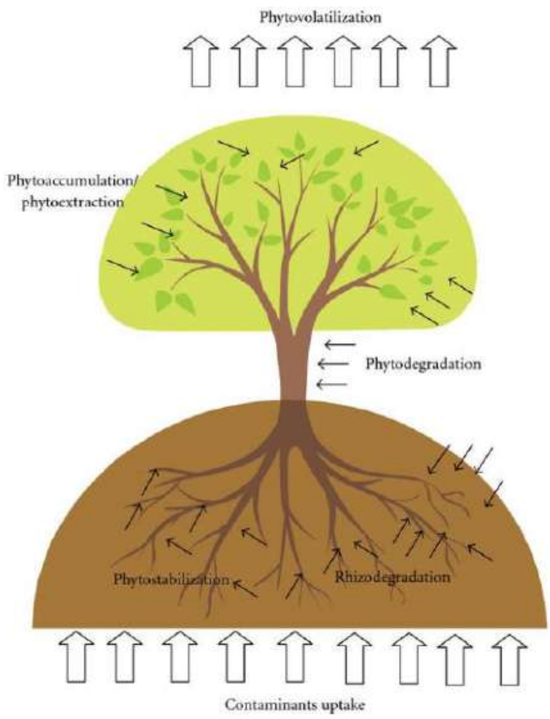

Figure 1 The mechanisms of heavy metals uptake by plant through phytoremediation technology.

20.6.1 Phytoextraction

Phytoextraction is the uptake/absorption and translocation of contaminants by plant roots into the above ground portions of the plants (shoots) that can be harvested and burned gaining energy and recycling the metal from the ash.

20.6.2 Phytostabilisation

Phytostabilisation is the use of certain plant species to immobilize the contaminants in the soil and groundwater through absorption and accumulation in plant tissues, adsorption onto roots, or precipitation within the root zone preventing their migration in soil, as well as their movement by erosion and deflation.

20.6.3 Rhizofiltration

Rhizofiltration is the adsorption or precipitation onto plant roots or absorption into and sequesterization in the roots of contaminants that are in solution surrounding the root zone by constructed wetland for cleaning up communal wastewater.

20.6.4 Phytovolatilization

Phytovolatilization is the uptake and transpiration of a contaminant by a plant, with release of the contaminant or a modified form of the contaminant to the atmosphere from the plant. Phytovolatilization occurs as growing trees and other plants take up water along with the contaminants. Some of these contaminants can pass through the plants to the leaves and volatilize into the atmosphere at comparatively low concentrations.

Plants also perform an important secondary role in physically stabilizing the soil with their root system, preventing erosion, protecting the soil surface, and reducing the impact of rain. At the same time, plant roots release nutrients that sustain a rich microbial community in the rhizosphere. Bacterial community composition in the rhizosphere is affected by complex interactions between soil type, plant species, and root zone location. Microbial populations are generally higher in the rhizosphere than in the root-free soil. This is due to a symbiotic relationship between soil microorganisms and plants. This symbiotic relationship can enhance some bioremediation processes. Plant roots also may provide surfaces for sorption or precipitation of metal contaminants.

In phytoremediation, the root zone is of special interest. The contaminants can be absorbed by the root to be subsequently stored or metabolised by the plant. Degradation of contaminants in the soil by plant enzymes exuded from the roots is another phytoremediation mechanism.

For many contaminants, passive uptake via micropores in the root cell walls may be a major route into the root, where degradation can take place.

Course Name	Problematic soils and their Management
Lesson 21	Quality and Standards of Irrigation water
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Learning Objective

- Understanding the criteria for evaluating irrigation water quality – salinity hazard, sodicity hazard, RSC and Excessive concentrations of elements that cause ionic imbalance

Glossary of terms

1. **Deflocculation:** Deflocculation is the process by which the solids that are stuck together are dispersed either by electrolyte concentration, raising the pH of the slurry, or adding thinners or dispersants to the system. Through the dispersion process the particles are usually broken down into finer ones. It is also defined as the act of reducing the viscosity of a suspension by adding a thinning agent, also known as a deflocculant.
2. **Infiltration Rate:** A measure of how fast water enters the soil, typically expressed in inches per hour but recorded in minutes for each inch of water applied to the soil surface.
3. **Permeability Index:** Permeability index (PI) was used to classify the irrigation water quality and was calculated by the formula given by Doneen. The concentration of all ions was taken in meq L^{-1}:

   Permeability Index (PI) = $\left(\frac{Na^{2+} + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^{+}}\right) X\ 100$

4. **Salt index:** Salt index is a numerical value expressed as a ratio in which the selected fertilizer product is compared to the same weight of sodium nitrate ($NaNO_3$), where sodium nitrate is assigned a value of 100.

5. **Water Quality Index (WQI):** It may be defined as a rating, reflecting the composite influence of different water quality parameters on the overall quality of water.

21.1 Introduction

The ever increasing human population, climate change due to increased emissions of greenhouse gases (GHGs), and intensification of agriculture, are putting severe pressure on the world's two major non-renewable resources of soil and water, and thus pose a big challenge to produce sufficient food to meet the current food demand. The present world population of 7.3 billion people is predicted to grow over 9 billion by 2050, with the majority of this population increase occurring in developing countries, most of which already face food shortages. A 70% increase in current agricultural productivity will be required to produce sufficient food if these human population growth predictions prove to be correct. In this context, concerted efforts are being made globally to improve the effectiveness of water which will be used for enhancing the production of irrigated crops. The concentration and composition of soluble salts in water will determine its quality for various purposes (human and livestock drinking, irrigation of crops, etc.). The quality of water is, thus, an important component with regard to sustainable use of water for irrigated agriculture, especially when salinity development is expected to be a problem in an irrigated agricultural area.

The suitability of irrigation water depends upon several factors, such as, water quality, soil type, plant characteristics, irrigation method, drainage, climate and the local conditions. The integrated effect of these factors on the suitability of irrigation water (SI) can be expressed by the relationship given below:

SI= ƒ(QSPCD)

where,

Q = quality of irrigation water, that is, total salt concentration, relative proportion of cations, etc;

S = soil type, texture, structure, permeability, fertility, calcium carbonate content, type of clay minerals and initial level of salinity and alkalinity before irrigation;

P = salt tolerance characteristics of 'the crop to be grown, its variety and growth stage;

C = climate, that is, total rainfall, its distribution and evaporation characteristics; and

D = drainage conditions, depth of water table, nature of soil profile, presence of hard pan or lime concentration and management practices.

There is a number of different water quality guidelines associated with irrigated agriculture. Separately each is valuable but none is completely acceptable because of the wide variability in field conditions. The modified guideline by Ayers and Westcot (1985) was found to be the most reliable to predict the water quality for irrigation. The suitability criterion of water for agriculture is determined not only by the total amount of salt present but also by the type of salt. Many soil and crop related problems are incurred as the total salt content increases. Special management practices may be required to maintain desirable crop yields. Water quality for use in agriculture is judged on the potential severity of problems that can be expected to be developed during long-term use. The process is slow and gradual so one must be very careful about the quality of water being used for domestic as well as for irrigation purpose. Evaluating the quality of water for domestic purpose especially for potable use Water Quality Index (WQI) based on chemical characteristics is found to be one of the most effective tools. Water Quality Index (WQI) was formulated in many countries based on their National standards. Horton (1965) proposed the first WQI to be used as a tool for assessing the overall quality of water.

As per Gupta and Gupta (2003) the characteristics of irrigation water that have been the most important in determining its quality, depends upon climatic condition, irrigation practices, soil water retention characteristics, crop tolerance, depth of water table and agronomic practices etc. are the following :

i. Salinity hazard (Total concentration of soluble salts): Electrical conductivity (EC)
ii. Specific ion toxicity hazard (Ionic composition)
    a. Major constituents (Na, Mg , Cl , HCO_3 , CO_3 , Silica, NO_3)
    b. Minor constituents (B, Li, F and other micro toxicants).
iii. Sodicity hazard (Relative proportion of Na to other cations, sodium adsorption ratio (SAR), sodium to calcium activity Ratio (SCAR), adjusted SAR/SCAR.

iv. Alkalinity hazard (Bicarbonate concentration as related to the concentration of (Ca + Mg) or calcium alone; residual sodium carbonate (RSC) or residual sodium bicarbonate (RSBC).

In addition to above individual parameters combined evaluation of two parameters viz., 1) EC and SAR, 2) SAR and RSC is also of practical importance.

21.2 Water quality criteria for irrigation

The following chemical properties shall be considered for determining water quality criteria for irrigation:

21.2.1 Electrical Conductivity

Salinity is estimated in terms of electrical conductivity (EC) and is obtained from the resistance recorded across a conductivity cell from the following relationship.

EC=K/R.

Where K is the cell constant and R is the resistance expressed in deci-Siemens per meter (dSm^{-1}) according to SI units (from the system International units). EC of the soil extracts at saturation (EC_e) has been widely recognized as an index to evaluate the plant growth. Ideally it would be inferred that EC of irrigation water should be as low as possible, but the water which is completely free of the soluble salts is never the best for irrigation. The water having EC less than 0.2 dS/m have no fertility value and are well known to create permeability problem in the soil. The irrigation water should however have EC preferably less than 1.5 dS/m so that the irrigated soil does not ever become saline and there is full choice to grow the crops (Table 1).

1. It can be stated that with an increase in EC of water Mg/Ca ratio tends to increase. It was believed that if the proportion of Ca + Mg is high, the sodicity hazard is low. If Na predominates the hazard is high. One of the most important criteria in determining quality of water for irrigation is the Mg content of the irrigation water. A harmful effect on soil appears when the ratio Mg: Ca + Mg exceeds 0.5.
2. The occurrence of chloride ions in natural irrigation water increase with an increase in EC and sodium ions. Therefore high salinity water is dominated by these ions. Unlike the sodium ions, neither the chloride ions have any effect on the physical properties the soil nor they adsorbed by the soil.
3. Nitrate (NO_3) is a highly water soluble molecule made up of nitrogen and oxygen. It is formed when nitrogen for ammonia or other sources combines with oxygen dissolved in water. Bureau of Indian Standard has set the maximum permissible level of nitrate-nitrogen in public drinking water at 20 mg /l or 20 ppm (parts per million) (BIS 2002) which is further revised in 2004 to maximum permissible level of 45 ppm. Infants who are fed water or formula made with water that is high in nitrate content can develop a condition called methemoglobinemia.

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

Water	EC (dsm^{-1})	Salt concentration	Remarks
Low salinity	0 – 0.25	< 0.16	Can be used safely
Medium salinity	0.25 – 0.75	0.16 – 0.50	Can be used with moderate leaching
Highly salinity	0.75- 2.25	0.50- 1.50	Cannot be use for irrigation purposes
Very high salinity	2.25 – 5.00	1.50 - 30	

12.2.2 Sodium Adsorption Ratio

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 (Table 2).

Sodium Adsorption Ratio (SAR) - shall be calculated from the following formula:

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

where,

SAR = sodium adsorption ratio

Na = sodium ion concentration, (me L^{-1})

Ca = calcium ion concentration, (me L^{-1})

Mg = magnesium ion concentration, (me L^{-1})

NOTE- (me L^{-1}) = milliequivalent/litre.

Most annual crops are not so sensitive, but may be affected by higher concentration. Sodium sensitive crops included deciduous fruits, nuts, citrus and beans. These plants suffer injury as a result of sodium accumulation in the leaves.

Table 2 Water class according to SAR value

	Water class	**SAR Value**	**Remarks**
S_1	Low sodium hazard	0 – 10	Little or no hazard
S_2	Medium sodium hazard	10 – 18	Appreciable hazard, but can be used with appropriate management
S_3	High sodium hazard	18 – 26	Unsatisfactory for most of the crops
S_4	Very high sodium hazard	>26	

21.2.3 Residual Sodium Carbonate

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 (Table 3) and is expressed in mel^{-1}.

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

Where,

RSC = Residual Sodium Carbonate

CO_3^{2-} = Carbonate ion concentration (me L^{-1})

HCO_3^- = Bicarbonate ion concentration (me L^{-1})

Ca = Calcium ion concentration, (me L^{-1})

Mg = Magnesium ion concentration, (me L^{-1})

Table 3 Water class according to RSC values

Class	RSC values	Remarks
Low	Below 1.5	Water can be used safely
Medium	1.5-3.0	Water can be used with certain management
High	3.0-6.0	Unsuitable for irrigation purposes
Very High	Above 6.0	

21.2.4 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.

21.2.5 Boron Content

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. Boron, though a nutrient, becomes toxic if present in water beyond a particular level. The permissible limits of boron in irrigation water are given below (Table 4).

Table 4 Permissible limits of Boron in irrigation water

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 to 2.00	Can be used with management
Medium	0.67 to 1.00	1.33 to 2.00	2.00 to 3.00	Unsuitable 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	

21.2.6 Chloride Concentration

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. Permissible limit of Cl in irrigation water is listed in Table 5.

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

Table 5 Permissible limits of Chloride in irrigation water

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

21.2.7 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.

21.2.8 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 on soils appears when Ca: Mg ratio declines below 50.

$$\text{Mg Adsorption ratio} = \frac{Mg^{2+}}{Ca^{2+}+Mg^{2+}} \times 100$$

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

21.2.9 Nitrate Concentration

Very frequency groundwater contains 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.

21.2.10 Lithium

Lithium is an important trace element which may be found in most of saline groundwater 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.

21.2.11 Water Infiltration Rate

Infiltration is an indicator of the soil's ability to allow water movement into and through the soil profile. Soil temporarily stores water, making it available for root uptake, plant growth and habitat for soil organisms. A high infiltration rate is generally desirable for plant growth and for the environment. In some cases, soils that have unrestricted water movement through their profile can contribute to environmental concerns if unscrupulous application of nutrients and chemicals reach groundwater and surface water resources via subsurface flow.

Permeability Index (PI) = $\frac{Na^{2+} + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+} \text{ X } 100$

PI <60 per cent – good quality water and suitable for irrigation

PI >60 per cent – poor quality water and unsuitable for irrigation

21.3 Water Quality Index

Water Quality Index (WQI) is a single score derived by considering different important parameters of water quality. It is an integration of the individual effect of all the parameters in right proportion in deciding the quality of water.

At first each parameter was assigned a weight (wi) according to its relative importance in the overall quality of water for drinking purposes based on per cent of samples within the permissible limit as per the standards. Weights of 5, 4, 3, 2, 1 are assigned to the quality parameters when 0-20, 21-40, 41-60, 61-80 and 81-100 % of samples are within the permissible limit respectively (Raychaudhuri et al. 2011). Secondly, the relative weight (Wi) is computed from using the following equation:

$$\mathrm{Wi} = \mathrm{wi} / \sum_{i=1}^{n} \mathrm{wi}$$

where, Wi is the relative weight, wi is the weight of each parameter and n is the number of parameters.

Third step involves assignment of a quality rating scale (qi) for each parameter by dividing its concentration in each water sample by its respective standard according to the guidelines laid down in the BIS followed by multiplication with 100:

$$\mathrm{qi} = (\mathrm{Ci}/\mathrm{Si}) \times 100$$

where, qi denotes the quality rating, Ci denotes the concentration of each chemical parameter in each water sample in mg/L, and Si is the Indian drinking water or irrigation water standard for each chemical parameter in mg/L according to the guidelines of the BIS 10500, 1991 or FAO respectively. For computing the WQI, the SI is first determined for each chemical parameter, which is then used to determine the WQI as per the following equation:

$$SIi = Wi.qi$$

$$WQI = \sum_{i=1}^{n} SIi$$

SI_i is the subindex of i^{th} parameter; qi is the rating based on concentration of i^{th} parameter and n is the number of parameters. The computed WQI values are then categorised into five classes, “excellent” “good”, “poor”, “very poor” and “unsuitable” for drinking purpose and in four classes based on “none”, “slight”, “moderate” and “severe” restrictions for irrigation use.

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Course Name	Problematic soils and their Management
Lesson 22	Use of saline water in agriculture
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Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Learning Objective

- Understand the tolerance of plants to salinity and conjunctive use of saline and fresh waters for irrigation

Glossary of terms

1. **Desalinization:** The removal of salt or other chemicals from something, such as seawater or soil. Desalinization can be achieved by means of evaporation, freezing, reverse osmosis, ion exchange, and electrodialysis.
2. **Electrical conductivity (EC):** Electrical Conductivity of water is its ability to conduct an electric current.
3. **Evapotranspiration (ET):** The process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants.
4. **Green manure:** Green manure is a cover crop sown on an agricultural plot in order to fertilize the soil for the following crop mainly through the intake of nitrogen. This cover crop is sown between two sales crops (usually between two highly demanding nitrogen crops) or in combination with the previous crop.
5. **Leaching requirement (L_r):** Leaching requirement is the minimum amount of irrigation water that must be drained through the crop root zone to control the soil salinity at the given specific level.

6. **Permeability:** Permeability refers to the movement of air and water through the soil, influencing the supply of root-zone air, moisture, and nutrients available for plant uptake.
7. **Salinity:** The term salinity refers to the amount of dissolved salts that are present in water. Sodium and chloride are the predominant ions in seawater, and the concentrations of magnesium, calcium, and sulphate ions are also substantial.

22.1 Introduction

Total volume of water available on earth is 1.4×10^9 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.

22.2 Assessing the Suitability of Saline Water for Crop Production

The suitability of water for irrigation should be evaluated on the basis of criteria indicative of its potential to create soil conditions hazardous to crop growth and subsequently to animals or humans consuming those crops. Relevant criteria for judging irrigation water quality in terms of potential hazards to crop growth are primarily (Rhoades et al., 1992):

- Permeability and tilth
- Salinity
- Toxicity and nutritional imbalance

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.

The total salt concentration and the proportion of sodium (Na) have long been recognized as key parameters in characterizing saline/brackish waters. The quantity of salts dissolved in water is usually expressed in terms of electrical conductivity (EC), mg/L (ppm), or meq/L, the former being most popular because of ease and precision in its measurement. The cations Na^+ Ca^{2+}, and Mg^{2+} and the anions Cl^-, SO_4^{2-}, HCO_3^- and CO_3^{2-} are the major constituents of saline water. Plant growth is affected adversely with saline irrigation, primarily through the impacts of excessive salts on osmotic pressures of the soil solution, though the excessive concentration and absorption of individual ions, for example, Na, Cl, and B, may prove toxic to plants and/or retard the absorption of other essential plant nutrients. The reduced water availability at high salinity thus causes water deficits for plants, and plant growth becomes inhibited, under field situations, the first reaction of plants for the use of saline water is reduction in the germination, but the most conspicuous effect is the growth retardation of crops.

22.3 Management of Saline water for use in agriculture

Management of saline water in agriculture includes an important aspect of safe use of saline water for irrigation. . The management practices for optimal crop production with saline/alkali water must aim at preventing the build-up of salinity, sodicity, and toxic ions in the root zone to levels that limit the productivity of soils, control the salt balances in the soil–water system, as well as minimize the damaging effects of salinity on crop growth. For sustainable agricultural production, a salinity balance has to be maintained at the irrigation and basin levels. Conjunctive use, water table management, rainwater conservation, and chemical amelioration of alkali waters are some of the important practices to achieve these objectives. The success of applying salt-rich irrigation water can only be achieved if factors such as rainfall, climate, and water table and water quality characteristics on soils and crops are integrated with appropriate crop and irrigation management practices. The available management options mainly include irrigation, crop, chemical, and other cultural practices, but there seems to be no single management measure to control salinity and sodicity of irrigated soils. Nevertheless, the crop production with saline/alkaline water is generally more costly per unit area of land, whereas crop yields are very low.

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 having 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 0-10 SAR 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 700 mm annual rainfall, but if rainfall is lesser then 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).

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

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Table 1 Classification of irrigation water based on its electrical conductivity (USSLS, 1954)

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

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.

22.3.1 Leaching Requirement

Leaching requirement is the minimum amount of irrigation water that must be drained through the crop root zone to control the soil salinity at the given specific level. The concept of leaching requirement is mainly of practical importance for the situations of no or very low rains, while it is invalid for irrigation with waters having residual alkalinity.

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, EC_d = 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

22.3.2 Irrigation Water Management

Proportional mixing of good quality (if available) water with saline water and then using for irrigation reduces the effect of salinity. Alternate furrow irrigation favours growth of plant than flooding. Drip, sprinkler and pitcher irrigation have been found to be more efficient than the conventional flood irrigation method since relatively lesser amount of water is used under these improved methods. Irrigation in saline soils should be more frequent because it reduces the cumulative water deficits (both matric and osmotic) between the irrigation cycles.

22.3.3 Fertilizer/Organic manure Management

Addition of extra dose of nitrogen to the tune of 20-25% of recommended level will compensate the low availability of N in these soils. Addition of organic manures like, FYM, compost, etc. helps in reducing the ill effect of salinity due to release of organic acids produced during decomposition. Green manuring (Sunhemp, Daincha, Kolingi) and or green leaf manuring also counteracts the effects of salinity.

22.3.4 Soil / Cultural Management

Planting the seed in the centre of the raised bed / ridge may affect the germination as it is the spot of maximum salt accumulation. A better salinity control can be achieved by using sloping beds with seeds planted on the sloping side just above the water line. Alternate furrow irrigation is advantageous as the salts can be displaced beyond the single seed row. Application of straw mulch had been found to curtail the evaporation from soil surface resulting in the reduced salt concentration in the root zone profile within 30 days.

22.3.5 Use of Amendments

Chemical amendments such as gypsum, when added to water will increase the calcium concentration in the water, thus reducing the sodium to calcium ratio and the SAR, thus improving the infiltration rate. The adverse effects of high Na on physical and chemical properties of soils can be mitigated by the use of amendments which contain Ca (e.g., gypsum).

Acids or acid-forming substances such as sulphuric acid or pyrites, which on reaction with soil $CaCO_3$ release Ca^{2+} in solution, can also be used. Whether or not to use amendments for saline–sodic conditions should be judged from their effectiveness in improving soil properties and crop growth in relation to the cost involved.

22.3.6 Crop Choice / Crop Management

The intergenic differences in crop tolerance can be exploited to select crops those produce satisfactory yield under the given levels of root zone salinity and sodicity. The general recommendations are that, for successful utilisation of saline waters, semi-tolerant to tolerant crops (mustards, wheat, cotton) and those with low water requirement should be grown whereas crops like rice, sugarcane and berseem requiring excess amount of water should be avoided. In low rainfall areas (< 400 mm), mono cropping is recommended. Crops are to be chosen based on the soil salinity level (Gupta and Gupta, 2003).

22.4 Guidelines for using saline water

The suitability of specific water for irrigation purposes, it is necessary to know not only its composition, but also the exact conditions of its proposed use (soil, climate, crops, etc.), the method of irrigation, and other management practices followed. Because of inherent problems in integrating the effects of all these factors, it is difficult to develop rigid standards universally. Therefore, broad guidelines for assessing the suitability of irrigation water have been suggested from time to time for average use conditions. Based upon the field experiences and the results of long-term experimentation, consultants recommended guidelines and the results for utilizing poor-quality water and their wider applicability in different agro-ecological zones in India (Table 2). Some of the points added to these guidelines are as follows:

- Use of gypsum for saline water
- Additional phosphorus application
- Use of canal water at early growth stages, including pre-sowing irrigation, in conjunction with saline water
- Using 20% extra seed and irrigating soon after sowing (within 2-3 days) to improve germination
- Irrigation with saline water just before the onset of the monsoon will lower the soil salinity and raise the soil moisture, resulting in greater salt removal by the rains
- Use of organic materials in a saline environment to improve crop yields
- For soils having either a shallow water table (within 1.5 m for a crop sown just before the monsoon) or hard subsoil layers, canal type irrigation is applicable

Table 2 Guidelines for using saline irrigation waters in India (USSLS, 1954)

Soil Texture (% Clay)	Crop Tolerance	EC_{iw} (dS m^{-1}) limit for rainfall region		
		<350	350-550	>550
Fine (> 30)	Sensitive	1.0	1.0	1.5
	Semi-tolerant	1.5	2.0	3.0

	Tolerant	2.0	3.0	4.5
Moderately Fine (20-30)	Sensitive	1.5	2.0	2.5
	Semi-tolerant	2.0	3.0	4.5
	Tolerant	4.0	6.0	8.0
Moderately Coarse (10-20)	Sensitive	2.0	2.5	3.0
	Semi-tolerant	4.0	6.0	8.0
	Tolerant	6.0	8.0	10.0
Moderately Coarse (<10)	Sensitive	-	3.0	3.0
	Semi-tolerant	6.0	7.5	9.0
	Tolerant	8.0	10.0	12.5

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Course Name	Problematic soils and their Management
Lesson 23	Utilization of Remote Sensing and GIS for diagnosis and management of problem soils
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Learning Objective

- *Understand the potential of RS-GIS based diagnostic tools in change detection, cropped areas, floods, drought monitoring and land use change*

Glossary of terms

1. **Remote Sensing:** Remote sensing is the acquisition of information about an object or phenomenon without making physical contact with the object and thus is in contrast to on-site observation.
2. **Active sensors:** Provide their own source of energy to illuminate the objects they observe. An active sensor emits radiation in the direction of the target to be investigated. The sensor then detects and measures the radiation that is reflected or back scattered from the target.
3. **Passive sensors:** They detect natural energy (radiation) that is emitted or reflected by the object or scene being observed. Reflected sunlight is the most common source of radiation measured by passive sensors.
4. **Geographical Information System (GIS):** A geographic information system (GIS) is a computer system for capturing, storing, checking, and displaying data related to positions on Earth's surface. GIS can show many different kinds of data on one map, such as streets, buildings, and vegetation.

5. **Global Positioning System (GPS):** The Global Positioning System (GPS), originally Navstar GPS, is a satellite-based radionavigation system owned by the United States government and operated by the United States Space Force. It is one of the global navigation satellite systems (GNSS) that provides geolocation and time information to a GPS receiver anywhere on or near the Earth where there is an unobstructed line of sight to four or more GPS satellites.

23.1 Introduction

Agriculture plays a vital role in every nation economy. It represents a substantial trading industry for an economically strong country. Production of food in a cost-effective manner is the essential goal of every farmer, large-scale farm manager, and regional agricultural agency. Remote sensing and Geographic information system used to analyze and visualize agricultural environments has proved to be very beneficial to farming community as well as industry. It plays great role in agriculture throughout the world by helping farmers in increasing production, reducing costs, and managing their land more efficiently. Geographic information systems (GIS) has been widely applied and been recognized as effective and powerful tool in detecting land cover and land use change. Using remote sensing and GIS are important to understand the health of crop, extent of infestation, potential yield and soil conditions. It applied to explore agricultural applications such as crop identification,

area estimation, crop condition assessment, soil moisture estimation, yield estimation, agriculture water management, agro meteorological etc.

Applications of remote sensing in agriculture includes important aspects such as; biomass and yield estimation, vegetation vigor and drought stress monitoring, assessment of crop phenological development, crop acreage estimation and cropland mapping, mapping of disturbances and land use land cover changes in addition to precision agriculture and irrigation management. GIS based mapping application can help to identify location of crops growing across the country and to adapt different variables, monitor the health of individual crops, estimate yields from a given field, and maximize crop production. By using land-use and primary food crop statistics, along with data collected by different tools including mobile devices able to identify areas in need and underlying causes of food insecurity, GIS is an instrumental in the efforts to end global hunger and it is an integral part of automated field operations.

Using data collected from remote sensors, and from sensors mounted directly on farm machinery, farmers have improved decision-making capabilities for planning their cultivation to maximize yields. Previous crop yields, terrain specifics, organic matter content, pH, moisture, and nutrient levels of the soil all aid in proper preparation for precise farming. Combine harvesters equipped with GPS tracking units can measure crop yields along with crop quality values like plant water

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content and chlorophyll levels in real time and at the exact location in the field from which they are harvested. Rapidly emerging remote sensing and geospatial technology can play vital role for crop growth monitoring, identification and management of different types of stresses, regional yield estimations, to sustain the natural resources and agricultural productivity.

Further, the timely information on the extent and geographic distribution of degraded lands viz., areas under soil erosion and shifting cultivation, salt affected soils, waterlogged areas, ravines, etc. forms an essential input for planning reclamation/conservation programmes of these lands. Moreover, these lands are to be monitored at regular intervals of time to know the impact of the implemented reclamation/conservation measures.

23.2 Remote Sensing

Remote sensing is the process of acquiring information about the Earth's surface by measuring its reflected and emitted radiation without coming into direct contact with the object. In much of remote sensing, the process involves an interaction between incident radiation and the targets of interest (Figure 1). The most useful electromagnetic radiation in remote sensing includes visible light (VIS), near infra red (NIR) and shortwave infrared (SWIR), to thermal infrared (TIR) and microwave bands. Passive remote sensing sensors record incident radiation reflected or emitted from the objects while active sensors emit their own radiation, which interacts with the target to be investigated and returns to the measuring instrument (Atzberger, 2013).

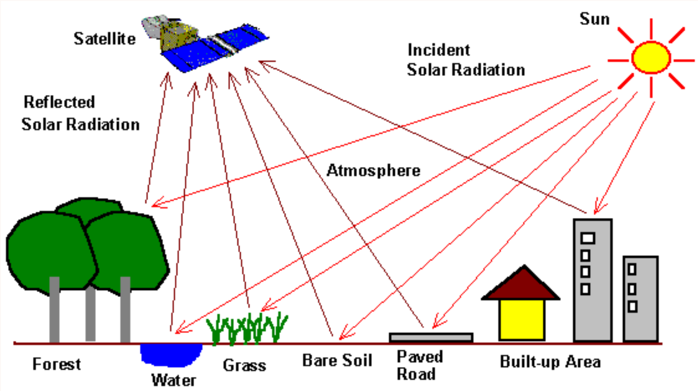

Figure 1 Processes involved in Remote Sensing

23.2.1 Stages in Remote Sensing

- Emission of electromagnetic radiation, or EMR (sun/self- emission)
- Transmission of energy from the source to the surface of the earth, as well as absorption and scattering
- Interaction of EMR with the earth's surface: reflection and emission
- Transmission of energy from the surface to the remote sensor
- Sensor data output
- Data Transmission and processing

23.2.2 Types of Remote Sensing

There are two types of remote sensing technology, active and passive remote sensing.

Active sensors emit energy in order to scan objects and areas whereupon a sensor then detects and measures the radiation that is reflected or backscattered from the target. RADAR and LiDAR are examples of active remote sensing where the time delay between emission and return is measured, establishing the location, speed and direction of an object.

Passive sensors gather radiation that is emitted or reflected by the object or surrounding areas. Reflected sunlight is the most common source of radiation measured by passive sensors. Examples of passive remote sensors include film photography, infrared, charge-coupled devices, and radiometers.

23.2.3 Components of Remote Sensing

These seven elements comprise the remote sensing process from beginning to end as shown in the figure.

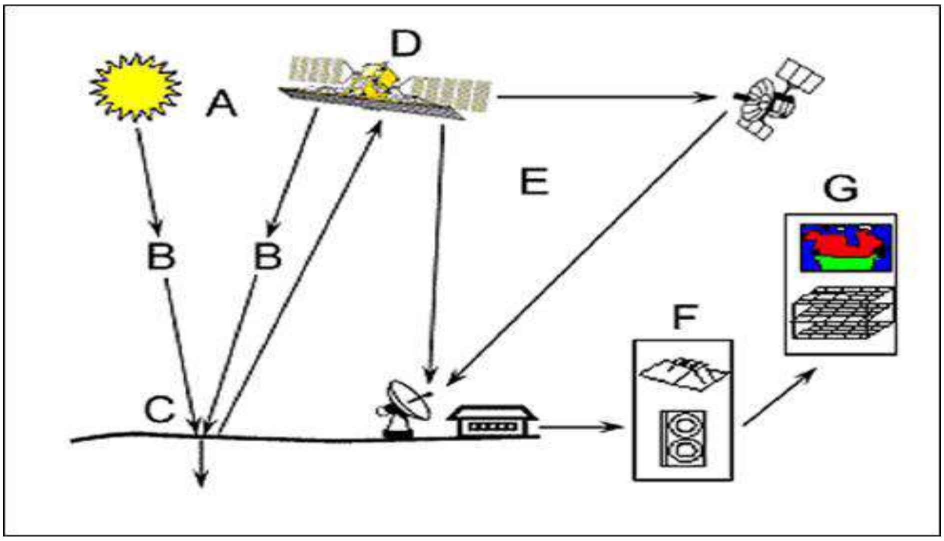

Figure 2 Components of Remote Sensing

1. **Energy Source or Illumination (A)** – the first requirement for remote sensing is to have an energy source which illuminates or provides electromagnetic energy to the target of interest.
2. **Radiation and the Atmosphere (B)** – as the energy travels from its source to the target, it will come in contact with and interact with

the atmosphere it passes through. This interaction may take place a second time as the energy travels from the target to the sensor.

3. **Interaction with the Target (C)** - once the energy makes its way to the target through the atmosphere, it interacts with the target depending on the properties of both the target and the radiation.
4. **Recording of Energy by the Sensor (D)** - after the energy has been scattered by, or emitted from the target, we require a sensor (remote - not in contact with the target) to collect and record the electromagnetic radiation.
5. **Transmission, Reception, and Processing (E)** - the energy recorded by the sensor has to be transmitted, often in electronic form, to a receiving and processing station where the data are processed into an image (hardcopy and/or digital).
6. **Interpretation and Analysis (F)** - the processed image is interpreted, visually and/or digitally or electronically, to extract information about the target which was illuminated.
7. **Application (G)** - the final element of the remote sensing process is achieved when we apply the information we have been able to extract from the imagery about the target in order to better understand it, reveal some new information, or assist in solving a particular problem.

23.3 Remote Sensing Technology and GIS in India

Among the new technologies developed for the study of natural resources the space borne remote sensing technology in association with computer technology proved to be the most valuable one to study the various aspects of environmental degradation. The systematic efforts in the application of remote sensing technology in the study of natural resources has resulted in the development of well established methodologies for mapping and monitoring of various degraded lands in a cost effective manner.

In India, initially aerial photographs were used in deriving information on degraded lands. The application of remotely sensed data in mapping degraded lands from space borne sensors started with the launch of the first Earth Resources Technology Satellite ERTS-l/Landsat-1. However, the satellites Landsat-TM, SPOT and Indian Remote Sensing Satellites (IRS) with better spatial and spectral resolution, enabled to map and monitor degraded lands more efficiently. Many studies are reported in literature on the use of Landsat-MSS, TM, IRS and SPOT data for inventory of degraded lands. Studies are carried out on mapping eroded lands, ravines, watershed prioritisation, salt affected soils and shifting cultivation (Wójtowicz *et. al*., 2016).

23.4 Geographical Information System (GIS)

The advancements in the field of computer technology, image processing, global position system, and mathematical morphology have resulted in the development of Geographical Information System (GIS) technology for storage, retrieval, management of spatial data (e.g. maps derived from remotely sensed data etc.), attribute data (eg. Soil properties, climatic parameters etc) and other related ancillary information are efficiently. GIS proved to be an effective tool in handling spatial data available at different scales, voluminous point data such as soil information, rainfall, temperature etc. and socioeconomic data and to perform integrated analysis of data on various resources of any region and to arrive at optimum solutions for various problems. In India, GIS is being used in various fields such as for optimum land use planning, planning for sustainable development of land resources, assessment of crop water requirements, development of wastelands etc.

The efforts are going on to use GIS in crop yield modelling, developing measures for reclamation / management of Salt-affected soils, quantification of soil loss to suggest suitable conservation processes, evaluation of soils for various purposes like horticulture, agroforestry, silvipasture, and aquaculture development.

23.5 Advantages and Disadvantages of Remote Sensing

Advantages of remote sensing are:

- Provides data of large areas
- Provides data of very remote and inaccessible regions
- Able to obtain imagery of any area over a continuous period of time through which the any anthropogenic or natural changes in the landscape can be analyzed

- Relatively inexpensive when compared to employing a team of surveyors
- Easy and rapid collection of data
- Rapid production of maps for interpretation

Disadvantages of remote sensing are:

- The interpretation of imagery requires a certain skill level
- Needs cross verification with ground (field) survey data
- Data from multiple sources may create confusion
- Objects can be misclassified or confused
- Distortions may occur in an image due to the relative motion of sensor and source

23.6 Remote Sensing in Agriculture

A recent report by the FAO projects that an increase in world population to 9.15 billion by 2050, which may need the current food production to increase by 60%. Many efforts are underway to increase overall production to feed the burgeoning population by increasing efficiency in production such as high intensity agriculture, efficient water use, and high yield varieties. Agricultural production follows strong seasonal patterns related to the biological lifecycle of crops. The production also depends on the physical landscape (e.g., soil type), as well as climatic driving variables and agricultural management practices. All these variables are highly variable in space and time. Moreover, as productivity can change within short time periods, due to unfavourable growing conditions, agricultural monitoring systems need to be real time for higher productivity. Therefore, use of remote sensing is indispensable in monitoring of agricultural field, crop & soil health, water management and its quality, and atmospheric conditions with emphasis to yield.

During the last two decades, remote sensing techniques are applied to explore agricultural applications such as crop discrimination, crop acreage estimation, crop condition assessment, soil moisture estimation, yield estimation, precision agriculture, soil survey, agriculture water management, agro meteorological and agro advisories. The application of remote sensing in agriculture, i.e. in crops and soils is extremely complex because of highly dynamic and inherent complexity of biological materials and soils. As mentioned, there are many applications of remote sensing in the agricultural sector. Below is a summary of these applications (Sinha *et al.*, 2018)

23.6.1 Crop Production Forecasting: Remote sensing is used to forecast the expected crop production and yield over a given area and determine how much of the crop will be harvested under specific conditions. Researchers can be able to predict the quantity of crop in a given farmland over a given period.

23.6.2 Assessment of Crop Damage and Crop Progress: In the event of crop damage or crop progress, remote sensing technology can be used to penetrate the farmland and determine exactly how much of a given crop has been damaged and the progress of the remaining crop in the farm.

Figure 3 Use of Remote Sensing in Agriculture

23.6.3 Crop Identification: Remote sensing has played an important role in crop identification especially in cases where the crop under observation shows some mysterious characteristics. The crop data collected will be taken to labs where various aspects of crop including the crop culture are studied.

23.6.4 Crop Acreage Estimation: Remote sensing has also played a very important role in the estimation of the farmland on which a crop has been planted. This is usually a cumbersome procedure if it is carried out manually because of the vast sizes of the lands being estimated.

23.6.5 Crop Yield Modelling and Estimation: Remote sensing also allows farmers and experts to predict the expected crop yield from a given farmland by estimating the quality of the crop and the extent of the farmland. This is then used to determine the overall expected yield of the crop.

23.6.6 Identification of Pests and Disease Infestation: Remote sensing technology plays a significant role in identification of pests in farmland and gives data on the right pests control mechanism to get rid of the pests and diseases on the farm.

23.6.7 Soil Moisture Estimation: Soil moisture can be difficult to measure without the help of remote sensing technology. Remote sensing gives the soil moisture data and helps in determining the quantity of moisture in the soil and hence the type of crop that can be grown in the soil.

23.6.8 Soil Mapping: Soil mapping is one of the most common yet most important uses of remote sensing. Through soil mapping, farmers are able to tell which soils are suitable for which crops and which soil require irrigation and which ones do not. This information helps in precision agriculture.

23.6.9 Monitoring of Droughts: Remote sensing technology is used to monitor the weather pattern of a given area. The technology also monitors drought patterns of the area too. The information can be used to predict the rainfall patterns of an area and also tell the time difference between the current rainfall and the next rainfall which helps to keep track of the drought.

23.6.10 Water Resources Mapping: Remote sensing is instrumental in the mapping of water resources that can be used for agriculture over a given farmland. Through remote sensing, farmers can tell where water resources are available for use over a given land and whether the resources are adequate.

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Course Name	Problematic soils and their Management
Lesson 24	Role of trees in bio-remediation of problem soils
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Learning Objective

- Develop understanding about phytoremediation and use of multipurpose tree species

Glossary of terms

1. **Agroforestry:** Agroforestry is the collective name for all land use systems in which woody perennials are deliberately grown with agricultural crops and/or animals either in some form of spatial or temporal sequence.
2. **Allelopathy:** The chemical inhibition of one plant (or other organism) by another, due to the release into the environment of substances acting as germination or growth inhibitors.
3. **Bio-remediation:** Bio-remediation means to use biological organisms to solve an environmental problem such as contaminated soil or groundwater.
4. **Multipurpose trees:** Multipurpose trees are trees that are deliberately grown and managed for more than one output.
5. **Phytoremediation:** It is defined as the use of green plants and the associated microorganisms, along with proper soil amendments and agronomic techniques to either contain, remove or render toxic environmental contaminants harmless.
6. **Reclamation:** Land reclamation is the process of improving land to make it more suitable for intensive use.

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7. **Shelterbelts:** A shelterbelt is defined as a barrier of trees and shrubs that provides protection from wind and storm and decreases erosion.
8. **Windbreaks:** A windbreak is a planting usually made up of one or more rows of trees or shrubs planted in such a manner as to provide shelter from the wind and to protect soil from erosion.

24.1 Introduction

"Remediate" means to solve a problem and "Bio-remediation" means to use biological organisms to solve an environmental problem such as contaminated soil or groundwater. Agroforestry is the collective name for all land use systems in which woody perennials are deliberately grown with agriculture crops and/or animals either in some form of spatial or temporal sequence. In agroforestry system there must be ecological and economic interaction between the components. Agroforestry systems have the potential to make use of marginal and degraded lands through the soil improving effects of trees (Lundgren and Raintree, 1982). Problematic soils are those soils which are not suitable for arable farming because of specific limitations.

24.2 Multipurpose Trees

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.

24.2.1 Tree species can be multipurpose in two ways:

A single tree can yield more than one product: For example, farmers in South India grow Glyricidia sepium as live fence that provide fuel, fodder, and green manure for agricultural crops-all at the same time.

Trees of same species, when managed differently, can yield different product: for example, Leucaena leucocephala is managed so that some trees will principally yield wood while others principally produce leaf meal.

Multipurpose trees can also be 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 agroforestry technology under consideration (Burley and von Carlowitz, 1984). Any woody perennial species can be 'multipurpose' in one situation and 'single purpose' in another.

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.

24.2.2 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.

24.3 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.

24.3.1 Forestry Applications

- ✓ Protection forestry,
- ✓ Land reclamation and rehabilitation
- ✓ Management of natural vegetation
- ✓ Industrial plantations
- ✓ Community woodlots
- ✓ Farm woodlots

24.3.2 Windbreaks and shelterbelts Trees

Species grown for this purpose should:

- ✓ tolerate harsh environments;
- ✓ have a bushy, deep crown that still allows some wind penetration;
- ✓ keep lower limbs for a long time;
- ✓ have strong roots;

- ✓ grow quickly;
- ✓ live long
- ✓ tolerate pests and diseases; and
- ✓ should not have roots that compete excessively with nearby crops for water and nutrients.

Some species often used for windbreaks and shelterbelts are: Casuarina equisetifolia and Erythrina peoppigiana.

24.3.3 Shade and nurse trees

Species grown for this purpose should:

- ✓ have fast early growth;
- ✓ establish easily, preferably by cuttings;
- ✓ be evergreen;
- ✓ live long;
- ✓ tolerate soil compaction by animals walking and sitting beneath them, as happens on pasture land;
- ✓ coppice well and withstand some lopping;
- ✓ fix nitrogen in the soil to enhance soil fertility;
- ✓ have a dense, suppressing crown, if used to shade grazing animals;
- ✓ have a light crown, if used as nurse trees for other crops; and
- ✓ should not compete with crops for soil nutrients if used as nurse trees.

Some species often used as shade or nurse trees are: Erythrina poeppigiana, Gliricidia sepium, Leucaena leucocephala, and Sesbania grandiflora.

24.3.4 Soil protection and rehabilitation

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

- ✓ Should reproduce vigorously, for example, from root suckers, or through abundant natural seed fall and seedling development.
- ✓ A dense network of fine roots, with a capacity for abundant mycorrhizal association.
- ✓ A vigorous root system to bind the soil and a strong taproot especially in the areas prone to landslides.
- ✓ Should associate well with nitrogen-fixing organisms and have high rate of nitrogen fixation.
- ✓ A high and balanced nutrient content in the foliage; litter of high quality (high in nitrogen, low in lignin and polyphenols).
- ✓ An appreciable nutrient content in the root system.
- ✓ Either rapid litter decay where nutrient release is desired or a moderate rate of litter decay, where maintenance of a soil cover is required.
- ✓ Absence of toxic substances in the litter or root residues.
- ✓ Capacity to grow on poor soils.

- ✓ Absence of severe competitive effects with crops, particularly for water.
- ✓ Low invasiveness.
- ✓ Productive functions or service functions other than soil improvement.

Some species often used for soil protection and rehabilitation are: Acacia auriculiformis, Casuarina equisetifolia and Prosopis juliflora.

24.4 Soil Management through agroforestry

Approaches to soil management, including problems of soil degradation and low soil fertility, have recently undergone major changes. The former view was to concentrate on achieving high levels of production from the more fertile areas, leaving the marginal lands for extensive use only. Steeply sloping and highly drought-prone areas were preferably not to be cultivated at all. Soil constraints were to be overcome by inputs: improved crop varieties, fertilizers, chemical control of pests and diseases, and the use of irrigation. It had been demonstrated that crop yields could be raised by a factor of three to five times or more by the use of fertilizers, applied to the newly developed high-yielding crop varieties. This approach was successful in giving large increases in crop productivity in Western countries and Asia and moderate improvements elsewhere, but it encountered problems of many kinds. Fertilizers are costly in terms of energy resources to produce them, and continued high rates of use lead to environmental problems. Yield responses to fertilizers have declined, for example because of soil physical degradation or micronutrient deficiencies. Above all, large numbers of poor farmers simply cannot afford high levels of fertilizers and other purchased inputs, nor do they have the capital to take on the risk which these involve. Finally, the former solution of increasing the area under irrigation has run into severe constraints in the form of limits to available freshwater resources. Aspects of this new approach include:

- find ways of making the use of marginal lands sustainable; reclaim and restore degraded land;
- improve germplasm to produce plant varieties which are adapted to soil constraints;
- maintain soil organic matter and biological activity, with benefits both for soil physical conditions and balanced nutrient supplies;
- improve nutrient cycling and nutrient use efficiency in agro ecosystems;
- use fertilizers and other external inputs at moderate levels, seeking strategic use to overcome deficiencies that cannot otherwise be remedied;
- Improve water-use efficiency.

Agroforestry can contribute to all these aspects and has a major role to play in some. The capacity of trees to grow under difficult climatic and soil conditions, coupled with their potential for soil conservation, gives agroforestry a potential in the main types of marginal lands: semiarid, sloping and those with soil constraints. There is a demonstrated potential for reclamation of degraded land. As well as crop breeding, research programmers' are under way to select or, in the longer term, breed trees tolerant of adverse soil conditions.

Tree litter and pruning's can substantially help to maintain soil organic matter and improve physical properties and at the same time supply nutrients. The contrast between natural and agricultural ecosystems suggests a high potential for agroforestry to lead to improved nutrient cycling and hence fertilizer use efficiency. In the case of water-use efficiency, there is a known potential, as demonstrated in studies of windbreaks and contour hedgerow, although tree-crop competition for water presents problems.

24.4.1 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.

24.4.2 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.

24.4.3 Bioremediation of soils with physical problems through agroforestry

- Tree species: Eucalyptus robusta, Syzygium cumuni, Terminalia arjuna, Salix tetrasperma, Dalbergia latifolia, Eucalyptus camaldulensis, Eucalyptus grandis
- Grasses: Brachiaria mutica, Dichanthium caricosum,Paspalum notatum, Brachiaria decumbens.

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24.4.4 Mechanism for reclamation of saline soils

Halophytes are the native flora of saline soils. Few are suitable for reclamation. The basic principle of reclamation is the removal of excess salt to a desired level in root zone. Providing proper drainage, use of salt free irrigation water, acidic fertilizers, organic manures etc. are some of the mechanisms adopted. The process of salinization is accelerated by rapid evaporation from the surface. Leaching with water of good quality and adequate drainage of excess water from the soil is carried out. The selection of salt tolerant species is done which include suitable tree species such as Prosopis juliflora, Tamarix articulate, Acacia nilotica etc. Agricultural crops include barley, sugarbeet, cotton wheat, rice beans etc.

- The removal of excess salts to a desired level in root zone.
- Leaching and adequate drainage.
- Mulching to reduce salinity.
- Organic matter addition keeps the salts in diluted form and increases water holding capacity of soil.
- Green manuring, tree planting.

24.4.4.1 Bioremediation of saline through Agroforestry

Promising woody species for saline soils are Salvadora spp., Prosopis juliflora, Acacia nilotica, Parkinsonia aculeata, Butea monosperma, Terminalia arjuna, Salix spp., D. sissoo and Casurina equisetifolia.

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Highly salt tolerant and high biomass producing grass species include Aeluropus lagopoides, Sporobolus helvolus, Cynodon dactylon and Brachiaria ramosa.

24.4.5 Mechanism for reclamation of alkali soils

The reclamation practice include proper drainage of water to remove salts from the root zone use of salt free irrigation water, addition of organic matter, addition of molasses, alkali tolerant crops such as paddy, cotton, mustard, wheat, tomato, onion etc. Green manuring of Dhaincha has been found to be beneficial. Higher dose of N should be made as there is N loss because of volatilization. Application of zinc should be done in initial years of reclamation.

24.4.5.1 Bioremediation of alkali soils through Agroforestry

Prosopis juliflora and Karnal grass improves the soil condition to such an extent that after some time or years, less tolerant but more palatable fodder species such as-

Berseem (Trifolium alexandricum) senji (Melilotus parviflora) and shaftal (Trifolium resupinatum) can be grown under trees (Singh et al., 1993).

24.4.6 Mechanism for reclamation of saline-sodic soils

Such soils have the mixture of characteristics of both saline and alkali soils. Therefore soils showing high salinity should be reclaimed for both first for salinity and later for excessive exchangeable sodium. Growing of crops tolerant to high exchangeable sodium ensures reasonable returns during initial years of reclamation. Cropping practice including a green manure crop and/or legume is common. Low organic matter and high pH deters the biological activity and thus decreases the transformation of\and availability of nutrients, and causes significant volatilization of nitrogen from applied nitrogenous fertilizers. Tolerant crops such as rice, sugarbeet and dhaincha are used. Trees species include Prosopis juliflora, Acacia nilotica, Prosopis chinensis etc.

24.4.6.1 Bioremediation of saline-sodic soils through Agroforestry

Acacia auriculiformis, Azadirachta indica, Casurina equisetifoia, Dalbergia sissoo, Alianthus excelsa, Prosopis cineraria, Acacia tortilis and A. nilotica tree species are used for bioremediation of the saline and sodic soils.

Several tree species, pastures, agricultural crops, and horticultural crops/trees adopted in different agroforestry systems such as agri-silvicultural system, silvi-pastoral system, multipurpose wood lot, and agri-horti-silvicultural system are well suited for reclamation of salt affected soils. These trees or plants physiologically ameliorating the salt affected soil particularly saline and alkali soils by reducing soil pH, EC, and ESP and by increasing CEC organic carbon; and available nutrient such as nitrogen, phosphorus, and potassium status of soil. Therefore, it is suggested to grow these MPT species in agroforestry systems to ameliorate the salt affected soil over a period of time to get the multiple benefits (Behera et al., 2015).

24.5 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. Where the net effect of tree-crop interactions is positive, the length of the tree-crop interface, or extent of the ecological fields, should be maximized. If the net effect is negative, the aim of agroforestry system design should be to reduce the length of the interface. 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 root 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 soil improving functions, but there is much scope to increase this range (Bhatt et al., 2017).

The following are the principal trees and shrubs that have been employed for soil improvement.

Acacia auriculiformis, Acacia senegal, Albizi alebbeck, Anacardium occidentale, Alnus acuminate, Alnus spp., Azadirachta indica, Bactrisgasipaes, 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, 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

24.6 Recent Study

The soil-improving capacities of trees, and how these can be applied in practical agroforestry systems, continues to be a major focus of agroforestry. One important recent change of emphasis is that less attention is being given to hedge-row intercropping (alley cropping), in view of the observed reluctance of farmers to adopt this system, whilst more emphasis is now placed on systems of managed tree fallows. An account of using trees to lower the water table, referred to above, is given by Burgess et al. (1998). A continuity of land disturbance from up- to down slope will facilitate sediment transport to streams. Roads, trails, and footpaths within these land management mosaics will further exacerbate linkages to streams. Fragmented intensive land uses that are interspersed by trees or brush land appear to be a viable solution for mitigating down slope sediment transport by providing areas of high infiltration along with 'roughness elements' on the landscape where sediment deposition can occur. A better understanding of sediment transport and routing processes is needed at the catchment scale to develop improved predictive methods and to assess the cumulative effects of distributed tropical land uses. Recognition of the "truths, myths, and uncertainties" related to erosion processes and consequences in tropical Southeast Asia will assist land managers, land owners, and policy makers in formulating appropriate and prudent decisions that will contribute to more sustainable use of forest lands as well as options for rehabilitation of previously forested lands that have been degraded. While widespread land cover changes in support of recreation have been noted to increase erosion and sedimentation in the region few studies have attempted to link either surface erosion or landslide processes with specific recreational impacts, such as forest clearance, resort construction, water diversions, roads, hiking and animal trails, and all-terrain vehicle tracks, in steep terrain. Agroforestry proves to

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be one of the cheapest and best modes for the reclamation of all such degraded lands.

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Course Name	Problematic soils and their Management
Lesson 25	Land Capability Classification- Understanding its Importance
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Learning Objectives

- To develop understanding about the key concepts of Land Capability Classification
- To assists in identifying optimal crop selection for a given field, and land use capability gives an indication of potential agronomic productivity.
- To predict the agricultural capability of the land development units in utility of the land resources

Glossary of terms

1. **Land Capability Classification:** Land capability classification is a scientific appraisal of the physical characteristics of the land, including characteristics of the soil and is a systematic grouping of different kinds of land according to the properties that determine the ability of the land to produce almost on a permanent basis.
2. **Land Capability Classes:** In all eight land capability classes are recognized. The soils having greatest capabilities for response to management and least limitations are grouped in Class-I and those having least capabilities and greatest limitations are grouped in Class-VIII.
3. **Land Capability Sub-Classes:** A capability subclass is defined in the original system as a group of capability units that have the same major conservation problem. It may be defined alternatively as land which has the same kinds of limitation.
4. **Land Capability Unit:** Land capability unit is the smallest and last category in the land capability classification system. A capability unit

consists of soil, which are nearly uniform in their characteristics, potentialities, and limitations and require fairly similar conservation treatments and management practices.

5. **Land Use Planning:** The land use planning is a multi-disciplinary holistic approach that not only meets the functions of the land but also actively involves all the stake holders through a participatory appraisal.

25.1 LAND USE PLANNING

According to FAO, it is the systematic assessment of land and water potential, alternative pattern of land use and physical, social and economic conditions, for the purpose of selecting and adopting land use options which are most beneficial to land users without degrading the resources or the environment, together with the selection of measures most likely to encourage such land uses.

Land use planning may be at international, national, district or local levels. It includes participation by land users, planners and decision-makers and cover educational, legal, fiscal and financial measures.

25.1.1 Land Use Plan

A coherent set of decisions about the use of land and ways to achieve the desired use.

25.1.2 Land Use

The management of land to meet human needs. This includes rural, urban and/or industrial land use.

25.2 LAND CAPABILITY CLASSIFICATION

The improper use of land leads to erosion hazards and deterioration of land with a consequent fall in productivity. For optimum productivity, every unit of land should be managed in accordance with its inherent characteristics, capability and limitations due to climate and local hazards. Because the factors affecting soil use and erosion may vary so widely and the combinations of factors are so numerous, some grouping of land according to its capability is needed. This involves grouping of an individual soil unit or tract having different characteristics into a few categories..

"Land capability classification is a scientific appraisal of the physical characteristics of the land, including characteristics of the soil and is a systematic grouping of different kinds of land according to the properties that determine the ability of the land to produce almost on a permanent basis."

"The land capability classification is the grouping of a land unit(s) into defined class(es) based on its capability. It is a broad grouping of soils based on their limitations and is designed to emphasize the hazards in different kinds of soils."

The land capability classification serves as a guide to assess suitability of land for arable crops, grazing and forestry. The classification also enables the farmers to use the land properly for long time production with suggestions for taking such measures as control of erosion, improved soil and water conservation and utilization.

The grouping of soils into capability classes and sub-classes is done on the basis of their capability to produce crops and pasture plants without deterioration over a long period of time. The criteria used in assessing a land unit are the physical land properties and degree of limitation as a function of the severity with which crop growth is inhibited. It is mainly based on:

1. The inherent soil properties
2. The external land features and
3. The environmental factors that limit land use.

The first two informations are provided by standard soil survey report and the third information, that is environment factors such as climate and vegetation, is provided by other agencies.

The following different factors that determine the capability of a soil are:

i. Depth of soil, stoniness, rockiness
ii. Drainage condition of soil
iii. Texture and structure of soil
iv. Relief (slope)
v. Intensity of soil erosion
vi. Permeability (movement of air and water through soil)
vii. Susceptibility to overflow and flooding and degree of wetness
viii. Problematic soils with particular reference to salts, alkali, acidity and other unfavorable chemical properties such as pH, gypsum etc.
ix. Climatic variation (temperature and moisture)

The land capability classification scheme was developed by the Soil Conservation Service of the United States Department of Agriculture (USDA). The classification scheme has four categories namely:

i. Land suitability classification: It is the first category of classification scheme and is a broad grouping of land into

(i) Land suited for cultivation, and

(ii) Land not suitable for cultivation because of severe limitations such as extreme wetness or dryness, very severe stoniness, steepness and rough land surface etc.

ii. Land capability classes: It is the second category comprises eight land capability classes.

iii. Land capability sub-class: It is third category and is a subgroup of land capability class

iv. Land capability units: It is fourth category and further subdivision of the sub-class.

25.2.1 Land Capability Classes: In all eight land capability classes are recognized. The soils having greatest capabilities for response to management and least limitations are grouped in Class-I and those having least capabilities and greatest limitations are grouped in Class-VIII. The class I (very good land), class II (good land), class III (moderately good land) and class IV (fairly good land) under the group – land suitable for cultivation; class V, class VI and class VII – land suitable for pasture and grazing and class VIII land suitable for wildlife and watershed under the broad group of land not suitable for cultivation. The gradation from class I to class VIII indicates the increased limitations for crop cultivation and hazards and decreased adaptability and freedom of choice of use.

25.2.2 Land Capability Sub-Classes: A capability subclass is defined in the original system as a group of capability units that have the same major conservation problem. It may be defined alternatively as land which has the same kinds of limitation. 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.

25.2.3 Land Capability unit: Land capability unit is the smallest and last category in the land capability classification system. A capability unit consists of soil, which are nearly uniform in their characteristics, potentialities, and limitations and require fairly similar conservation treatments and management practices. Adding numbers to the sub classes forms land capability units. For example, capability unit IIc 1, IIIc 2 would represent several class II soils with climate hazards arising from different causes. Some might be because of erosion due to water or wind, salt other might be because of factors like overflow or too hot or cold conditions.

25.3 LAND CAPABILITY CLASSES

25.3.1 Land Suitable for Cultivation

Class I: Soils in this class are very good cultivable land, very deep, nearly level, productive land with almost no limitation. They are not subjected 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. Soils in this class are suitable for intensive cultivation of all climatically adapted crops or variety of crops including wheat, barley, cotton, maize, tomato and been. In this class, soils need no special management practices for cultivation. Thus, Class I does not have any sub-class. Class I land shown by green colour on maps.

Class II: As far as natural conditions are concerned, it is a good cultivable land on almost level plain or gentle slopes that have slight limitations of soil depth, salinity, texture, drainage or erosion that reduce the choice of crops/plants. These soils may require special practices, such as contour tillage, crop rotation and water-control devices. In general, these soils are suitable for wheat, barley and cotton; moderately suitable for maize, alfalfa, tomato; and slightly suitable for beans. Recommendation is to cultivate with precaution and need simple management practices. Class II land shown by yellow colour on maps.

Class III: These are moderately good cultivable land on almost level plain or on moderate slope. These soils have limitation(s) of moderate erosion, soil depth, soil salinity, soil texture. 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. They have vertic characteristics or drainage problem that reduces the choice of crop. In general, these areas have varying suitability for different crops. They are unsuitable for growing vegetable crops. Recommendation is to cultivate with careful management practices and need intensive care. Class III land shown by brown colour on maps.

Class IV: It is a fairly good land on almost level plains or moderately steep slopes which are vulnerable to erosion. There are severe limitations on the choice of crops in these soils. These lands are suitable only for occasional or limited cultivation. These soils are generally unsuitable for growing a variety of crops because of strong or very strong salinity (S3/S4), shallow depth, erosion, fine texture or poor or excessive drainage. Suitable for selected crops and for pasture. These soils are affected by severe permanent hazards like waterlogging and water deficiency. The soils are low in fertility. Such soils may not be economical to cultivate as they need intensive soil and moisture conservation measures, like water disposal of terraces, contour tillage and stabilization of gullies, should be undertaken. These soils are shown by pink colour on maps.

25.3.2 Land Unsuitable for Cultivation but Suitable for Permanent Vegetation (Grazing)

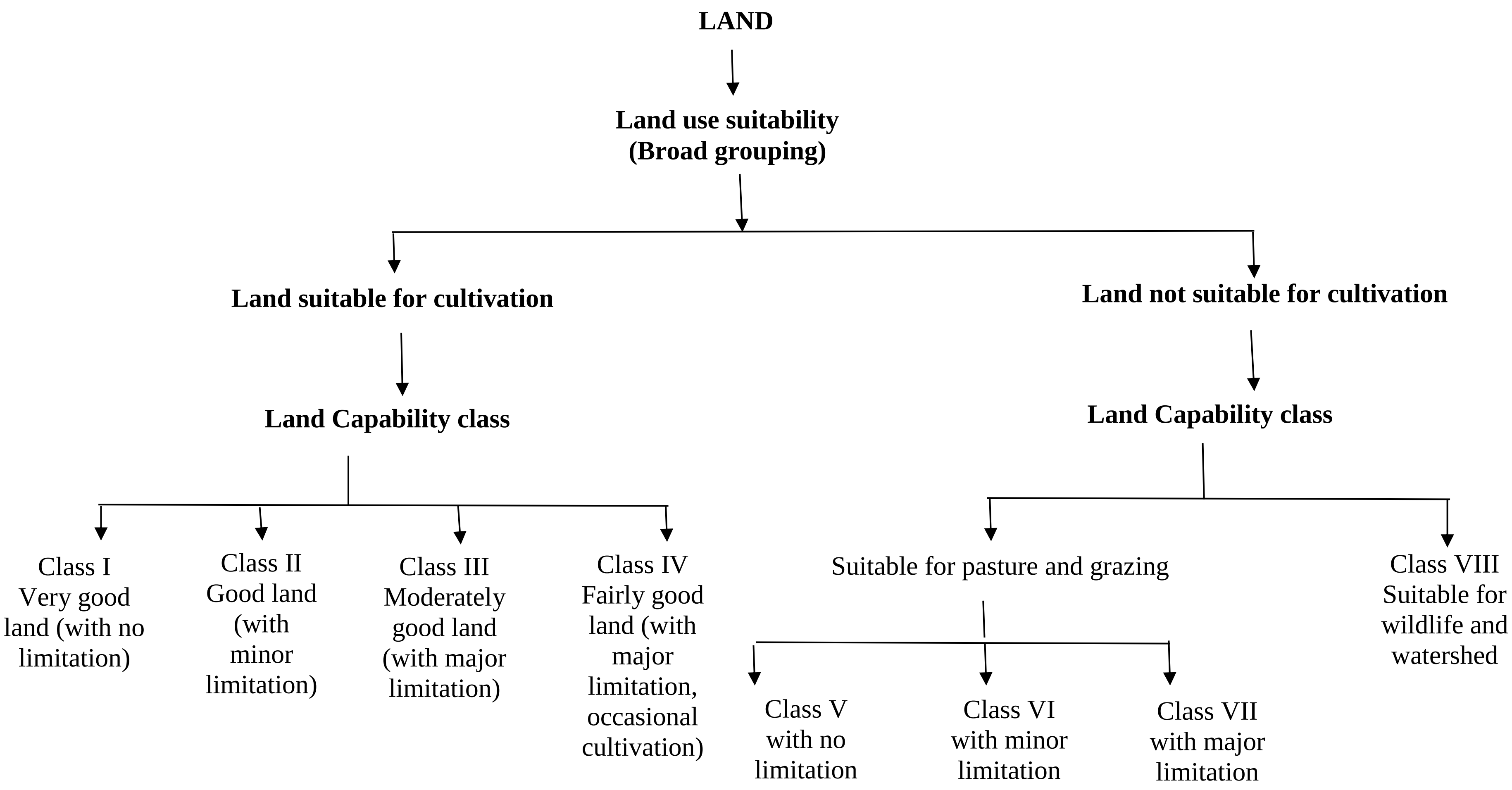
Class V: These soils are found in foothills or in mountain valleys and are suitable for grasses, shrubs, etc. These soils should be used for pasture or forestry operations. Cultivation is not feasible because these soils are wet and stony. The land is nearly level and subject only to slight erosion by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

Class VI: These soils have moderate permanent limitations and are unsuitable, for cultivation. These soils should be used for grazing and forestry. Have moderate limitations such as steep slope, severe erosion, limited soil depth, strongly gypsiferous, stony or sand-dune areas and more prone to erosion than class V soils. These soils are shown as orange on maps.

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 fairly well suited 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. These soils are indicated on the land capability maps by red colour.

Class VIII: Class VIII land covers Bad Lands, sand dunes, barren mountain tops and extremely rough, rocky, arid, wet or extremely saline land. 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 or recreation. Have very severe limitations. These soils are indicated on the land capability maps by purple colour.

LAND CAPABILITY CLASSIFICATION SCHEME



Land capability subclass

[grouped according to kind of limitation in each subclass *viz.*,erosion (e), climate (c),excess of wetness (w), soil limitation (s)]

Land capability units

(land management grouped based on physical characteristics- land that is suited for essentially the same kind of management and same kind of management and same kind of soil and water conservation treatment)

Examples: IIe, IIc, IIw mean good land with problem of erosion, climate condition, wetness and soil limitations, respectively.

25.4 LAND USE PLANNING

25.4.1 Land Use Planning Concept

The land use planning is a multi-disciplinary holistic approach that not only meets the functions of the land but also actively involves all the stake holders through a participatory approach. Land use planning is as old humankind. The optimal land use planning is to create the pre-conditions to achieve sustainable and environmentally sound, socially desirable and economically viable form of land use. Land use planning process involves spatial zoning of the resources across the land units.

This concept is different in rural agricultural land use planning as compared to peri-urban land use planning. In the rural agricultural planning the agricultural production and environmental protection attains importance. In this process, usually bio-physical characteristics, qualities of the various land units (climate, soil, water, resources and existing land use) and prevailing socio- economic conditions are considered. The basic purpose of land use planning in the rural areas across the land units is to obtain homogenous land resource management units (resource management domains). While the peri-urban land use planning is the allocation of land for specific use such as housing, industry, recreation and development of physical, infrastructure through legal rules and market value.

25.4.2 Land Use Planning Approaches

“Top-down” or “bottom –top” are two basic approaches to land use planning. Land use planning addresses the present and projected land utilization pattern under agricultural and non-agricultural sectors. It attempts to strike a balance between agricultural and non-agricultural sectors as per the potential of land and demand of the growing population in an area. The soil resource, climatic, land use information and the data base as per the management unit differ for sustainable planning at State/Regional, district and village level.

The state/regional level planning usually emphasizes the top-down approach and is primarily concerned with the priority allocation of the resources between the competing demands of different sectors which may form the key for sustainable land use planning. The land systems, land facets Agro-eco regions and sub-regions provide information on the potentials and problems of an area. This enables a planner, a policy maker to allocate the land resources under different sectors of agricultural and non-agricultural uses. This also helps to distribute the input resources as per the priorities and problems. A perspective land use plan includes a set of decisions about the ways and means to bring out the desired land use.

Land use planning at district level requires a data base such as soil information at series level, climatic information at tahsil level and present land use. This information will provide guidance for planner to allocate funds as per the need in the region. For framing the villages as independent viable units, detailed land resource information, socio-economic status of the farmers and other related factors that contribute to yield variation form a base for planning.

25.4.3 Strategies for Perspective Land Use Planning

25.4.3.1 State level planning: The soil resource information at great group, subgroup land family level could be utilized for planning at state level. The state/regional level planning usually emphasizes the top-down approach and is primarily concerned with the priority allocation of the resources between the competing demands of different sectors which may form the key for sustainable land use planning. The land systems, land facets Agro-eco regions and sub-regions provide information on the potentials and problems of an area. This enables a planner, a policy maker to allocate the land resources under different sectors of agricultural and non-agricultural uses. This also helps to distribute the input resources as per the priorities and problems. A perspective land use plan includes a set of decisions about the ways and means to bring out the desired land use.

25.4.3.2 District level planning: Land use planning at district level requires a data base such as soil information at series level, climatic information at tahsil level and present land use. This information will provide guidance for planner to allocate funds as per the need in the region. There are two approaches in planning at district level viz. (i) Agro-eco approach and (ii) Growing period zone approach. This plan helps for sectoral allocation of resources at district level.

25.4.3.3 Village/Watershed level planning: For framing the villages as independent viable units, detailed land resource information, socio-economic status of the farmers and other related factors that contribute to yield variation could form a base for planning. The detailed soil information at series /phase level, weekly/daily climatic data, socio-economic data and present land use will form a data base at village/watershed/farm level planning. Participatory/negotiative PRA approaches with the involvement of all the stake holders in the village are mandatory for successful planning at this level.

25.5 SIGNIFICANCE

Land capability classification has value as a grouping of soils. National Resource Inventory information, Farmland Protection Policy Act, and many field office technical guides have been assembled according to these classes. The system has been adopted in many textbooks and has wide public acceptance. Some state legislation has used the system for various applications.

25.6 APPLICATION

All map unit components, including miscellaneous areas, are assigned a capability class and subclass. Agriculture Handbook No. 210 (Exhibit 622-2) provides general guidance, and individual state guides provide assignments of the class and subclass applicable to the state. Land capability units can be used to differentiate subclasses at the discretion of the state. Capability class and subclass are assigned to map unit components in the national soil information system.

As an output from soil survey, classification provides a framework for making local generalization about soil, based on the properties of the soil series identified. Recently, for making soil survey data a more precise and useful, geographic information system (GIS) and soil information system (SIS) techniques are being used to give physical distribution of soil classes, to assess full range of soil variability, to relate individual data with the spatial variability of social properties, to interpret individual components of map units and other current information about land use practices through a comprehensive electronic database. However, of late, these techniques have been widely used to increase efficiency and speed of the soil survey and land use planning programme. These modern systems were developed mainly because it was not possible for humans to handle in an orderly way the huge amounts of data derived from soil and land surveys until and unless advanced computer hardware and software technology is used for the purpose.

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Course Name	Problematic soils and their Management
Lesson 26	Land suitability classification- Concepts
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Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Learning Objectives

- Understanding the scientific basis of suitability of soils for specific land use – with or without improvements and the concept of the length of growing season

Glossary of terms

1. **Current Suitability:** Refers to the suitability for a defined use of land in its present condition, without major improvements.
2. **Land Evaluation:** Land evaluation is a process for matching the characteristics of land resources for certain uses using a scientifically standardized technique. The results can be used as a guide by land users and planners to identify alternative land uses.
3. **Land Suitability:** Land Suitability is the degree of appropriateness of land for a certain use.
4. **Land Suitability Order:** Land suitability Orders indicate whether land is assessed as suitable or not suitable for the use under consideration. There are two orders represented in maps, tables, etc.
5. **Land Suitability Units:** Land Suitability Units reflect minor differences in the required management within Subclasses (e.g. S2d-2, etc.)
6. **Land Suitability Subclasses:** The sub classes reflect kinds of limitations or major improvements required within classes.

7. **Potential Suitability:** Refers to the suitability, for a defined use, of land units in their condition at some future date, after specified major improvements have been completed where necessary.
8. **Qualitative Classification:** A qualitative classification is one in which relative suitability is expressed in qualitative terms only, without precise calculation of costs and returns. Qualitative classifications are based mainly on the physical productive potential of the land, with economics only present as a background.
9. **Quantitative classification:** A quantitative classification is one in which the distinctions between classes are defined in common numerical terms, which permits objective comparison between classes relating to different kinds of land use.

26.1 Land Suitability

26.1.1 The concept of land evaluation and suitability

Land evaluation is a process for matching the characteristics of land resources for certain uses using a scientifically standardized technique. The results can be used as a guide by land users and planners to identify alternative land uses. Land Suitability is the degree of appropriateness of land for a certain use. Land suitability could be assessed for present condition (Actual Land Suitability) or after improvement (Potential Land Suitability). Actual Land suitability is a land suitability that is based on current soil and land conditions, i.e. without applying any input. The information is based on physical environment data generated from soil or land resources surveys. The information is based on soil characteristics and climate data related to growth requirements of crops being evaluated. Potential Land Suitability is the suitability that could be reached after the land is improved. The land to be evaluated can be natural (conversion) forest, abandoned or unproductive lands, or land currently used for agriculture, at a sub-optimal level of management in such a way that the productivity can be improved by changing to more suitable crops.

26.1.2 Land suitability classification

The land suitability classification, using the guidelines of FAO (1976) is divided into Order, Class, Sub Class, and Unit. Order is the global land suitability group. Land suitability Order is divided into S (Suitable) and N (Not Suitable). Class is the land suitability group within the Order level. Based on the level of detail of the data available, land suitability classification is divided into: (1) For the semi detailed maps (scale 1:25.000-1:50.000) the S order is divided into Highly Suitable (S1), Moderately Suitable (S2), and Marginally Suitable (S3). The “Not Suitable” order does not have further divisions. (2) For reconnaisance level map (scale 1:100.000-1:250.000), the classes are Suitable (S), Conditionally Suitable (CS) and Unsuitable (N). The difference in the number of classes is based on the level of details of the database in each scale.

26.1.2.1 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.

26.1.2.2 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.

26.1.2.3 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

26.1.2.4 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).

Table 1: 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

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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	

The Subclasses are a more detailed division of classes based on land quality and characteristics (soil properties and other natural conditions). For example, Subclass S3rc is land that is marginally suitable due to rooting condition (rc) as the limiting factor. Furthermore, the Units S3rc1 and S3rc2, are differentiated by the soil effective depths of 50 -70 cm and < 50 cm, respectively. This land unit is however rarely used in land suitability evaluation.

26.1.2.5 Conditional Suitability

The designation Conditionally Suitable may be added in certain instances to condense and simplify presentation. This is necessary to cater for circumstances where small areas of land, within the survey area, may be unsuitable or poorly suitable for a particular use under the management specified for that use, but may be suitable if certain conditions are fulfilled. The possible nature of the conditions is varied and might relate to modifications to the management practices or the input e of the defined land use (occasioned, for example, by localized phenomena of poor soil drainage, soil salinity); or to restrictions in the choice of crops (limited, for example, to crops with an especially high market value, or resistant to frost). In such instances, the indication "conditional" can avoid the need for additional classifications to account for local modifications of land use or local major improvements.

Conditionally suitable is a phase of the Order Suitable. It is indicated by a lowercase letter c between the order symbol and the class number, e.g. Sc2. The conditionally suitable phase, subdivided into classes if necessary, is always placed at the bottom of the listing of S classes. The phase indicates suitability after the condition(e) have been met.

Employment of the Conditionally Suitable phase should be avoided wherever possible. It may only be employed if all of the following stipulations are met:

i. Without the condition(s) satisfied, the land is either not suitable or belongs to the lowest suitable class.
ii. Suitability with the condition(s) satisfied is significantly higher (usually at least two classes).
iii. The extent of the conditionally suitable land is very small with respect to the total study area.

If the first or second stipulation is not met, it may still be useful to mention the possible improvement or modification in an appropriate section of the text. If the third stipulation is not met, then the area over which the condition is relevant is sufficiently extensive to warrant either a new land utilization type or a potential suitability classification, as appropriate.

As the area of land classed as Conditionally Suitable is necessarily small, it will not normally be necessary to subdivide it at the unit level. It is important to note that the indication "conditional" is not intended to be applied to land for which the interpretation is uncertain, either in the sense that its suitability is marginal or because factors relevant to suitability are not understood. Use of "conditional" may seem convenient to the evaluator, but its excessive use would greatly complicate understanding by users and must be avoided.

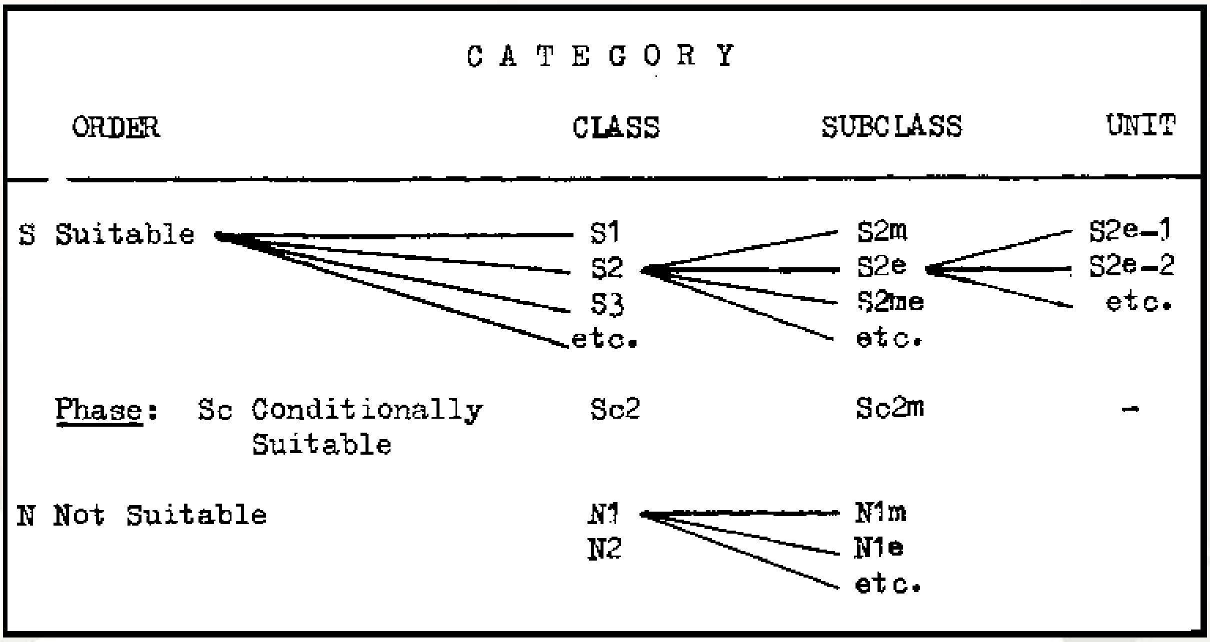

Figure 1: Structure of the Suitability Classification

26.2 The range of classifications

The Framework recognizes four main kinds of suitability classification, according to whether it is qualitative or quantitative, and refers to current or potential suitability.

Each classification is an appraisal and grouping of land units in terms of their suitability for a defined use.

26.2.1 Qualitative and Quantitative Classifications

A **qualitative classification** is one in which relative suitability is expressed in qualitative terms only, without precise calculation of costs and returns. Qualitative classifications are based mainly on the physical productive potential of the land, with economics only present as a background. They are commonly employed in reconnaissance studies, aimed at a general appraisal of large areas.

A **quantitative classification** is one in which the distinctions between classes are defined in common numerical terms, which permits objective comparison between classes relating to different kinds of land use. Quantitative classifications normally involve considerable use of economic criteria, i.e. costs and prices, applied both to inputs and production. Specific development projects, including pre-investment studies , usually require quantitative evaluation.

Qualitative evaluations allow the intuitive integration of many aspects of benefits, social and environmental as well as economic. This facility is to some extent lost in quantitative evaluations. The latter, however, provide the data on which to base calculations of net benefits, or other economic parameters, from different areas and different kinds of use. Quantitative classifications may become out of date more rapidly than qualitative ones as a result of changes in relative costs and prices.

26.2.2 Classifications of Current and Potential Suitability

A classification of **current suitability** refers to the suitability for a defined use of land in its present condition, without major improvements. A current suitability classification may refer to the present use of the land, either with existing or improved management practices, or to a different use.

A classification of **potential suitability** refers to the suitability, for a defined use, of land units in their condition at some future date, after specified major improvements have been completed where necessary.

Common examples of potential suitability classifications are found in studies for proposed irrigation schemes. For a classification to be one of potential suitability it is not necessary that improvements shall be made to all parts of the land; the need for major improvements may vary from one land unit to another and on some land units none may be necessary.

In classifications of potential suitability, it is important for the user to know whether the costs of amortization of the capital costs of improvements have been included. Where these are included, the assumptions should state the extent to which inputs have been cost and the rates of interest and period of repayment that have been assumed.

Classification with amortization is only possible if the repayment of capital costs can be apportioned to identifiable areas of land. If the benefits from major expenditure are not confined to the agricultural sector (as in multipurpose irrigation and power schemes), responsibility for capital repayments is difficult to assess. In these circumstances, amortization costs will usually be excluded from the evaluation.

The distinction between qualitative and quantitative classifications, and between current and potential suitability, do not fully describe the nature of a classification. Two further considerations of importance are treatment of the location factor and of amortization of capital costs, but these by no means exhaust the range of possibilities. They are not distinguished as further specific types of classification. A suitability classification needs to be read in conjunction with the statement of the data and assumptions on which it is based.

26.3 The results of land suitability evaluation

i. The results of an evaluation will usually include the following types of information, the extent to which each is included varying with the scale and intensity of the study. The context, physical, social and economic, on which the evaluation is based. This will include both data and assumptions.
ii. Description of land utilization types or of major kinds of land use which are relevant to the area. The more intensive the study, the greater will be the detail and precision with which these are described.

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iii. Maps, tables and textual matter showing degrees of suitability of land mapping units for each of the kinds of land use considered, together with the diagnostic criteria. Evaluation is made separately for each kind of use.

iv. Management and improvement specifications for each land utilization type with respect to each land mapping unit for which it is suitable. Again, as the survey becomes more intensive, so the precision with which such specifications are given increases; thus in a semi-detailed survey a need for drainage might be specified, whilst in a detailed survey the nature and costs of drainage works would be given.

v. Economic and social analysis of the consequences of the various kinds of land use considered.

vi. The basic data and maps from which the evaluation was obtained. The results, particularly the suitability classification itself, are based upon much information of value to individual users. Such information should be made available, either as an appendix to the main report or as background documentation.

vii. Information on the reliability of the suitability estimates. Such information is directly relevant to planning/policy decisions. It will also aid any subsequent work directed towards improving the land suitability classifications, by indicating weaknesses in the data and aspects which might repay further investigation.

26.4 Relationship study between soil site suitability and crop planning

Land evaluation is the ranking of soil units on the basis of their capabilities (under given circumstances including levels of management and socio-economic conditions) to provide highest returns per unit area and conserving the natural resources for future use. The FAO (1976) panel for land evaluation suggested the classification of land in different categories: Orders, Classes, Sub-classes and Units. The soil-site characteristics are expressed in terms of degree of limitation (0, 1, 2, 3 or 4); the limitation of 2 is considered critical at which the expected yield declined significantly and the cultivation is considered marginally economical. The final soil-site evaluation/suitability is based on the number and degree of limitation (s). Modern approaches involve simulation model predicting yield as a measure of suitability. Although very well refined, yet these approaches are largely based on local experience of farmers or of the researchers.

Since crop performance reflects the integrated effect of the environmental and soil characteristics, it would be appropriate to study the relationships, through regression analysis, between the crop performance and yield-influencing parameters. In order to construct a knowledge base by which deductive reasoning may lead to ranking of land units, the present attempt is made to interpret the black cotton soils in terms of their characteristics and qualities for developing soil-site suitability models for different crops through a multivariate regression yield model.

The model may need further refinement by having a large number of test sites. The yield and soil site parameters were compared through a linear equation of the following form based on collected yield data under similar management practices from different locations varying in rainfall and covering the entire black soil region (Table 1).

$Y = a + b1x1 + b2x2 + b3x3 + b4x4 + b5x5 + \mu$. . .

Where :

Y = yield of the crop, q ha-1;

X1 = rainfall, mm;

X2 = soil depth, cm;

X3 = growing period, weeks;

X4 = clay, per cent;

X5 = calcium carbonate, per cent;

μ = random error;

a = intercept;

b1 = partial regression coefficient.

In order to find the optimum range of any parameter for crop performance, a quadratic equation was fitted in the following form:

$Y = a + bx + cx2 + \mu$ . . .

Where:

Y = yield of the crop (q ha-1)

X = explanatory variable (rainfall, calcium carbonate)'

μ = random error

a = intercept

b, c = are regression coefficients

The Vertic intergrades (Inceptisols and Entisols) occurring in geographic association with the Vertisols, are mainly cultivated for sorghum and cotton. Yield of sorghum and cotton crops from six experiments and three locations near Nagpur area under similar rainfall pattern were also compared with the soil parameters.

Table 2. Relationship of crop performance to soil-site parameters in Vertisols

Name of crop	Number of observations	Intercept	Regression Coefficients					R^2
			X_1	X_2	X_3	X_4	X_5	
Sorghum	15	-14.4091	0.0074* (0.0025)	0.0432 (0.0204)	0.2423* (0.01024)	0.0746 (0.0957)	-0.0606 (0.0923)	0.8505
Cotton	10	-12.0748	0.0172* (0.0045)	-0.0313 (0.0295)	-0.2043 (0.1465)	0.1803 (0.2255)	0.7278* (0.2243)	0.8583
Pigeon pea	12	-4.365	0.0023* (0.0008)	0.0059 (0.0020)	0.1646* (0.0756)	0.0671 (0.0982)	0.0926 (0.1154)	0.4199
Chick pea	13	4.1164	0.0065* (0.0015)	-0.0478 (0.0291)	-0.0347 (0.0686)	-0.0931 (0.0311)	-0.3878 (0.0735)	0.7515
Pearl millet	8	12.9200	0.0073 (0.0075)	0.0193* (0.0019)	*-0.0049 (0.1475)	-0.2310 (0.0917)	-0.0755 (0.0735)	0.9477

Ground nut	9	-8.6524	0.0071 ((0.0057)	0.0038 (0.0372)	0.3702* (0.0633)	-0.0093 (0.1179)	0.1089 (0.1047)	0.8181

***Significant at 5% level**

X_1: rainfall (mm)

X_2: soil depth (cm)

X_3: growing period (weeks)

X_4: clay %

X_5: CaCO3 %

( ) : standard error of variable

26.5 Conclusion

It has sometimes been thought that a land classification map is the main output from land evaluation. At least in quantitative surveys, however, the information on land utilization types, their required inputs and management specifications may be equally important.

Suitability evaluation does not necessarily identify a single form of use as "best" on each land unit. Suitability class limits are defined separately for each use. It follows that suitability classes for different uses cannot be compared in a routine, automatic manner. Thus, a particular land mapping unit might be classified as S1 for forestry and S3 for arable farming, but this does not necessarily mean that the former use will be selected. The physically and economically viable alternatives are presented, with information on the consequences of each, as a basis for planning decisions. The decision-making process of the agricultural production provides insight in establishing the suitable sites. The results can be more precise by critically analyzing the methods and techniques utilised. The study comprises the physical properties (topographical properties, soil and geological characteristics, etc.) only and need to include the economic and social criteria for agricultural production. Since in analytic hierarchy process, the pairwise comparison method is established on expert opinions which are mostly subjective in nature. Therefore, any wrong judgement on the any selected parameters can be efficiently conveyed to the score assignment and weights designation. This is the prime drawback of the analytic hierarchy process, and hence, weights and scores need to be designated carefully. For more beneficial and accurate results the study demands to be emphasized on some important species which have significant economic value and also influences the scope of progress of other avenues too. The utilisation of very high-resolution satellite image aids in evaluating more finer areas. Also, the identified areas have to be documented on ground level with some other local and regional parameter before the final implementation.