Tamil Nadu Agricultural University

B.Sc. (Agri.)

Optional Course

SAC 452 Rejuvenation of Deteriorated Lands (1+1)

Theory Lecture Notes

Compiled by

Dr. M. Gopalakrishnan
Asst. Professor (SS&AC), TNAU, Coimbatore

Dr. D.Jegadeeswari
Assoc. Professor (SS&AC), TNAU, Coimbatore

Dr.M.Elayarajan
Assoc. Professor (SS&AC), WTC, TNAU, Coimbatore

Dr.D.Lenin Raja
Asst. Professor (SS&AC), AC&RI, Killikulam

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SAC 452 Rejuvenation of Deteriorated Lands (1+1)

Lecture 1.Type, factors and processes of soil / land deterioration.

Degraded Land degradation has deteriorated the quality of land and it is now estimated that about 120.72 million ha of the total area in India (arable land and open forest) suffers from degradation of which 104.19 m ha under arable land. Soil erosion affected an area of 85.67 m ha of which water erosion in an area of 73.27 m ha and wind erosion affected an area of 12.40 million ha, Salt-affected area is 6.64 million ha and degraded acid soils occupy 10.81 m ha. The mining and industrial wastes affected land is in an area of 0.19 m ha and permanent surface inundation (water logging) is in area of 0.88 million ha.

Today, nearly two-thirds of the area requires special treatment to restore such lands to become productive and put into profitable use. It is also estimated that about 6,000 million tonnes of top soil are lost annually along with valuable plant nutrients such as nitrogen, phosphorus, potassium and micro nutrients. As a result of the loss of top soil along with nutrients, there is low agricultural production of about 2.7 million tones annually. Thus, the management of basic natural resources of soil, land and water assumes special importance and plays a vital role, in improving the country's economy and environment.

1.2. Land Degradation- Definition

Land Degradation is generally understood to be the reduction or loss of biological or economic productivity resulting in degrade the quality of soils, land utility, decreased yields, incomes, food security, and the loss of vital ecosystem services.

Land degradation in general, implies temporary or permanent recession from a higher to a lower status of productivity through deterioration of physical, chemical and biological aspects. It is a complex ensemble of surface processes (e.g. wind erosion, water erosion, soil compaction, salinization and water-logging). Principal processes of land degradation include erosion by water and wind, chemical degradation (comprising acidification, salinization, fertility depletion and decrease in cation retention capacity), physical degradation (comprising crusting, compaction, hard-setting, etc.) and biological degradation (reduction in total and biomass carbon and decline in land biodiversity).

1. 3. Processes of land degradation

Water erosion	Wind erosion
	
Physical Degradation	**Chemical Degradation**

Land degradation - Causes of land degradation involves two interlocking, complex systems: the natural ecosystem and the human social system. Causes of land degradation are not only biophysical, but also socioeconomic (e.g. land tenure, marketing, institutional support, income and human health) and political (e.g. incentives and political stability).

1. 4. Causes of land degradation:

Land degradation is a global problem, largely related to agricultural uses which include:

1. Land clearance, such as clear cutting and deforestation

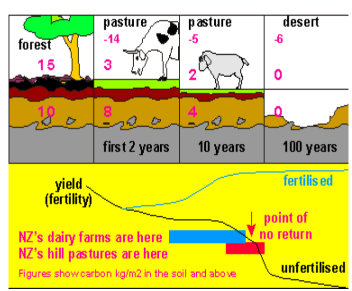
Deforestation is taking place at a faster rate due to increasing demands of timber, fuel and forest products which results into degradation of land resources.

2. Agricultural depletion of soil nutrients through poor farming practices

The modern agricultural practises, excessive use of fertilizers and pesticides has adversely degraded the natural quality and fertility of the cultivation land.

3. Livestock overgrazing

Overgrazing refers to excessive eating of grasses and other green plants by cattle. It results into reduced growth of vegetation, reduced diversity of plant species, excessive growth of unwanted plant species, soil erosion, and degradation of land due to cattle movement.



Overgrazing

4. Deforestation

Removal of natural vegetation (for firewood, commercial logging, industrialization or farming and settlements). In world 579 million ha area are degraded due to deforestation of which 50% comes under Asia followed by south America (17%). It is the sole cause for 98% of the area affected by wind erosion. It serves as a contributory cause to salinization.Deforestation of unsuitable land like steeply sloping, shallow or easily erodible soils where the clearance is not followed by good management may causewater erosion in steeply sloping humid environments. It may lead to wind erosion, soil fertility decline and salinization. Overcutting of vegetation occurs when people cut forests, woodlands and shrub lands to obtain timber, fuel wood and other products at a pace exceeding the rate of natural re growth. This is frequent in semi-arid environments, where fuel wood shortages are often severe.

Deforestation

5. Shifting cultivation

It is an indigenous and sustainable form of land use at past time when low population densities allow forest fallow periods of sufficient length to restore soil properties. It is mainly practised in hill areas of northeast India. It involves burning and cutting of small plots of forests for cultivation and followed by shifting to new areas when nutrient status gets depleted in former plots. Now due to increased food demand there is shortening of fallow period and insufficient time for soil regeneration to replenish nutrients that in turn causes soil erosion.

6. Inappropriate irrigation

7. Urban sprawl and commercial development

8. Soil contamination

9. Quarrying of stone, sand, ore and minerals and over mining destabilizing the local ecosystem

Over Mining - Damages the soil and underlying structure of the land. Chemicals used or mined themselves pollute soil and water. Methods of mining cause soil loss. Ex-digging of strip mines and open-pit mines involves removal of plants and soil from the surface of the ground. By exposing rocks and minerals to the air and to rainwater, these forms of mining speed up the rate of chemical weathering.In mining operations that expose sulphide minerals undergo increased chemical weathering, which in turn leads to acid mine drainage.

10. Exposure of naked soil after harvesting by heavy equipment

11. Monoculture and intensive tillage

Monoculture is a type of intensive farming and harvesting two or three crops annually which in turn depletes soil with single nutrient. It reduces soil microbial diversity aiding biological degradation of soil, declining level of nutrients, builds up of crop pathogens and decline in soil health and quality over long run as it devoid of crop rotation.

Intensive Tillage makes soil loose, bare and more prone to erosion. Repeated tillage leads to decline in soil organic carbon and destruction of soil structure. Hence Inappropriate farming practices destabilizes the local ecosystem.

12. Dumping of non-biodegradable trash, such as plastics

1.5. Types and extent of land degradation

The main types of land degradation in the country are : (i) gullied and ranvinous land; (ii) upland with or without scrub; (iii) water logging; (iv) salinity and alkalinity; (v) shifting cultivation; (vi) soil erosion die to water and wind; (vii) degraded pasture and grazing land; (viii) sands, deserts (inland and coastal); (ix) barren /rocky/stony areas and (x) snow cover and glaciers. The extent of areas affected under these categories is as follows:

1. Gullied and ravinous land

Gullies are formed as a result of localised surface runoff affecting the unconsolidated material resulting in the formation of perceptible channels causing undulated terrain. Gullies are the first stage of excessive land dissection followed by their networking which lead to the development of ravinous land. The word ravine is usually associated with a network of gullies formed generally in deep alluvium and entering nearby river, flowing much lower than the surrounding table lands. About 4.0 million ha's of land are affected by this type of land degradation mostly in the state of Gujarat, Madhya Pradesh, Rajasthan and Uttar Pradesh.

2. Upland with or without scrub

The lands, which are generally prone to deterioration due to erosion may or may not have scrub cover belong to this category. Such lands occupy relatively high topographic locations. In India about 13.57 million ha (6. 67% of geographical area) comes in this category.

3. Water logging

Water-logged lands are those where the water is at/ or near the surface and water stands for most of the year. Nearly 8.53 million ha of lands is subjected to serious water logging problem. Water logging results in restriction of the normal circulation of air inside the soil. When the water table rises up to 2 m and above in the below ground surface, problems of water logging are felt. Immediately after the monsoon rains, vast tracts of land are subjected to surface flooding. In irrigated areas of 37 major irrigation projects situated in 15 states, water logging is felt in 0.88 million ha.

4 Salinity and alkalinity

Saline ground water, high water table, ingress of sea and irrigation without the provision of drainage result in salinization in arid, semiarid and coastal areas. As per ICAR (2010) statistics, 2.96 million ha of land is subjected to soil salinity and 3.77 million ha under alkaline soils. The larger area in saline soils found in Gujarat, West Bengal, Maharashtra and Odisha. The alkaline soils in Uttar Pradesh, Gujarat, Maharshtra, Tamil Nadu, Andhra Pradesh (includes Telangana), Haryana, Punjab, Rajasthan and Karnataka

Water logging **Saline soils**

5. Areas with shifting cultivation

The areas with shifting cultivation are developed due to cyclical land use consisting of felling of trees and burning of forest areas for growing crops without any management. After one or two crop seasons as yields decrease, new forest areas are cleared for the purpose, leaving the earlier area to the vagaries of nature causing serious soil erosion. The allotment of lands for shifting cultivation depends on the tribe in the region. About 4.91 million ha of land has been subjected to degradation due to shifting cultivation practiced mainly in the hilly areas of the northeastern states of India

6. Soil erosion by water and wind

The causes of soil erosion are deforestation, over-grazing practices in undulated lands, improper cropping pattern and other kinds of poor and unscientific lands management practices. As a result, soil erosion by water, recharge of ground water gets reduced, low lands are flooded and sedimentation of water harvesting tanks and reservoirs occurs. It has been estimated that about 85.67 million ha of land is degraded due to water (73.27 million ha) and wind (12.40 million ha). At many locations other forms of degraded lands also overlap this area.

Sheet erosion **Stream erosion**

Wind erosion

Factors influencing water erosion

Soil particles, which are either detached by splash erosion or by the effect of running water.

Rainfall: The impact of raindrops on the soil surface can break down soil aggregates and disperse the aggregate material over the surface.

Soil type: Soils with faster infiltration rates, higher levels of organic matter and improved soil structure have a greater resistance to erosion

Slope gradient: Steeper and longer slopes of a field lead to greater amount of soil erosion by water.

Soil use: Plants may protect the soil from raindrop impact and splash, slow down the movement of surface runoff and allow infiltration of excess surface water.

Types of water erosion

Sheet erosion: Removal of a fairly uniform layer of soil from an entire surface area.

Rill erosion: Small channels running over the soil surface causing deeper incision of the channels into the surface.

Gully erosion: Rills flowing together form larger streams and tend to become deeper with successive flow of water.

Bank erosion: Water cutting into the banks of streams and rivers.

Factors influencing wind erosion

Soil erodibility: Fine and medium soil particles can be transported over great distances. Coarse particles can be blown along the surface.

Soil surface roughness: Soil surfaces that are not rough or ridged offer little resistance to the wind.

Climate: Soil moisture levels can be very low at the surface during periods of drought, thus releasing particles for transport by wind.

Vegetative cover: The lack of permanent vegetation cover may lead to extensive erosion by wind as loose, dry and bare soil is most susceptible

7. Degraded pasture and grazing land

Due to a large animal population, the traditional pasture and grazing land have been degraded as they are overexploited. The study of 241 districts has indicated that about 1.34 million ha equivalent to 0.66% of the geographicalarea is covered under this category. One district, i.e. Bhilwara in Rajasthan accounts the maximum area under this category. More than 10% of the geographical area of the district is affected.

8. Sands, deserts (inland and coastal)

Sandy areas are those areas which have developed due to accumulation of sands in coastal, riverine or inland areas. The Indian desert situated in the northwest occupies about 28.6 million ha area falling in Rajasthan, Gujarat and Punjab. Nearly 70% of the desert region is covered by wind eroded sandy soils, sands, loamy sand and sand dunes. India has also a long coastline of 5,600 km. Sand dunes occupy large areas, and during cyclone periods, there is blowing and shifting of sands causing damage to standing crops in the neighbouring areas.

9. Barren rocky/stony area

Substantial land still remains as barren (un-utilised) and stony / rocky in the country. Most of these areas are found in the mountainous regions of the country. The main problems in such regions are serious soil erosion, mining activities in stony/rocky areas, landslides, grazing, etc. About 2.58 million ha (1.26% of geographical area) comes under this category.

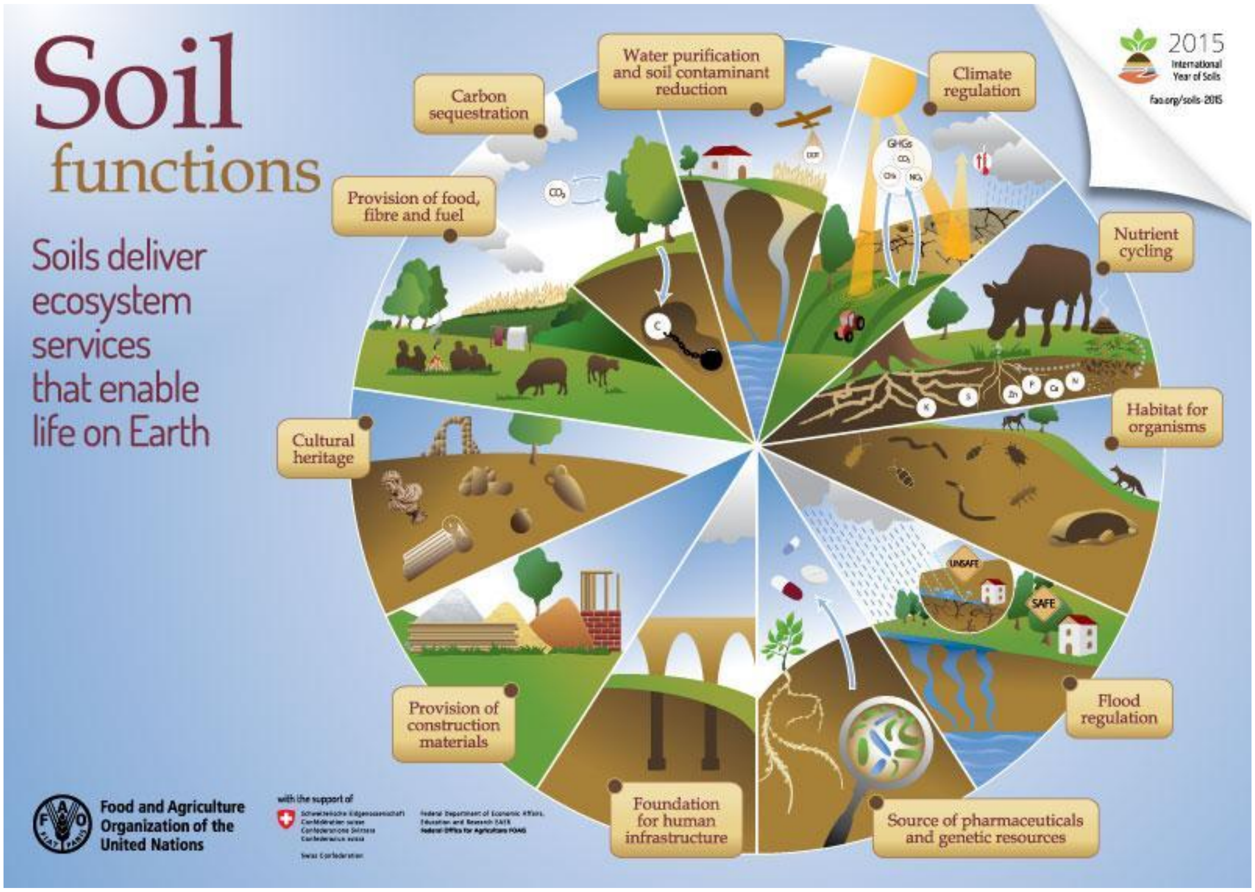
10. Snow cover and glaciers

A large area of the Great Himalayas remains covered with snow and affected by glaciers. This category accounts for 0.46 million ha equivalent to 0.23% of geographical area. The states *viz*., Jammu & Kashmir, Himachal Pradesh and Uttar Pradesh have lands which belong to this category.

Lecture 2. Soil / land deterioration impact on soil productivity, including soil fauna, bio deterioration and environment

Functions of the soil

The functions of the soil can be better understood from the following picture



Consequences of land degradation

The consequences of land degradation are as follows

1. Soil Erosion and Land Degradation
2. Depletion of natural resources
3. Lower productivity
4. Ground Water Depletion
5. Shortage of Drinking Water
6. Reduction in Species Diversity

7. Increase in the extent of Wastelands

The impact land deterioration on soil productivity

Land degradation has been the single largest threat to soil productivity and has remained till date. The land degradation becomes the global issue of 21st centuryhaving adverse impact on soil productivity, soil fauna, bio degradation, environment, and its effect on food security and the quality of life. The Productivity impacts are due to the decline in land quality. The Loss of soil productivity through soil degrading processes occurs throughout the world. The annual soil loss of 75 billion tons of soil occurs on a global basis. The soil erosion is a symptom of poor soil and crop management. Soil erosion by water is the greatest factor limiting soil productivity. Both forms of erosion viz; water erosion and wind erosion defines land degradation. The colloidal fractions are detached and washed away through runoff water. The soil colloidal fractions are needed for soil fertility, aggregation, structural stability, and favorable pore size distribution. The humus content is usually higher in top soils while that of clay is in sub soils due to illuviation. The humus has much greater capacity to hold water and nutrient ions compared to clay which is more easily eroded during land degradation. Land is a non-renewable resource at a human time-scale and some adverse effects of gradation processes on land quality are irreversible, e.g. reduction in effective rooting depth.

Soil Productivity

Soil productivity is the capacity of a soil to produce a definite yield of crops or other plant's parts under a well-defined conditions and set of management practices.

The ways by which land degradation reduces soil productivity are:

(i) Removal of plant nutrients in the eroded sediments

(ii) Exposure of root-toxic and poorly aerated sub soils

(iii) Phosphorus fixation or adsorption in illuviated clay and other Fe and Al containing minerals which makes it the most deficient nutrient in eroded soils

(iv) Soil structure deformation leading to surface sealing and crusting which reduce seedling emergence and infiltration

(v) Non-uniform removal of soil within a field which complicates the task of managing the soil to maximize production.

Impact of land degradation on Soil

Land degradation affected soil productivity by affecting physical, chemical and biological properties of soil.

The impacts of land degradation on physical properties of soil are:

- ✓ Decline in soil structure

- ✓ Decrease in root zone depth
- ✓ Increase in crust formation in soil
- ✓ Increase in soil compaction
- ✓ Increase in gravel content
- ✓ Altered particle size distribution
- ✓ Increase in soil strength
- ✓ High bulk density
- ✓ Low porosity
- ✓ Lower aggregate stability
- ✓ Decrease in moisture and nutrient retention capacity
- ✓ Altered moisture characteristics
- ✓ Decrease in saturated hydraulic conductivity
- ✓ Decrease in infiltration and percolation rates
- ✓ Decrease in aeration
- ✓ Poor emergence of seedlings

Thesoil organic matter (SOM) in the surface soil generally promotes aggregation and favours moisture retaining pores in soil.Soil erosion reduces productivity primarily through the loss of plant available water capacity and resulting in the loss of nutrient holding capacity. The removal of the top soil reducedmoisture retention capacity and saturated hydraulic conductivity of the exposed soil layer. The limited moisture and increased compaction caused greater reduction in root growth and dry matter of crops .

Soil chemical properties affected by land degradation

Soil chemical properties affected by land degradation in following ways following ways

1. Reduction in soil pH which cause acidity in soil
2. Leaching causes removal of soluble salts and nutrients from soil surface
3. Accumulation of weathered salt causes salinity and alkalinity
4. Removal of soil organic carbon from surface soil
5. Reduction in total N content
6. Loss of available P
7. Removal of exchangeable bases
8. Decrease in cation exchange capacity
9. Depletion in soil fertility.

The enrichment ratio (ER; the concentration of plant nutrients in eroded soil materials to that in residual soil). ER >organic matter, > total N, > available P, 1.7 > exchangeable K, > exchangeable Ca, and >exchangeable Mg.

1. Nutrient depletion as a form of land degradation has a severe economic impact at the global scale, especially in sub-Saharan Africa.
2. An estimated 950 million ha of salt-affected lands occur in arid and semi-arid regions, nearly 33 per cent of the potentially arable land area of the world. Productivity of irrigated lands is severely threatened by buildup of salt in the root zone especially in South Asia
3. Soil acidity and the resultant toxicity of high concentrations of Al and Mn in the root zone, a serious problem in sub-humid and humid regions.
4. Salinity is considered as one of the most important abiotic stresses, limiting crop production in arid and semi-arid regions, where salt content is naturally high and precipitation can be insufficient for leaching.
5. Soil salinity, erosion and land degradation problems not only deteriorate the quality and quantity of crop production but also severely affect the lands and it cannot be further used for cultivation.

Soil Biological properties affected by land degradation

The Biological properties of soil affected by land degradation are

1. Reduction in organic matter content due to loss of vegetation from top soil
2. Reduction in microbial population
3. Decrease in organic carbon
4. Reduction in total and biomass carbon
5. Reduction in biomass N, P and S
6. Reduction in soil respiration rate
7. Decline in enzyme activity viz; dehydrogenaze, phosphatase, urease, arylsulphatase etc.
8. Reduction in microbial activity (ix) Decline in land biodiversity

The Impact of land degradation on soil fauna and bio-degradation process

The Physical, chemical and biological characteristics of soil play important role in survival of soil fauna or micro-organisms. Mostly micro-organisms or soil animals lives on top soil layers Land degradation decreases microbial activity and soil fauna population due to reduction in organic matter content, microbial biomass carbon, microbial biomass N and basal respiration. The activity of various soil enzymes involve in the cycle of C, N, P and S decreased due to decrease in C turn-over and nutrient availability which results a death of soil fauna and decrease land biodiversity.

Bio degradation of organic compounds by soil micro-organisms involves mineralization process - convert the organic molecules to obtain carbon and energy for growth and multiplication, releasing inorganic forms of N, P, S or other elements. Bio degradation process depends on soil and microbial population. Land degradation process erodes top soil results a reduction in bio degradation process.

Effects of land degradation on productivity

- ✓ The economic impact of land degradation is extremely severe in densely populated South Asia, and sub-Saharan Africa.
- ✓ There are also serious productivity losses caused by erosion in Asia, especially in India, China, Iran, Israel, Jordan, Lebanon, Nepal, and Pakistan.
- ✓ In South Asia, annual loss in productivity is estimated at 36 million tons of cereal equivalent valued at US$5,400 million by water erosion, and US$1,800 million due to wind erosion.
- ✓ On a global scale the annual loss of 75 billion tons of soil costs.
- ✓ The reduction in yield is significant when the soil depth decreases. It may also be noted that a moderate water erosion in alluvium derived deep soils may show significantly less reduction in soil productivity as compared with the deep red and black soils
- ✓ In deep alluvial siltyloam soils at Dehradun, each centimeter desurfacing of soil caused 76 Kg ha^{-1} in maize yield. This reduction is likely to be more severe in shallow soils.

Table 1. Loss of soil productivity due to erosion by water in different soils

Soil erosion class	Soil loss (t/ha)	Loss in productivity (%)		
		Alluvial soils (Inceptisols)	Black soils (vertisols)	Red soils (Alfisols
Nil to very slight	<5	Nil	<5	<10
Slight	5-10	<5	5-10	10-25
Moderate	10-20	5-10	10-25	15-50
Strong	20-40	10-25	25-50	>50
Severe	>40	25-50	>50	N.A

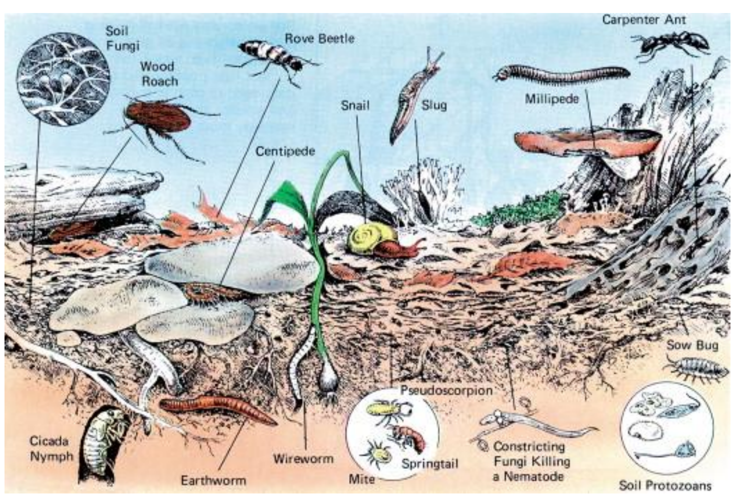


Fig.1. The soil organisms affected by land degradation

Biodiversity of soil fauna affected by land degradation

In general, soil invertebrates are classified according to their size in microfauna, mesofauna, macrofauna and megafauna.

Microfauna:

Microfauna are organisms whose body size is between 20 μm and 200 μm. Eg. protozoa, small mites, nematodes,rotifers, tardigrades and copepod crustaceans.

Mesofauna:

Mesofauna are organisms whose body size is between 200 μm and 2 mm. Microarthropods such as mites and springtails (nematodes, rotifers, tardigrades, small araneidae, pseudoscorpions, opiliones, enchytraeids, insect larvae, small isopods and myriapods).

Macrofauna:

Macrofauna areorganisms whose size is between 2 mm and 20 mm. Earthworms, gastropods, isopods, myriapods, some araneidae and majority of insects.

Megafauna:

Megafauna are organisms whose size exceeds 20 mm. Large size invertebrates (earthworms, snails, myriapods) and vertebrates (insectivores, small rodents, reptiles and amphibians).

The Loss of biodiversity is major global concerns today. India's biodiversity is unique in the world with 45,000 species of wild plants &over 77,000 of wild animals comprise of 6.5 per cent of the world's known wildlife. The Loss of seeds and propagules in the erosion fluxes, washing away of nutrients and run-offs deplete the biodiversity. During the past few decades, India has lost at least half of its forest, has polluted over 70 per cent of its water-bodies and has degraded most of its coasts. The land biodiversity comprises important concerns related to eutrophication of surface water, contamination of groundwater, and emissions of trace gases (CO_2, CH_4, N_2O, NO_x) from terrestrial/aquatic ecosystems to the atmosphere. Soil structure is the important property that affects all three degradative processes. Thus, land degradation is a biophysical process driven by socioeconomic and political causes.

Environmental pollution or environment degradation

Environmental degradation is a result of socio-economical, technological and institutional activities.This degradation occurs when earth's natural resources are depleted due to land degradation or top soil loss. The resources which are depleted include: (i) Water (ii) Air and (iii) Soil.

- ✓ The degradation of land also impacts our (i) Wildlife (ii) Plants (iii) Animals and (iv) Micro-organisms. Besides it, the major effects on environmental degradation are: (i) Water pollution and water scarcity (ii) Air pollution (iii) Solid and hazardous wastes (iv) Soil degradation (v) Deforestation (vi) Loss of biodiversity (vii) Atmospheric changes

Land degradation or top soil loss removes nutrients from the field through runoff and subsurface lateral flow towards streams and rivers, and by leaching to groundwater and pollute water. Land degradation also causes deposition of sediment. Sediment is one of the major pollutants. In India the situation is still worse, since the sediment load from agricultural lands not only continues unabated, but is also on the increase due to the fast rate of our developmental activities. If erosion continues unchecked at its present rate, we shall be left with the reclamation of soil rather than its conservation and management.

Lecture 3. Land rejuvenization and conservation techniques; Land configuration techniques; Surface / vertical mulching.

Watershed approach

The ridge to valley approach for executing soil and water conservation measures could be successfully handled only through the watershed concept. If the treatment measures are properly identified according to the location and positive impacts could be generated.

Possible range of treatment measures

- Check dams (Temporary and Permanent)
- Retaining walls
- Farm ponds and Percolation ponds
- Renovation of existing water bodies and inlet channels

Water table improves water availability increase in wells in irrigated area and soil erosion control are some of the positive results.

Check dam

Check dams are constructed across the gullies and on small streams and long gullies formed by erosive activity of flood water. It cuts the velocity and reduces erosive activity. The stored water improves soil moisture of the adjoining area and allows percolation to recharge the aquifers. Spacing between the check dams water spread of one should be beyond the water spread of the other. Height depends on the bank height, varies from a metre to 3 metre and length varies from less than 3m to 10m.

Percolation pond:

Percolation ponds are constructed to augment the ground water recharge. Shallow depressions are created at lower portions in a natural or diverted stream course. Percolation ponds are preferable under gentle sloping stream where narrow valley exists and located in soils of permeable nature so as to allow the water to percolate down. It recharges the ground water and increases the water levels in the wells. The zone of influence varies from 800 – 900 m. Percolation ponds also act as silt detention reservoir.

Soil and Water Conservation Technology for Hill Slopes

Contour trenches and stone walls

Contour trenches and stone walls

Contour trenches and stone walls are Suitable erosion control in hills. It can be adopted for hill slopes >20%. The normal size ranges from 1 m to 2.5m height/ depth and width. It may be continuous or interrupted type. Stoneterraces and walls are adopted where ever stones are available.

Bench Terracing

Bench Terracing helps to bring sloping land into different level strips to enable cultivation. It consists of construction of step like fields along contours by half cutting and half filling. Original slope is converted into level fields. The vertical and horizontal intervals are decided based land slope.

The Salient features are

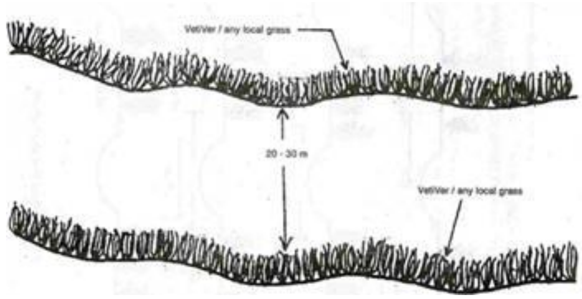
The benches may be inward sloping to drain off excess water.

The outward sloping benches will help o reduce the existing steep slope to mild one.

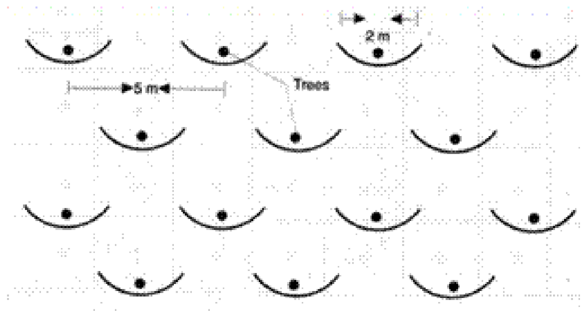
It is adopted in soils with slopes greater than 6%.

Land Configuration methods

- Contour stone walls
- Contour bunding
- Contour trenching
- Bench terraces
- Bunding / Compartmental Bunding
- Land levelling
- Summer ploughing
- Basin listing and tied ridging



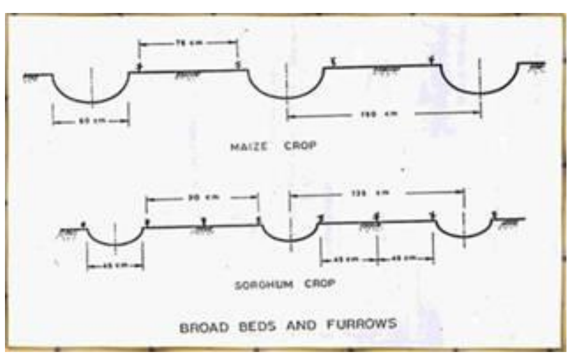
In-Situ soil and Moisture Conservation Techniques
Micro catchments:



Micro catchments serve to conserve insitu moisture and reduce soil loss. These micro catchments can beadopted by following any one from the following three methods

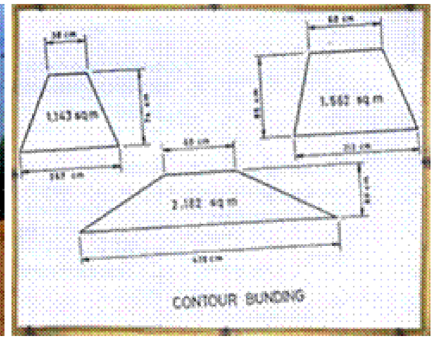
1. Circular basin of one meter diameter are made for level lands depending upon infiltration and rainfall.
2. ‘ V’ ditches of size 5m x 5m with trees planted centre and height according to the rainfall and slope of slopy lands
3. Saucer basins / semi circular bunds with 2m diameter to a height of 15-20cm across the slope

Broad beds and furrows:



The broad bed and furrow system is laid within the field boundaries. The land levels taken and it is laid using either animal drawn or tractor drawn ridgers. It control erosion and to conserve soil moisture in the soil during rainy days. It controls soil erosion and conserves soil moisture in dryland. In addition it acts as a drainage channel during heavy rainy days.

Contour bund:



It can be adopted in light and medium textured soils. It can be laid up to 6% slopes. It helps to retain moisture in the field. Contour bund intercept the runoff flowing down the slope by an embankment It helps to control runoff velocity. The embankment may be closed or open, surplus arrangements are provided whenever necessary.

Situations for various bunding options

Bunding options	Soil type	Rainfall (mm)	Slope (%)
Contour bund	Light soil	<600	>1.5
Graded bund	All soils	>600	1.5
Bench terraces	Deep soil	>1000	6.0
Graded boarder strip	Deep alfisol and related red soil	>800	>1.5

Crop / enterprise selection

- Fodder crops and live stock improvement
- Agro forestry with suitable species
- Dry land Horticulture improvement
- Avenue planting

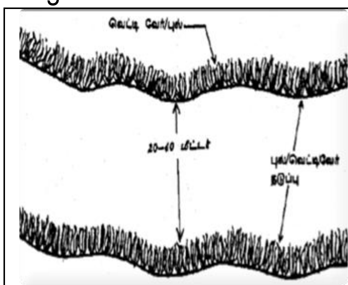
Crop management options

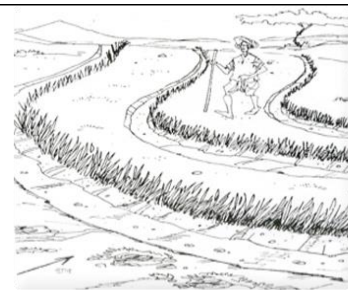
- **Vegetative barriers**

Vegetative barrier is a strip planted with a grass or shrub that runs across the slope. It slows down water flowing down the slope and catches the sediment that has been eroded uphill. Over time, soil may build up behind the strip.

Vettiver Plantation

- Slope of the land is <1% planting of vettiver, kollukattaipull, supapul, velimasal, gliricidia and lemon grass in across the slope as vegetative barriers.
- Vettiver can be planted in 15-20 cm interval in a paired row system. According to sloppiness vegetative barriers could be planted at 30-50 metre distance.





Vegetative barrier yields good benefits in the dryland soils. During heavy rainfall, barriers checks the run-off water which carrying potential soil from the land. It checks soil erosion and conserve moisture through reduction in velocity of water flow. Reduction in run off velocity increased the infiltration rate, only clear water alone will flow out of land. Vegetative barriers are cheap and easy to establish. Once they are growing, they are easy to maintain.

Mulching

Mulch is a material placed on the soil surface to maintain moisture, reduce weed growth, mitigate soil erosion and improve soil conditions. Mulching (installing mulches) can help to improve crop yield and optimise water use. **Mulch** can be expensive however and labour intensive to obtain, transport and disperse. Materials for mulching can be organic (straw, shredded bark, wood chips) or inorganic (plastic sheeting, volcanic rock). It depends on the ecological situation of the site which mulch type should be used. Especially plastic mulch might be more expensive, not always available, and difficult to remove properly causing environmental problems. If the mulching is not installed correctly, it can have negative effects on plants and soil.

Advantages

Mulches keep the soil underneath moist longer than bare soil and prevent evaporation
Controls soil erosion by cushioning the impact of raindrops and by slowing runoff
Can prevent weed growth by shading them out
Helps maintaining warm temperatures even at night
Synthetic mulches play a major role in soil solarisation processes
Mulching improves soil structure and aeration
Some mulch can improve soil fertility

Disadvantages

Mulching is labour-intensive

Inorganic mulches are costly

Too much mulch can create rotting of the root zone or provoque pests, etc.

Mulch material can introduce new pests and diseases into a field.

When plastic mulch starts to break down into non-recyclable bits; it is hard to remove it again

Introduction

Inorganic Mulches

Plastic mulches are completely impermeable; they therefore prevent direct soil evaporation and limit water losses and erosion via the soil surface. The prevented evaporation also has a supplementary effect; it avoids the rise of water containing salt, which is important in countries with high salt content water resources. Furthermore, mulches can provide a barrier to soil pathogens and especially opaque plastic mulches prevent germination of annual weeds from receiving light. They also help to maintain warm temperatures at night, which enable seeds to germinate quickly and for young plants to rapidly establish a strong root growth system. Inorganic mulches are often applied by machinery and holes or slits allow plants to grow through.

Opaque plastic mulch used in small crop production.

Organic Mulches

Typical materials for organic mulching are straw, leaves, cut grass, wood chips, peat, cut branches or the leftover of old harvested crops and various types of compost. Since organic mulches are derived from plant material, decomposition does occur, and several undesired effects on the soil and on plant growth will be apparent to gardeners. The addition of organic mulches such as leaves or shredded bark brings almost an immediate positive effect. These effects are physical (infiltration, improved water-holding capacity, soil structure and if decomposing organic material is correctly incorporated into the soil it also has a positive effect on aeration), chemical (soil **pH**, release of small amounts of nutrients, decomposing) and biological (temperature regulation for increasing microorganism activity). However, if organic mulches are kept to wet disease-causing pests fungi and other undesired microorganism may develop

Cost Considerations

Proper mulching can reduce the water needs because of reduced evaporation and enhanced water holding capacity of the soil. In general, plastic mulch is more expensive than organic mulch. It must be fabricated and disposed of. It might not be available in some countries. **Organic** material is almost available everywhere. It can be collected by the farmers (e.g. straw, leaves, cut grass) and does not necessarily need to be bought.

Operation and Maintenance

Inorganic Mulches

Lateral pipelines for irrigation are laid under the mulch *covering*

The selection of mulches depends on the ecological situation. Plastic mulching application depends on the crop, climate, soil, precipitation, and water quality. The colour influences temperature of the soil and airflow around the plants. Deteriorated plastic mulch might be difficult to remove if it has fallen apart in little pieces and is mixed with the soil. In case the mulch film needs to be used for more than one season (thicker film) the plant is cut at its base near the film and the film is removed and reused.

Table general instructions for selecting the correct plastic mulch

Rainy season	Perforated mulch
Orchard and plantation	Thicker mulch
Soil solarisation	Thin transparent film
Weed control through solarisation	Transparent film
Weed control in cropped land	Black film
Sandy soil	Black film
Saline water use	Black film
Summer cropped land	White film
Insect repellent	Silver colour film
Early germination	Thinner film

A common practice to irrigate plastic mulched fields is the **drip irrigation system** where the laterals are laid under the mulch. With this technique the water can be distributed without moving the plastic mulch. Furthermore there is no evaporation or water loss.

Organic Mulches

The organic mulching material should be applied around established plants in mid-spring, when the soil has warmed up sufficiently for active root growth. If the mulch is applied too early, it will keep the ground cool and root development will be delayed. Organic mulches such as leaves, sawdust, or shredded bark can be applied to the soil. *In addition to protecting the soil from erosion, this practice conserves water and reduces the need for irrigation.*

Mulching of staked tomatoes.

Benefits of Organic Mulching

As beneficial as organic mulch is, too much mulch can be harmful. A thick layer of organic mulch can be effective in suppressing weeds and reducing maintenance,

Constraints of Organic Mulching

Deep mulch can lead to excess moisture (root rot, mould fungus); it can create a habitat for rodents, which damage the plant. Furthermore, thick blankets of fine mulch may prevent penetration of water and air.

Some organisms can proliferate too much in the moist and protected conditions of the mulch layer. Slugs and snails can multiply very quickly under a mulch layer. Ants or termites, which may cause damage to the crops also may find ideal conditions for living. When crop residues are used for mulching, in some cases there is an increased risk of sustaining pests and diseases.

Damaging organisms such as stem borers may survive in the stalks of crops like cotton, corn or sugar cane. Plant material infected with viral or fungal diseases should not be used if there is a risk that the disease might spread to the next crop. Crop rotation is very important to overcome these problems.

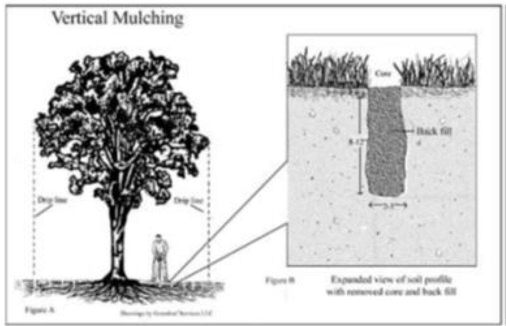
When carbon rich materials such as straw or stalks are used for mulching, nitrogen from the soil may be used by microorganisms for decomposing the material. Thus, nitrogen may be temporary not available for plant growth (risk of N-immobilisation)

Vertical Mulching

Vertical mulching is the creating of holes around the base of a tree or shrub that is stressed. The holes are filled with a mixture of organic material. The back fill and aeration can dramatically improve root growth and reduce or eliminate stress caused by degraded environment.

Purpose of Vertical Mulch

- To alleviate soil compaction and allow air to flow more easily to the roots
- To add of organic rich compost to poor soil.
- To expands the root system by the addition of Mychorizae
- To allows faster percolation of water in wet areas by changing soil structure and aerating



It is a relatively simple and unobtrusive process. The holes are created with spade or auger. Starting a few feet away from the trunk and continued in a grid pattern (approximately 2 feet apart) beyond the drip line. They are usually back filled with a mixture of compost, organic fertilizer, and Mychorizae. The actual fill may vary according to the individual needs of the plant treated.

Some of the benefits are

- Reduced compaction
- Increased drainage
- Increased oxygen to the root system
- Introduction of organic mater to existing soil
- Increased soil organisms
- Increased water retention

Vertical mulching is one of the most effective ways to treat stressed trees and shrubs. The aeration and soil treatment create an environment that mimics nature and allows for greater nutrient uptake, increased root growth and the potential regeneration of a damaged root system. Vertical mulching with compost tea and humate applications further help the root system repair and provide for itself.

Lecture 4

Afforestation and sylviculture methods; Soil carbon restoration – use of industrial C- rich by products

Agroforestry is an integrated approach of using the interactive benefits from combining trees and shrubs with crops and/or livestock. It combines agricultural and forestry technologies to create more diverse, productive, profitable, healthy and sustainable land-use systems

Agroforestry is a collective name for land use systems and practices in which woody perennials are deliberately integrated with crops and/or animals on the same land management unit. The integration can be either in a spatial mixture or in a temporal sequence. There are normally both ecological and economic interactions between woody and non-woody components in agroforestry". -World Agroforestry Centre (ICRAF) 1993

Benefits of agroforestry

Agroforestry systems can be advantageous over conventional agricultural and forest production methods through increased productivity, economic benefits, social outcomes and the ecological goods and services provided. Biodiversity in agroforestry systems is typically higher than in conventional agricultural systems. Agroforestry incorporates at least several plant species into a given land area and creates a more complex habitat that can support a wider variety of birds, insects, and other animals. Agroforestry also has the potential to help reduce climate change since trees take up and store carbon at a faster rate than crop plants.

Agroforestry practices may also be employed to realize a number of other associated Environmental Services, including:

- ✓ Carbon sequestration
- ✓ Odour, dust, and noise reduction
- ✓ Waste water or manure management (e.g. utilizing urban waste water on intensive, short rotation forests for wood fibre production)
- ✓ Green space and visual aesthetics.
- ✓ Enhancement or maintenance of wildlife habitat.

Soil

- ✓ Protecting soil from erosion.
- ✓ Increasing nutrients in poor soils.
- ✓ Improving the structure of soil so that it holds more water.

Energy supply

- ✓ Providing cheaper and more accessible fuelwood.
- ✓ Producing better quality fuelwood depending on the species planted.

Shelter and structures

- ✓ Providing cheaper building materials.
- ✓ Protecting animals, crops and humans from wind and sun.
- ✓ Providing fencing to protect crops from livestock and wild animals.

Plant resources / biodiversity

- ✓ Improving local environmental conditions for naturally occurring plants to grow.
- ✓ Maintaining and increasing the number of species of plants.

Cash income

- ✓ Providing additional or off-season employment.
- ✓ Enabling the sale of tree products.
- ✓ Providing investments such as orchards, tree products, agro-business and long-term supply of materials for the production of crafts.

Dispersed trees on cropland

Trees may be grown in fields while crops are grown alongside or underneath. The practice of growing trees in this way can be done either by protecting and managing the trees that are already there or by planting new trees. These trees are usually grown to provide a product of commercial or subsistence value, such as food, fuel, building poles, fodder or gum. They also provide nutrients and organic matter for the soil and provide shade for crops and livestock. There are different spacing patterns and densities of placement depending on the type of tree chosen and also the type of crop grown, but trees are generally planted at least 8-10m apart and often much further apart.

Advantages

- ✓ Growing trees with crops can increase crop yields due to shading and the addition of nutrients and organic matter to the soil.
- ✓ Trees can be a breeding place for beneficial insects and other creatures that can reduce crop pest numbers.
- ✓ Trees can provide products of commercial and subsistence value.

Disadvantages

- ✓ Trees can attract birds and crop pests, which can damage crops.

- ✓ Competition with crops for water, nutrients. It is important to plant trees with deeper roots than those of the crops grown alongside.

Alley cropping

Alley cropping is also known as alley farming or hedgerow intercropping. Rows of woody plants are grown with annual crops planted in the alleys in between. The main purpose of this method is to maintain or increase crop yields by improving the soil and micro-climate through the cycling of nutrients, mulching and weed control. Alley cropping is mostly used in humid or subhumid tropical areas on fragile soils and seems to work best where farmers need to intensify crop production but have soil fertility problems. The technique of alley cropping requires careful planning and management. It is preferable that the species used have a light open crown that lets sunlight pass through onto the crops that are being grown. It is also possible to prune species with a denser crown. The trees used must also be capable of rapid rerouting after coppicing. This is how the alley cropping cycle proceeds:

Alley cropping management cycle

- ✓ The trees are planted in lines and crop grown between the rows.
- ✓ When the shade from the trees begins to interfere with the crops they are coppiced or pollarded.
- ✓ The coppiced branches are placed between the rows. Leaves will fall to the ground adding organic matter to the soil when they breakdown.
- ✓ Branches and twigs can be gathered for fuel or other purposes.
- ✓ Trees re sprout
- ✓ The cycle is repeated.

Advantages

- ✓ Improvement of soil fertility and structure and micro-climate conditions, thereby benefiting crops.
- ✓ A longer cropping period and higher land use intensity.
- ✓ Trees used can provide products of commercial and subsistence value.

Disadvantages

- ✓ The technique will take some years to establish, so farmers will have to wait for the benefits.
- ✓ Farmers may not have the capital available for the investment in trees.
- ✓ Alley cropping requires considerable labour and management – results will be poor if planting and pruning schedules are not carried out properly.
- ✓ Competition with crops for water, nutrients. It is important to plant trees with deeper roots than those of the crops grown alongside.

Improved fallow

Improved fallow is the replacement or enhancement of natural fallow vegetation by the introduction of selected trees or shrubs. The purpose of improved fallow is to shorten the fallow period and/or increase the yield of subsequent crops. This is done by planting trees or shrubs which can help to restore nutrients to the soil and to suppress weeds as well as providing useful by-products. The trees therefore enrich the fallow both biologically and economically. In this practice the cropping period usually alternates with the tree-growing period. However, it is possible to keep some trees standing during the cropping period and many farmers have combined the method of improved fallow with alley cropping. By planting mainly soil enriching species, the minimum fallow period can be shortened from 15 to 20 years to about 8 to 10 years.

Advantages

- ✓ The time required for soil enrichment can be shortened; the tree canopy and fast growing species can suppress weeds.
- ✓ Soil erosion is minimised.
- ✓ The use of a wide variety of species can reduce pests, weeds and diseases.
- ✓ This method is relatively inexpensive to establish and maintain.
- ✓ The wood can be used or sold at the end of the fallow period.

Disadvantages

- ✓ The planting of seedlings and tree cutting must be done during the same period of crop planting - labour may be a limiting factor at this time.
- ✓ The fallow will need protection from browsing animals.

Contour vegetation strips

In traditional systems, lines of grasses, stones, crop residues and other organic debris are placed along hillsides to control water and soil erosion. Contour vegetation strips are living barriers of trees and shrubs which are planted along the contour lines of a slope. These lines of vegetation can serve the same purpose and can also provide useful products such as food, fuel, building poles, fodder or gum. There are many factors to consider when building contour strips as bad design can lead to even more severe erosion. The effectiveness of the strip depends on the type of tree planted, the spacing of the trees and the width of the strip, the steepness of the slope, the amount of rainfall and the type of soil.

Advantages

- ✓ Strips can provide additional nutrients and organic matter into the soil.
- ✓ This can be increased by using nitrogen-fixing plants.

- ✓ Excess vegetation can provide food for animals. These can be allowed to browse through the strip to feed on crop remains after harvesting.

Disadvantages

- ✓ Contour strips take up land which could be used for crops.

Planting on terraces

Terraces are usually put in place as soil and water conservation measures on slopes and hills. They provide flat areas of land that can be planted with crops. Building terraces involves digging ditches and making ridges along the contours of a slope. Grasses, trees and shrubs can be planted on the ridges to stabilise the ground, provide leaf mulch and protection from wind for crops and provide other useful products such as food, fuel, building poles or fodder. Trees can be planted on the ridge of the terrace or at the back of the terrace. If the tree is planted at back of the terrace it will get all of its water requirements. If a tree is planted on the ridge of the terrace, it will be on drier ground but the leaves will spread around more evenly and provide more nutrients for crops. Trees can be planted in both locations if the terrace is wide enough. The type of tree or hedge used will vary according to the site it is planted on and what products or services you wish it to provide. If the aim of the terrace is to stabilise the soil, trees and shrubs with strong roots systems should be planted. These will be able to withstand the movements of soil and water.

Advantages

- ✓ Stabilisation of the slope, which results in soil and water conservation and a better environment for crops to grow in.
- ✓ Shelter from wind.
- ✓ Pest control by providing a breeding place for beneficial insects.
- ✓ Increased area of land that can be cropped.
- ✓ Useful by-products such as food, fuel, building poles or fodder.

Disadvantages

- ✓ As the structure of the land is changed quite dramatically, land tenure rights may first need to be established or secured.
- ✓ Building terraces require adequate skills and material, labour and capital and also the capacity to maintain the structures for years to come.

Living fences

Living fences are lines of trees or shrubs planted on farm boundaries or on the borders of farmyards, pasture plots, animal enclosures or around agricultural fields. They have been used by farmers for hundreds of years and they are becoming more and more popular in areas where materials for fence posts are scarce or expensive. Living fences serve mainly as field boundaries. They can be made of single or multiple, densely planted rows consisting of a mixture of plant species. Alternatively, one row of trees can be planted widely spaced with wire, sticks or dead branches twisted between them - these are termed 'living fenceposts'. Both types of living fences are regularly pollarded and trimmed. A wide range of vigorously sprouting species of trees and shrubs can be used to create a living fence.

Advantages

- ✓ Animals are kept away from growing crops.
- ✓ The fences offer shade for animals.
- ✓ Trees provide a micro-climate with a higher humidity and more shade, which will improve pasture growth.
- ✓ Legumes used in fences can improve the soil by fixing nitrogen.
- ✓ Pruned materials can be used as a mulch; foliage can be used as fodder.
- ✓ An established living fence can be harvested for fuelwood.
- ✓ Prunings can be used as cuttings to replenish the fence at very little cost.
- ✓ Trees may need protection from animals during their early stages of growth.
- ✓ Trees may compete with crops and pasture for light, water and nutrients.
- ✓ Living fences can act as a refuge for pests and diseases.
- ✓ Animals walking close to the fence compact the soil and may cause damage to the root system.
- ✓ Pruning may be necessary depending on the species chosen.

Shelterbelts

A shelterbelt, or windbreak, is a barrier formed by trees and shrubs strategically planted to reduce wind speed in order to protect agricultural lands, people, animals and buildings. They can also be used to support sand dune stabilisation. Shelterbelts are most successfully introduced in areas where there are high wind speeds and/or prevailing winds for long periods, or where the soil is dry for a large part of the year and/or where loose soil structures are present. A Shelterbelts are made up of strips of trees, shrubs and grasses planted in single or multiple rows. Ideal species are those that are bushy and withstand harsh environmental conditions such as hot or cold winds, salt-laden winds, wind-borne sand, or drought. Evergreen species are recommended unless trees and shrubs are in full foliage during the period of winds. Grasses and herbaceous plants can be planted at the base of the shelterbelt to protect the wind from eroding the surrounding soil. The shelterbelts are sited on the upwind side of the land to be protected and are most effective when planted perpendicular to the prevailing wind direction. Sometimes large areas are protected by several parallel shelterbelts. Research shows that wind speed is reduced on both sides of the barrier.

Advantages

- ✓ Physical damage to soils, crops, pasture and animals is reduced.
- ✓ Temperature of soil and air behind shelterbelts is modified.
- ✓ Moisture loss (caused by high winds) is reduced.
- ✓ Leaves from shelterbelt can help to fertilise fields.
- ✓ Soil erosion can be prevented.

Disadvantages

- ✓ The space that the shelterbelt takes up reduces the overall land available to the farmer.
- ✓ The trees that make up the shelterbelt may compete with crops for water or nutrients, leading to decreased production.
- ✓ Pests and diseases may develop in the trees and shrubs and spread to nearby crops.
- ✓ Shelterbelts need continual maintenance to ensure maximum efficiency.
- ✓ A badly designed shelterbelt, or one which has developed gaps, will allow wind to be funnelled through at a very high speed, resulting in serious soil erosion.

Carbon-enriched Soil Amendments

Soil carbon (C) is an important indicator of soil health and an integral part of the physical, chemical, and biological properties of the soil. Loss of soil carbon can lead to soil degradation and loss of productivity. Soil carbon is lost from the soil through erosion, residue removal, intensive tillage, and land-use changes. Carbon-enriched soil amendments, including animal manure, bio-solids, municipal compost, and biochar, among others, can restore soil productivity

History Of Carbon-enriched Soil Amendment: Terra Preta Soils

Addition of carbon-enriched materials to the soil is not a new practice. Thousands of years ago, the indigenous people of the Amazon basin used charcoal-like material from cooking and heating as a soil amendment to agricultural soils. Through the addition of this carbon material, the indigenous people created what are now called the Terra Preta soils of the Amazon. The Terra Preta soils are deep, dark brown, rich in nutrients, and contain significantly large amounts of soil organic matter compared to the surrounding soils. In addition, these soils have higher water-holding capacity; all of which make the soil highly valuable and productive. The Terra Preta soils are an excellent case study illustrating the long-term success of using high-carbon materials as soil amendments.

High-Carbon Char

Another potential carbon-enriched soil amendment with properties similar to biochar is char, also known as high-carbon char. High-carbon char is a residue from incomplete burning of coal High-carbon char contains 30% carbon, 0.37% nitrogen, 0.22% phosphorus, 4.76% potassium, 4.76% calcium, 1.08% magnesium, and 0.51% sulfur in addition to many plant essential nutrients. Like other by-products recycled as soil amendments, including bio-solids and manure, potential contaminants need to be considered when using high-carbon char.

Spent Microbial Mass (SMB)

SMB is a biotechnology waste byproduct that can provide nutrients that are also in conventional fertilizers. Recycling biotechnology byproducts can enhance soil health while reducing carbon emissions and maintaining crop yields

Agro industrial wastes

Food processing industry wastes

Fruit processing industry wastes

Coffee seed wastes

Lecture 5

Causes, reclamation and management of soil physical deterioration - surface and sub surface hard pans, shallow, slowly permeable and highly permeable and fluffy paddy soils

Soil physical deterioration

Soils show some problems which affects normal cultivation by means of physical nature without any chemical reactions. That leads to formation of deterioration of lands which needs some management options to carry out normal cultivation. These includes:

- ❖ Surface crusting (surface hard pans)
- ❖ Sub surface hard pans
- ❖ Shallow soils
- ❖ Slowly permeable soils
- ❖ Highly permeable soils and
- ❖ Fluffy paddy soils

1. Surface crusting of soil

Occurrence

In Tamil Nadu, surface crusting is prevalent in Trichy, Thanjavur, Pudukottai, Cuddalore and Sivaganga districts and surface crusting problems are common in red soil areas. In Tamil Nadu, the area under soil crusting is around 4,51,584 ha (4.49% TGA).

Causes

Surface crusting is due to the presence of colloidal oxides of iron and aluminium in Alfisols which binds the soil particles under wet regimes. On drying it forms a hard mass on the surface which is also called as crust (hard layer formed on the surface).

Impact on soil properties

- Prevent germination of seeds results in poor crop stand and finally leads to reduction in yield
- Retards/inhibits root penetration and root growth and hence uptake of nutrients and water will be restricted thereby poor growth
- Results in poor infiltration of water
- Accelerates surface run off, that leads to soil erosion
- Creates poor aeration in the rhizosphere

- Affects nodule formation in leguminous crops

Reclamation and management measures

- When the soil is at optimum moisture regime, ploughing is to be done.
- Lime or gypsum @ 2 t ha^{-1} (based on pH) may be uniformly spread and another ploughing given for blending of amendment with the surface soil.
- Farm yard manure or composted coir pith @12.5 t ha^{-1} or other organics may be applied to improve the physical properties of the soils.
- Scraping the surface soil by tooth harrow will be useful.
- Bold grained seeds may be used for sowing on the crusted soils.
- More number of seeds/hill may be adopted for small seeded crops.
- Seed rate may be doubled.
- Sprinkling water at periodical intervals may be done wherever possible.
- Foliar application and split application of nutrients can be recommended
- Soil test based IPNS will increase the yield of crops.
- Resistant crops like cowpea can be grown.

2. Sub soil hard pan

Sub soil hard pan is also commonly found in red soils. Though soil is fertile, crops cannot absorb nutrients from the soil which leads to reduction in crop yields. In Tamil Nadu, it is prevalent in Coimbatore, Erode, Dharmapuri, Trichy, Cuddalore, Villupuram, Pudukottai, Sivagangai, Madurai and Salem districts particularly under rainfed conditions. In Tamil Nadu, the area under subsoil hardpan is around 10, 54,661 ha (10.48% TGA).

Causes: 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 and accumulation in the sub surface which forms very hard layer.

Impact on soil physical properties: The sub soil hard pan is characterized by high bulk density (>1.8 Mg m^{-3}) which in turn lowers infiltration, water holding capacity, available water and movement of air and nutrients with concomitant effect on the yield of crops. Root penetration pose problem.

Chiseling technology to overcome the sub soil hard pan:

Chisel plough is used to break sub soil hard pan in red soil. It is a tractor drawn heavy iron plough which goes up to 45 cm depth.

Methodology: The field is to be ploughed with chisel plough at 50 cm interval in both the directions. Chiseling helps to break the hard pan in the sub soil besides it ploughs up to 45 cm depth. Farm yard manure or press mud or composted coir pith at 12.5 t ha^{-1} is to be spread evenly on the surface. The field should be ploughed with country plough twice for incorporating the added manures. The broken hard pan and incorporation of manures make the soil to conserve more moisture.

Other management options : Cultivation of deep rooted plants, crop rotation

3. Shallow soils

In Tamil Nadu, shallow soils occur over an area of around 1,16,509 ha (1.16.% TGA).

Causes: The reason for the formation of Shallow soils is due to the presence of parent rocks immediately below the soil surface (15-20 cm depth).

Impact: The shallow soil restricts root elongation and spreading. Due to shallowness less volume of soil is available to exhaust soil nutrients.

Management

- ❖ Growing shallow rooted crops.
- ❖ Frequent renewal of soil fertility
- ❖ Application of organic manures
- ❖ Growing crops that can withstand shallowness (Mango, West Indian cherry, country goose berry, fig ,tamarind, ber and cashew etc)

4. Slow permeable soils/Impermeable soils

In Tamil Nadu, the area under slow permeable soils is around 7,54,631 ha (7.5% of TGA)

Causes: Slow permeable soil is mainly due to very high clay content, infitration rate < 6cm/day, entry of water into the soil profile is reduced so more runoff which eventually leads to soil erosion and nutrient removal. Since the capillary porosity is high it leads to impeded drainage. Poor aeration and reduced conditions. Nutrient fixation and toxicity of elements ultimately leads to poor crop growth and in certain cases leads to complete death of crops.

Distribution: These soils cover an area of 49.8 m.ha in the Central India comprising Madhya Pradesh, Andhra Pradesh, Gujarat and in Tamil Nadu about 14.32 lakh ha of land is affected by these soils.

Characteristics

- Very high clay content and bulk density
- Poor drainage and hydraulic conductivity because of high capillary porosity

- Infiltration rates of less than 6 cm/day due to high clay content of the soil
- Due to low infiltration rates, the amount of water entering the soil profile is reduced thus increasing the run-off. Further, it encourages erosion of surface soil leading to nutrient removal in the running water
- Temporary waterlogging of the soil develops oxygen stress in root zone.
- Reduced condition results in toxicity of some nutrients and induces nutrient fixation in the clay complex.
- High soil pH and calcareousness promotes ammonia volatilization
- Soils are low in organic carbon, N,P, Zn and Fe.

Remedial measures

(i) Incorporation of organics: Addition of organics namely FYM/composted coir pith/press mud at 12.5 t ha^{-1} found to be optimum for the improvement of the physical properties besides, it facilitates water movement to the root zone.

(ii) Formation of ridges and furrows: For rainfed crops, ridges are formed along the slopes for providing adequate aeration to the root zone. Interception drainage channels should be provided to carry the excess water to rice fields located at lower end of the slope.

(iii) Raised and sunken beds formation in between adjacent raised beds: The bulk density was found to be reduced due to increase in non capillary pores in upper 10 cm layer of raised bed besides increase in yield of crops by forming raised and sunken beds.

(iv) Formation of broad beds: To reduce the amount of water retained in black clay soils during first 8 days of rainfall, broad beds of 3-9 m vide should be formed either along the slope or across the slope with drainage furrows in between broad beds.

v) Providing drainage open/ subsurface

vi) Huge quantity of sand /red soil application to change the texture

vii) Contour /compartmental bunding to increase the infiltration

viii) Application of soil conditioners like vermiculite/ jalsakthi to reduce runoff and erosion

5. Highly permeable / Excessively Permeable Soils

The high permeability is associated with sand and loamy sand texture of soils. These soils occur in coastal areas, river delta and in the desert belts.

Distribution: These soils cover large areas in Rajasthan and Haryana. These soils are spread over 24, 12, 086 ha in Tamil Nadu (23:97% of total geographic area).Such soils do occur in Coimbatore, Trichy, Kanyakumari, Tuticorin, Thanjavur and Tirunelveli districts and in part of coastal areas in Tamil Nadu.

Characteristics

- Sand content exceeding 70 percent occur in coastal areas, river delta and in the desert belts.
- Soil structure is loose to very weakly developed depending upon clay content
- Since the sandy soils are devoid of structural development, they suffer from intensive erosion
- These soils being devoid of finer particles and organic matter, the aggregates are weakly formed and hence there is lack of cohesion, adhesion and plasticity of soil
- The nature of excessive permeability of the sandy soils results in very poor water retention capacity, nutrient retention capacity and high infiltration rates.
- Soils are lighter in colour
- Very low in organic carbon, nitrogen and medium in P and K.
- Low nutrient diffusivity and buffering capacity.
- Sand - > 70 per cent
- Clay - <15 per cent
- Hydraulic conductivity- 20 cm/hr

Management technology

1. Compacting the field with 400 kg stone roller (tar drum filled with 400 kg of sand or stones can also be used) 8-10 times at optimum moisture conditions (Preferably 24 hours after a good rainfall). This practice increases the bulk density of (0-30 cm) layer to optimum range (1.5 -1.7 Mg m^{-3}. Then shallow ploughing can be given and crops can be raised.
2. Application of clay soil up to a level 100 t ha^{-1} based on the severity of the problem and availability of clay materials.
3. Application of organic materials like farm yard manure, compost, press mud, sugar factory slurry, composted coir pith, sewage sludge etc.
4. Providing asphalt sheet, polythene sheets etc. below soil surface to reduce the infiltration rate.
5. Crop rotation with green manure crops like Sunhemp, sesbania, daincha, kolinchi etc.
6. Forming minimum plot size and applying minimum and frequent irrigations.
7. Split application of fertilizers especially

Improving water and nutrient holding capacities

1. Application of organics like compost, Farm Yard Manure, Green manures and Green leaf manures
2. Frequent irrigation with low quantity of water
3. Frequent split application of fertilizers /foliar nutrition
4. Application of slow release fertilizers

6. Fluffy paddy soils

Occurrence: In Tamil Nadu, fluffy paddy soils are prevalent in Cauvery delta zone and in many parts of the state. It is formed due to the continuous rice-rice cropping sequence. In Tamil Nadu about 25,919 ha of land if affected by fluffiness (0.26 % of TGA).

Causes: The traditional method of preparing the soil for transplanting rice consists of puddling which results in substantial break down of soil aggregates into a uniform structure less mass. The solid and liquid phases of the soil are thus changed. Under continuous flooding and submergence of the soil for rice cultivation in a cropping sequence of rice-rice-rice, as in many parts of Tamil Nadu, the soil particles are always in a state of flux and the mechanical strength is lost leading to the fluffiness of the soils. This is further aggravated by in situ incorporation of rice stubbles and weeds during puddling.

Impact of fluffiness: Sinking of draught animals and labourers is one of the problems during puddling in rice fields in many parts of Tamil Nadu. This has been thus, an invisible drain of finance for the farmers due to high pulling power needed for the bullocks and slow movement of labourers during the puddling operations. Further the fluffiness of the soil lead to very low bulk density and thereby leading to very rapid hydraulic conductivity and in turn the soil does not provide a good anchorage to the roots and the potential yield of crops is adversely affected.

Methodolgy

- The irrigation should be stopped 10 days before the harvest of rice crop
- After the harvest of rice, when the soil is under semi-dry condition proctor moisture level), compact the field by passing 400 kg stone roller or an empty tar drum filled with 400 kg sand 8 times.
- The usual preparatory cultivation is carried out after compaction.

Lecture 6

Causes and Management of Soil Erosion

Soil erosion is a naturally occurring process that affects all landforms. In agriculture, soil erosion refers to the wearing away of a field's topsoil by the natural physical forces of waterand windor through forces associated with farming activities such as tillage.

Three distinct actions of erosion: whether it is by water, wind or tillage, involves three distinct actions :soil detachment, movement and deposition. Topsoil, which is high in organic matter, fertility and soil life, is relocated elsewhere "on-site" where it builds up over time or is carried "off-site" where it fills in drainage channels. Soil erosion reduces cropland productivity and contributes to the pollution of adjacent watercourses, wetlands and lakes.

Soil erosion can be a slow process that continues relatively unnoticed or can occur at an alarming rate, causing serious loss of topsoil. Soil compaction, low organic matter, loss of soil structure, poor internal drainage, salinisation and soil acidity problems are other serious soil degradation conditions that can accelerate the soil erosion process.

.Soil Erodibility

Soil erodibility is an estimate of the ability of soils to resist erosion, based on the physical characteristics of each soil. Texture is the principal characteristic affecting erodibility, but structure, organic matter and permeability also contribute. Generally, soils with faster infiltration rates, higher levels of organic matter and improved soil structure have a greater resistance to erosion. Sand, sandy loam and loam-textured soils tend to be less erodible than silt, very fine sand and certain clay-textured soils.

Tillage and cropping practices that reduce soil organic matter levels, cause poor soil structure, or result in soil compaction, contribute to increases in soil erodibility. As an example, compacted subsurface soil layers can decrease infiltration and increase runoff. The formation of a soil crust, which tends to "seal" the surface, also decreases infiltration. On some sites, a soil crust might decrease the amount of soil loss from raindrop impact and splash; however, a corresponding increase in the amount of runoff water can contribute to more serious erosion problems.

Past erosion also has an effect on a soil's erodibility. Many exposed subsurface soils on eroded sites tend to be more erodible than the original soils were because of their poorer structure and low organic matter. The low nutrient levels often associated with subsoils contribute to lower crop yields and generally poorer crop cover, which in turn provides less crop protection for the soil.

Slope Gradient and Length

The steeper and longer the slope of a field, the higher the risk for erosion. Soil erosion by water increases as the slope length increases due to the greater accumulation of runoff. Consolidation of small fields into larger ones often results in longer slope lengths with increased erosion potential, due to increased velocity of water, which permits a greater degree of scouring (carrying capacity for sediment).

Cropping and Vegetation

The potential for soil erosion increases if the soil has no or very little vegetative cover of plants and/or crop residues. Plant and residue cover protects the soil from raindrop impact and splash, tends to slow down the movement of runoff water and allows excess surface water to infiltrate.

The erosion-reducing effectiveness of plant and/or crop residues depends on the type, extent and quantity of cover. Vegetation and residue combinations that completely cover the soil and intercept all falling raindrops at and close to the surface are the most efficient in controlling soil erosion (e.g., forests, permanent grasses). Partially incorporated residues and residual roots are also important as these provide channels that allow surface water to move into the soil.

The effectiveness of any protective cover also depends on how much protection is available at various periods during the year, relative to the amount of erosive rainfall that falls during these periods. Crops that provide a full protective cover for a major portion of the year (e.g., alfalfa or winter cover crops) can reduce erosion much more than can crops that leave the soil bare for a longer period of time (e.g., row crops), particularly during periods of highly erosive rainfall such as spring and summer. Crop management systems that favour contour farming and strip-cropping techniques can further reduce the amount of erosion. To reduce most of the erosion on annual row-crop land, leave a residue cover greater than 30% after harvest and over the winter months, or inter-seed a cover crop (e.g., red clover in wheat, oats after silage corn).

Tillage Practices

The potential for soil erosion by water is affected by tillage operations, depending on the depth, direction and timing of plowing, the type of tillage equipment and the number of passes. Generally,the less the disturbance of vegetation or residue cover at or near the surface, the more effective the tillage practice in reducing water erosion. Minimum till or no-till practices are effective in reducing soil erosion by water.

Tillage and other practices performed up and down field slopes creates pathways for surface water runoff and can accelerate the soil erosion process. Cross-slope cultivation and contour farming techniques discourage the concentration of surface water runoff and limit soil movement.

Water Erosion

The widespread occurrence of water erosion combined with the severity of on-site and off-site impacts have made water erosion the focus of soil conservation efforts.The rate and magnitude of soil erosion by water is controlled by the following factors:

Rainfall and Runoff

The greater the intensity and duration of a rainstorm, the higher the erosion potential. The impact of raindrops on the soil surface can break down soil aggregates and disperse the aggregate material. Lighter aggregate materials such as very fine sand, silt, clay and organic matter are easily removed by the raindrop splash and runoff water; greater raindrop energy or runoff amounts are required to move larger sand and gravel particles.

Soil movement by rainfall (raindrop splash) is usually greatest and most noticeable during short-duration, high-intensity thunderstorms. Although the erosion caused by long-lasting and less-intense storms is not usually as spectacular or noticeable as that produced during thunderstorms, the amount of soil loss can be significant, especially when compounded over time.

Surface water runoff occurs whenever there is excess water on a slope that cannot be absorbed into the soil or is trapped on the surface. Reduced infiltration due to soil compaction, crusting or freezing increases the runoff. Runoff from agricultural land is greatest during spring months when the soils are typically saturated, snow is melting and vegetative cover is minimal.

Forms of Water Erosion

Sheet Erosion

Sheet erosion is the movement of soil from raindrop splash and runoff water. It typically occurs evenly over a uniform slope and goes unnoticed until most of the productive topsoil has been lost. Deposition of the eroded soil occurs at the bottom of the slopeor in low areas. Lighter-coloured soils on knolls, changes in soil horizon thickness and low crop yields on shoulder slopes and knolls are other indicators.

Rill Erosion

Rill erosion results when surface water runoff concentrates, forming small yet well-defined channels (Fig.4). These distinct channels where the soil has been washed away are called rills when they are small enough to not interfere with field machinery operations. In many cases, rills are filled in each year as part of tillage operations.

Gully Erosion

Gully erosion is an advanced stage of rill erosion where surface channels are eroded to the point where they become a nuisance factor in normal tillage operations.Surface water runoff, causing gully formation or the enlarging of existing gullies, is usually the result of improper outlet design for local surface and subsurface drainage systems. The soil instability of gully banks, usually associated with seepage of groundwater, leads to sloughing and slumping (caving-in) of bank slopes. Such failures usually occur during spring months when the soil water conditions are most conducive to the problem.

Gully formations are difficult to control if corrective measures are not designed and properly constructed. Control measures must consider the cause of the increased flow of water across the landscape and be capable of directing the runoff to a proper outlet. Gully erosion results in significant amounts of land being taken out of production and creates hazardous conditions for the operators of farm machinery.

Bank Erosion

Natural streams and constructed drainage channels act as outlets for surface water runoff and subsurface drainage systems. Bank erosion is the progressive undercutting, scouring and slumping of these drainageways (Fig.6). Poor construction practices, inadequate maintenance, uncontrolled livestock access and cropping too close can all lead to bank erosion problems.

Poorly constructed tile outlets also contribute to bank erosion. Some do not function properly because they have no rigid outlet pipe, have an inadequate splash pad or no splash pad at all, or have outlet pipes that have been damaged by erosion, machinery or bank cave-ins.The direct damages from bank erosion include loss of productive farmland, undermining of structures such as bridges, increased need to clean out and maintain drainage channels and washing out of lanes, roads and fence rows.

Effects of Water Erosion

On-Site

- ✓ The implications of soil erosion by water extend beyond the removal of valuable topsoil.
- ✓ Crop emergence, growth and yield are directly affected by the loss of natural nutrients and applied fertilizers.
- ✓ Seeds and plants can be disturbed or completely removed by the erosion.

- ✓ Organic matter from the soil, residues and any applied manure, is relatively lightweight and can be readily transported off the field, particularly during spring thaw conditions.
- ✓ Pesticides may also be carried off the site with the eroded soil.
- ✓ Soil quality, structure, stability and texture can be affected by the loss of soil.
- ✓ The breakdown of aggregates and the removal of smaller particles or entire layers of soil or organic matter can weaken the structure and even change the texture.
- ✓ Textural changes can in turn affect the water-holding capacity of the soil, making it more susceptible to extreme conditions such as drought.

Off-Site

- ✓ The off-site impacts of soil erosion by water are not always as apparent as the on-site effects. Eroded soil, deposited down slope, inhibits or delays the emergence of seeds, buries small seedlings and necessitates replanting in the affected areas.
- ✓ Also, sediment can accumulate on down-slope properties and contribute to road damage.
- ✓ Sediment that reaches streams or watercourses can accelerate bank erosion, obstruct stream and drainage channels, fill in reservoirs, damage fish habitat and degrade downstream water quality. Pesticides and fertilizers, frequently transported along with the eroding soil, contaminate or pollute downstream water sources, wetlands and lakes.
- ✓ Because of the potential seriousness of some of the off-site impacts, the control of "non-point" pollution from agricultural land is an important consideration.

Wind Erosion

Wind erosion occurs in susceptible areas of – mainly sandy and organic or muck soils. Under the right conditions it can cause major losses of soil and property

Figure 7. Wind erosion can be severe on long, unsheltered, smooth soil surfaces.

Soil particles move in three ways, depending on soil particle size and wind strength - suspension, saltation and surface creep.

The rate and magnitude of soil erosion by wind is controlled by the following factors:

ind is controlled by the following factors:

Soil Erodibility

Very fine soil particles are carried high into the air by the wind and transported great distances (suspension). Fine-to-medium size soil particles are lifted a short distance into the air and drop back to the soil surface, damaging crops and dislodging more soil (saltation). Larger-sized soil particles that are too large to be lifted off the ground are dislodged by the wind and roll along the soil surface (surface creep). The abrasion that results from windblown particles breaks down stable surface aggregates and further increases the soil erodibility.

Soil Surface Roughness

Soil surfaces that are not rough offer little resistance to the wind. However, ridges left from tillage can dry out more quickly in a wind event, resulting in more loose, dry soil available to blow. Over time, soil surfaces become filled in, and the roughness is broken down by abrasion. This results in a smoother surface susceptible to the wind. Excess tillage can contribute to soil structure breakdown and increased erosion.

Climate

The speed and duration of the wind have a direct relationship to the extent of soil erosion. Soil moisture levels are very low at the surface of excessively drained soils or during periods of drought, thus releasing the particles for transport by wind. This effect also occurs in freeze-drying of the soil surface during winter months. Accumulation of soil on the leeward side of barriers such as fence rows, trees or buildings, or snow cover that has a brown colour during winter are indicators of wind erosion.

Unsheltered Distance

A lack of windbreaks (trees, shrubs, crop residue, etc.) allows the wind to put soil particles into motion for greater distances, thus increasing abrasion and soil erosion. Knolls and hilltops are usually exposed and suffer the most.

Vegetative Cover

The lack of permanent vegetative cover in certain locations results in extensive wind erosion. Loose, dry, bare soil is the most susceptible; however, crops that produce low levels of residue (e.g., soybeans and many vegetable crops) may not provide enough resistance. In severe cases, even crops that produce a lot of residue may not protect the soil.

The most effective protective vegetative cover consists of a cover crop with an adequate network of living windbreaks in combination with good tillage, residue management and crop selection.

Effects of Wind Erosion

- ✓ Wind erosion damages crops through sandblasting of young seedlings or transplants, burial of plants or seed, and exposure of seed.
- ✓ Crops are ruined, resulting in costly delays and making reseeding necessary.
- ✓ Plants damaged by sandblasting are vulnerable to the entry of disease with a resulting decrease in yield, loss of quality and market value.
- ✓ Also, wind erosion can create adverse operating conditions, preventing timely field activities.
- ✓ Soil drifting is a fertility-depleting process that can lead to poor crop growth and yield reductions in areas of fields where wind erosion is a recurring problem.
- ✓ Continual drifting of an area gradually causes a textural change in the soil.
- ✓ Loss of fine sand, silt, clay and organic particles from sandy soils serves to lower the moisture-holding capacity of the soil.
- ✓ The removal of wind-blown soils from fence rows, constructed drainage channels and roads, and from around buildings is a costly process.
- ✓ Soil nutrients and surface-applied chemicals can be carried along with the soil particles, contributing to off-site impacts.
- ✓ In addition, blowing dust can affect human health and create public safety hazards.

Tillage Erosion

Tillage erosion is the redistribution of soil through the action of tillage and gravity (Fig.8). It results in the progressive down-slope movement of soil, causing severe soil loss on upper-slope positions and accumulation in lower-slope positions. This form of erosion is a major delivery mechanism for water erosion. Tillage action moves soil to convergent areas of a field where surface water runoff concentrates. Also, exposed subsoil is highly erodible to the forces of water and wind. Tillage erosion has the greatest potential for the "on-site" movement of soil and in many cases can cause more erosion than water or wind.

Type of Tillage Equipment

Tillage equipment that lifts and carries will tend to move more soil. As an example, a chisel plow leaves far more crop residue on the soil surface than the conventional mouldboardplough but it can move as much soil as the mouldboardplough and move it to a greater distance. Using implements that do not move very much soil will help minimize the effects of tillage erosion.

Direction

Tillage implements like a plough or disc throw soil either up or down slope, depending on the direction of tillage. Typically, more soil is moved while tilling in the down-slope direction than while tilling in the up-slope direction.

Speed and Depth

The speed and depth of tillage operations will influence the amount of soil moved. Deep tillage disturbs more soil, while increased speed moves soil further.

Number of Passes

Reducing the number of passes of tillage equipment reduces the movement of soil. It also leaves more crop residue on the soil surface and reduces pulverization of the soil aggregates, both of which can help resist water and wind erosion.

Effects of Tillage Erosion

- ❖ Tillage erosion impacts crop development and yield.
- ❖ Crop growth on shoulder slopes and knolls is slow and stunted due to poor soil structure and loss of organic matter and is more susceptible to stress under adverse conditions.
- ❖ Changes in soil structure and texture can increase the erodibility of the soil and expose the soil to further erosion by the forces of water and wind.
- ❖ In extreme cases, tillage erosion includes the movement of subsurface soil.
- ❖ Subsoil that has been moved from upper-slope positions to lower-slope positions can bury the productive topsoil in the lower-slope areas, further impacting crop development and yield.

Research related to tillage-eroded fields has shown soil loss of as much as 2 m of depth on upper-slope positions and yield declines of up to 40% in corn. Remediation for extreme cases involves the relocation of displaced soils to the upper-slope positions.

Conservation Measures

The adoption of various soil conservation measures reduces soil erosion by water, wind and tillage. Tillage and cropping practices, as well as land management practices, directly affect the overall soil erosion problem and solutions on a farm.

- ❖ When crop rotations or changing tillage practices are not enough to control erosion on a field, a combination of approaches or more extreme measures might be necessary.
- ❖ For example, contour plowing, strip-cropping or terracing may be considered.
- ❖ Bio fencing to arrest the wind speed.

- ❖ Vettiver planting to bind the soil particles and also to reduce particle movement.
- ❖ In more serious cases where concentrated runoff occurs, it is necessary to include structural controls as part of the overall solution grassed waterways, drop pipe and grade control structures, rock chutes, and water and sediment control basins.

Universal Soil Loss Equation

The Universal Soil Loss Equation (USLE) predicts the long-term average annual rate of erosion on a field slope based on rainfall pattern, soil type, topography, crop system and management practices. USLE only predicts the amount of soil loss that results from sheet or rill erosion on a single slope and does not account for additional soil losses that might occur from gully, wind or tillage erosion. This erosion model was created for use in selected cropping and management systems, but is also applicable to non-agricultural conditions such as construction sites. The USLE can be used to compare soil losses from a particular field with a specific crop and management system to "tolerable soil loss" rates. Alternative management and crop systems may also be evaluated to determine the adequacy of conservation measures in farm planning.

Five major factors are used to calculate the soil loss for a given site. Each factor is the numerical estimate of a specific condition that affects the severity of soil erosion at a particular location. The erosion values reflected by these factors can vary considerably due to varying weather conditions. Therefore, the values obtained from the USLE more accurately represent long-term averages.

Universal Soil Loss Equation (USLE)

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

A represents the potential long-term average annual soil loss in tonnes per hectare (tons per acre) per year.

R is the rainfall and runoff factor by geographic location, it can be taken from table. The greater the intensity and duration of the rain storm, the higher the erosion potential

K is the soil erodibility factor. It is the average soil loss in tonnes/hectare (tons/acre) for a particular soil in cultivated, continuous fallow with an arbitrarily selected slope length of 22.13 m (72.6 ft) and slope steepness of 9%. 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 is the slope length-gradient factor. The LS factor represents a ratio of soil loss under given conditions to that at a site with the "standard" slope steepness of 9% and slope length of 22.13 m (72.6 ft). The steeper and longer the slope, the higher the risk for erosion.

C is the crop/vegetation and 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 C Factor can be determined by selecting the crop type and tillage method (respectively) that corresponds to the field and then multiplying these factors together.

P is the support practice factor. It reflects the effects of practices that will reduce the amount and rate of the water runoff and thus reduce the amount of erosion. The P factor represents the ratio of soil loss by a support practice to that of straight-row farming up and down the slope. The most commonly used supporting cropland practices are cross-slope cultivation, contour farming and strip cropping.

Summary

Soil erosion remains a key challenge for agriculture. However, because of continued advances in soil management and crop production technology that have maintained or increased yields in spite of soil erosion, others are not aware of the increasing problem on farmland. Awareness usually occurs only when property is damaged and productive areas of soil are lost.

The increase in extreme weather events predicted with climate change will magnify the existing water and wind erosion situations and create new areas of concern. Farmland must be protected as much as possible, with special attention to higher risk situations that leave the soil vulnerable to erosion.

Causes, reclamation and management of mined and ravine lands

Mined out lands

Mining is an unique industry and it is site specific, has to be planned around where the mineral deposit exists, it cause damage to land, soil, water, vegetation, habitation and land surface get disturbed.

Permanent loss of the land (i.e, Natural ores depletion). Next to agriculture, mining industry is prominent.

- Minerals and mineral based products are integral part of economic and social development of the society
- Though it has a negative effect it is inevitable.

Tamil Nadu:

- Neyveli coal lignite
- Salem iron ore
- Madurai – granite
- Thoothukudi – $CaCO_3$ (cement ore)
- Namakkal – platinum ore
- Sand mining – Trichy, Nagapattinam

Eg: minerals

- Petroleum, Natural gas, manganite, iron ore, gypsum, graphite ,silica, sand , bauxite , gem stone.
- Thiruvannamalai – platinum
- Tirumangarathur – platinum
- Goa, Karnataka, Oddissa – iron ore etc.

Reclamation:

- Land filling / rain water harvest / pisciculture
- Tree planting, erosion control measures
- Stabilization of slopes
- Developing alternate land use/ land filling
- Filled area is levelled and covered with organic matter, crop residue

Definition of gully and ravine

Gully erosion

The gullies are linear incision channels of at least 0.3m width and 0.3m depth. Gully erosion creates either V- or U-shaped channels. Gullies are primarily formed by concentrated runoff converging towards lower points of the watershed. Thus, erosion occurring in these channels is known as concentrated flow erosion. Undulating fields cause runoff to concentrate in natural swales as runoff moves down slope in narrow paths in the form of channelized flow. A **swale** is a low tract of land, which is moist or marshy. It may be naturally occurring landscape or human-created. Continued gully erosion removes entire soil profiles in localized segments of the field. As gullies grow, more sediment is transported.

Gully erosion is the advance stage of channel or rill erosion in which the size of rill is enlarged which cannot be smoothened by ordinary tillage implements. Process of gully formation follows sheet and rill erosion. Gully erosion produces channels larger than rills. These channels carry water during and immediately after rains. Gullies may also be developed from rills which are unchecked. Development of gullies also takes place by ruts or tracks formed by the movement of machineries, down the slope.

Fig.1. Gully erosion

(Source: http://www.permacultureplants.net/NgareNdare/NgareNdareIntro.htm)

The rate of gully erosion depends primarily on the runoff-producing characteristics of the watershed, the drainage area, soil characteristics, the alignment, size and shape of the gully, and the slope in the channel.

Stages of gully erosion

The four recognized stages of gully development are:

Stage1: In this stage channel erosion and deepening of the gully bed takes place. It is initiation stage and this stage normally proceeds slowly.

Stage 2: It is the development stage, in which due to runoff from up stream portion of the gully head, the size of gully width and depth is enlarged.

Stage 3: This is the healing stage, in which vegetation starts to grow in the channel. During this stage, there is no appreciable erosion in any form, from the gully section.

Stage 4: This is the last stage of gully development, in which gully is fully stabilized. No further development of gully occurs, unless healing process is disturbed. The channel has a stable gradient and gully walls gain a stable slope and vegetation begins to grow in abundance to cover the soil surface.

Classification of Gully: Gullies are classified as:

1.Based on Shape of the Gully: Gullies are classified into the following two shapes:

a.U Shaped

Generally found in the alluvial plains, where surface and sub-surface soils are easily erodible. The specific features of these gullies are:

- U-shaped cross-section
- Longitudinal slope of gully bottom is usually parallel to the slope of the land, through which the gully passes.
- The runoff contributing catchment area being large, the discharge passing through these gullies is large.
- The velocity of flow is relatively lower than that of the V-shaped gullies.
- U-shaped gullies continue to grow headward.
- The lateral spacing of these gullies is large.
- Active erosion in these gullies, is from side banks and the gully head as a result of undercutting at these at the base of vertical cut.
- These gullies do not grow deeper, but becomes wider and longer, progressing headward.

b. V –Shaped

- The V-shaped gullies are often developed where the sub-soils are tough enough to resist the rapid cutting of soil by the runoff. As resistance to erosion increases with depth, the width of cut decreases accordingly and results in development of V-shaped gully.
- V-shaped gullies have the following major features:
- V-shaped cross-section
- Generally appear on sloping field.
- Longitudinal gradient of channel is greater than the land slope.
- Catchment area contributing the runoff is small.
- The lateral spacing between these gullies is small.
- The amount of discharge, passing through these gullies is small but has higher velocity.
- The V-gullies make the contour cultivation difficult.
- V-shaped gullies often develop from rill erosion, when water is concentrated from several rills into one.
- The shape of the gully depends upon the soil characteristics, climatic conditions, age of the gully and the types of erosion.

2. **Based on State of the Gully**

Gullies can be classified into the following types:

Active Gullies: active gullies are those, whose dimensions are enlarged with time. The size enlargement is based on the soil characteristics, land use and volume of runoff passing through the gully. The gullies found in plain area are active.

Inactive Gullies: dimension do not appreciably change with time. These gullies found in rocky areas, are inactive because rocks are resistant to erosion by the runoff flow.

3. **Based on Dimensions of Gully**

Gullies are classified based on their size as:

a.Small Gullies, can be easily crossed by farm implements and can also be smoothened by ploughing and other land development operations and by stabilizing them through vegetation.

b.Medium Gullies, cannot be easily crossed by farm implements. They can be controlled by terracing or ploughing operations. In medium gullies, the sides are stabilized by promoting vegetative growth on them.

c.Large Gullies: these gullies can not be reclaimed. For controlling these tree plantation is done as an effective measure.

Causes of Gully Erosion

Natural Causes: Rainfall, runoff, flood, soil properties, vegetative cover

Anthropogenic Causes

- ❖ Creating land surface without vegetation
- ❖ Road construction
- ❖ Adoption of faulty tillage practice
- ❖ Overgrazing and other form of biotic pressure on the vegetative cover, existing on the land surface
- ❖ Absence of vegetative cover
- ❖ Improper construction of water channels, roads, rail lines, cattle trails etc.

Effect of gully erosion:

- o Loss of soil productivity
- o Adverse effect on other water resource facilities
- o Loss of reservoir storage capacity
- o Flood impacts
- o Recreational impacts
- o Deterioration of water quality

Control Measures

- ✓ For controlling gully erosion, the following considerations are very important.
- ✓ Improving the catchment area of the gully.
- ✓ Stabilization of gully head.
- ✓ Safely conduct water through the gully, provided that it is not a part of natural drainage system of the area.
- ✓ Adoption of gully control measures to stabilize them.

Gully Control Measures

Control by Vegetation: vegetation provides soil cover and protect the gully against scouring. It also reduces the flow velocity by increasing the hydraulic resistance of the channel section, thereby the scouring and ability of runoff is reduced to a great extent.

Control by Structures: structures are used to control the flow velocity. Structures are of two types:

1.Temporary Structures: temporary structures are constructed to serve the following purposes:

- ❖ To collect sufficient amount of soil on their upstream portion to build up a huge growth of vegetative cover.
- ❖ To check the gully erosion until sufficient vegetation has been established at the critical points of gully.

A.Temporary Structures are:

1.Brushwood dam

- Single row brushwood dam
- Double row brushwood dam

2. Loose rock fill dam
3. Log check dam
4. Netting dam
5. Staggered trenches or bunds
6. Terraces (there are stable permanent terraces also used for crop cultivation)
7. Grassed water ways

B. Permanent structures: These structures are made of permanent materials such as: masonry, reinforced concrete or earth etc.

For the purpose of gully control, the following types of permanent structures are used:

1. Spillway
   a. Drop inlet spillway
   b. Straight drop spillway
   c. Chute spillway
2. Rubble masonry dam
3. Concrete dam
4. Gabions
5. Silt trap dam

Ravine erosion

A ravine is a very narrow, steep sided fissure in the Earth's surface. Ravines are smaller than valleys, but larger than gullies, although a ravine has the potential to develop into a valley, over the course of thousands of years. A ravine is generally a fluvial slope landform of relatively steep (cross-sectional) sides, of the order of twenty to seventy percent in gradient. Ravines may or may not have active streams flowing along the down slope channel which originally formed them. Moreover, often they are characterized by intermittent streams, since their geographic scale and their catchment areas may not be sufficiently large to support a perennial stream.

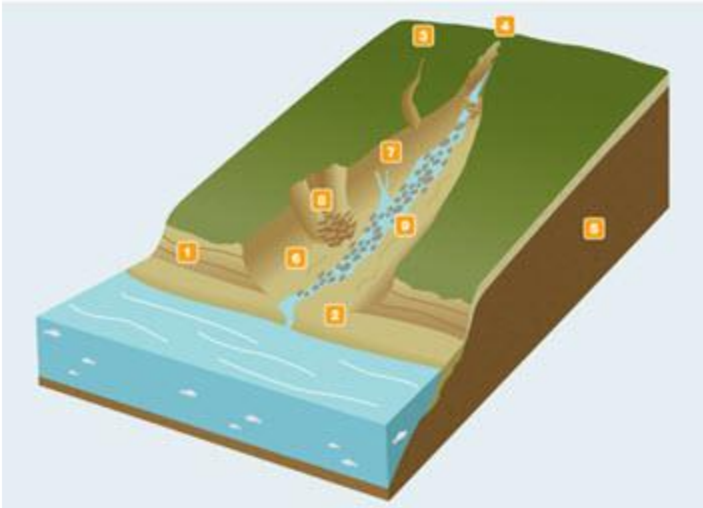


Fig.2. Ravine erosion

(Source: http://wiki.fis-ski.com/images/Ravines.jpg)

Typically, a ravine is formed through the process of erosion and it starts out as the site of a small stream or river. Over time, the water wears a deep groove into the Earth, which attracts water as it drains from other locations, speeding up the erosion process. Eventually, a ravine may lose its stream, or have only intermittent water flow, because of lack of water supply from the catchment. Sometimes, however, a ravine will have a year-round watercourse.

Generation of large quantities of waste water in the urban areas and a generally poor urban drainage promote the formation of ravines. It is common for water to collect in a large mass in urban areas, creating a torrent, because it cannot percolate naturally through the soil to drain away. Because the water eventually finds a path to flow under gravity, it can end up creating a cutting in periods of flooding and heavy rain, and this will develop into a ravine.

Ravines have historically been used for garbage disposal, because of their depth and steep sides. Although this practice is largely discouraged today, ravines still tend to collect garbage, which is carried by the water which periodically pours through them as well as being tossed in by careless litterers. In urban areas, service organizations may designate a day each year to clean up local ravines, canyons, and waterways so that the garbage is not allowed to accumulate for too long.

Depending on the location of a ravine, it may also serve as habitat for local wildlife, especially in regions where wildlife is under pressure due to human habitation. Humans tend to avoid ravines, since they are difficult to navigate, and this allows a variety of creatures to move in and live undisturbed at the site. As a result, ravines are sometimes developed into habitations for birds and other forms of wildlife (http://www.wisegeek.com/what-is-a-ravine.htm)

Lecture 8

Causes, reclamation and management of sand dunes, coastal and seasonally inundated soils

The sand covered terrain spreads over 80 per cent of the Thar desert of Rajasthan area, a large part of which comprises sand dunes. Census 2011 shows that 28 million people live across western Rajasthan in over 12 districts and four agro-climatic zones that have a dominant agrarian land use. Wind erosion and deposition causing sand movement and dust storms are the characteristic features of the Thar. Their severity is felt more in summer and is caused due to high wind speed, sandy terrain, sparse vegetation cover and human activity.

About 0.15 million ha or 72 per cent of the area, is affected by wind erosion or deposition, of which 5,800 sq km is very severely degraded, 25,540 sq km is severely affected, 73,740 sq km is moderately affected and 52,690 sq km is slightly affected.

Problems in sand dunes

- ✓ Unlevelled land due to sand deposits, here and there
- ✓ Problem in cultivation: poor crop growth, sandy texture
- ✓ Highly permeable nature, high infiltration, less nutrients retention
- ✓ Poor soil fertility

Management techniques:

- ❖ Tree planting, erosion control measures
- ❖ Stabilization of slopes
- ❖ Developing alternate land use/ land filling
- ❖ Filled area is levelled and covered with organic matter, crop residue
- ❖ Soil breeding: In batches like, pit cultivation for tree crops
- ❖ Wind control measures: shelter belts/biofencing
- ❖ Nutrient management for pit cultivation: Split application,organic manure addition, foliar nutrition

Case study

Strategies for wind or sand control measures have been targeted for dune covered areas and sandy plains of Rajasthan. There are some known mechanical and chemical methods to stabilise sand dunes. CAZRI's afforestation technique has been quite effective for the Thar. The institute targeted old sand dunes formed some 10,000 years ago and which had stabilised naturally.

Their mobility was as low as 3 to 5 metres per annum. CAZRI's activities include

a) Fencing of dune areas to protect against biotic interferences;

b) Creating micro-wind breaks in parallel stripe or checkerboard patterns by planting locally available brushwood and grass;

c) Afforestation on dune slopes by directly sowing grass seeds and transplanting seeds of indigenous and exotic species;

d) Planting grass slips, seeds of grasses or leguminous creepers on the leeward side of the micro-wind breaks; and

e) Continuous management of dunes till the input cost is recovered.

f). Plantations in checkerboard or parallel stripes restricts sand movement on dune slopes

g). Development of improved variety of crops, identification and development of agro-forestry, agri-horticulture, horti-pastoral and silvi-pastoral systems are helping farmers with better livelihood options.

Leptadenia pyrotechnica (khimp), *Ziziphus nummularia* (pala), *Crotalaria burhia* (sinia) and *Panicum turgidum* (murath) were the species can be planted as brushwood to create micro-wind breaks. *Acacia tortilis, Prosopis* spp, *Acacia senegal*, *Parkinsonia articulata* and *Tamarix articulata* were planted as trees, and *Lasiurus sindicus* and *Cenchrus ciliaris* as grass.

Today, the technique is being used in Rajasthan's desert districts Jaisalmer, Barmer, Bikaner, Jodhpur and Churu. With help from the state forest department, sand dunes over 0.4 million ha have been fixed. In areas that do not have dunes, CAZRI carried out shelterbelt plantation. Vegetative barriers of trees, shrubs and bushes minimise the adverse effects of winds.

Trees like A.*tortilis,* E camal-dulensis, D. *sissoo* and T.*undulata* were planted in some 800 km in Jodhpur, Barmer, Jaisalmer, Churu, Jhunjhunu, Nagaur, Ajmer and Pali districts; 100 km along the railway tracks in Sikar-Loharu, Sikar-Fatehpur and Palsana-Deshnoke sections; and, 250 km in the Indira Gandhi Nahar Project (IGNP) area.

At least 14 per cent higher soil moisture and 70 per cent more grain yield of pearl millet was recorded on the lee side of the shelterbelt. But shelterbelts are not popular among farmers because in many cases trees hinder agricultural operations and inter-field movements. Nowadays, planting trees on field bunds across the direction of the wind is encouraged.

Plantations in checkerboard or parallel stripes have restricted sand movement on dune slopes.

In IGNP area, such systems along with increased vegetation cover have influenced the micro-climate, shows research done by the Indian Space Research Organisation, or ISRO, in collaboration with CAZRI in 2015.

CAZRI has developed Integrated Farming System (IFS) on 7 ha which has the capacity to generate employment of more than 845 mandays and provide up to Rs 2.5 lakh per annual returns. The farming community's rising livestock population and dependency on them is the key to IFS. Crop production technologies such as farm yard manure management, optimum tillage, inter-cropping, rain-water harvesting and use of pressurised irrigation have helped in sustainable crop production.

The use of techniques for efficient rainwater management, the introduction of new arid fruit and fodder crops, forest trees suitable for arid region, the management of plant diseases and insect pests, and enhancing gum exudation from trees have increased the scope for better crop prices to farmers.

Coastal and seasonally inundated soils

Soils flooded during the formation of reservoirs are relatively rich in nutrients, phytoplanktonic productivity is high. Although nutrients tend to decline during several years following flooding, usually nutrient loading from the drainage basin is adequate to maintain moderate-to-high primary production.

Fluctuating water levels can alter severely the habitat and survival of invertebrates of reservoirs. Macrovegetation, particularly submersed vegetation, does not survive well under marked fluctuations of water level. As a result, major habitat for invertebrates is almost completely eliminated from many reservoirs. Changes in water level can also expose sediments to freezing conditions, and sandy sediments are more susceptible to freezing in winter than are organic-rich and stony detrital sediments. Such freezing of the sediments can eliminate over three-quarters of the invertebrate fauna from the exposed sediments.

Sediment accumulation increases markedly from the riverine erosive habitat to greatly enlarged (10- to 20-fold) depositional, organic-rich sediment that is readily colonized by highly productive aquatic macrophytes and periphyton. Increased nutrient loads are leached from the inundated surrounding land, in a manner similar to the well-known increased nutrient loading and productivity that follows periodic drawdown and desiccation of sediments of reservoirs.

Effects of Flooding

- ❖ The poor soil aeration in flooded soils is accompanied by a number of soil and plant changes that adversely influence crop growth and drastically affects the yield.
- ❖ Alterations in soil structure include breakdown of aggregates, deflocculation of clay, and destruction of cementing agents.
- ❖ Flooding also reduces the soil redox potential, increases the pH of acid soils (largely because of a change of Fe^{3+} to Fe^{2+}), and decreases the pH of alkaline soils (mainly because of CO_2 accumulation which eventually forms H_2CO_3).

❖ Soil inundation also decreases the rate of decomposition of organic matter sometimes by as much as half. Whereas the organic matter in unflooded soil is decomposed by a variety of aerobic organisms (including bacteria, fungi, and soil fauna), decomposition in flooded soil is accomplished only by anaerobic bacteria.

❖ A variety of toxic compounds accumulate in flooded soils. Some of these (e.g., ethanol, acetaldehyde, and cyanogenic compounds) are produced by the roots. Compounds produced by anaerobic bacteria in flooded soil include gases (N_2, CO_2, methane, and hydrogen), hydrocarbons, alcohols, carbonyls, volatile fatty acids, non volatile acids, phenolic acids, and volatile S compounds.

❖ Flooding injury has been linked to altered respiration, with several possible causes of injury. Some investigators claimed that the end products of glycolysis (e.g., CO_2, ethanol, and/or lactic acid) accumulated to toxic levels in flooded tissues. Still another view is that energy consumption through utilization of ATP exceeds the capacity of glycolysis to synthesize ATP. Hence, the energy charge of flooded tissues decreases to levels that do not maintain metabolic control.

❖ In some plants the harmful effects of flooding are linked to blocking of water transport. Bubbling of CO_2 through a nutrient solution in which Euphorbia roots were immersed induced wilting and stem degradation. Wilting was attributed to reduced water transport associated with occlusion of vessels by protoplasam from collapsed adjacent parenchyma cells.

Management strategies

- ✓ Proper drainage
- ✓ Correction of soil pH: ie. Application of lime
- ✓ Growing tolerant crops
- ✓ Correction of nutrient deficiencies and toxicities especially Fe and Al toxicity

Lecture 10

Cause, reclamation and management of Saline and Saline Sodic Soils

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Saline soil

The process by which the saline soil is formed is called Salinization. Saline soils occur mostly in arid or semi-arid regions. Saline soils are practically non-existent in humid regions except when the soil has been subjected to sea water in river deltas and low lying lands near the sea. Soils are said to be **saline** if they contain an excess of soluble salts and **sodic or alkaline** if they contain an excess of sodium. Soils are said to be **saline-sodic** or **saline-alkali** if they contain appreciable amounts of both soluble salts and sodium.

Saline alkali soils

The US Salinity Laboratory Staff (1954) have defined saline-alkali soils as the soils with EC more than 4 dSm^{-1} at 25ºC and ESP more than 15. These soils have been formed as a result of both salinization and alkalization processes. When high ECe is due to high concentration of chlorides and sulphates of sodium, the pH of these soils seldom exceeds 8.5. Clay particles in these soils remain flocculated. But when EC is high because of soluble carbonates of sodium, the pH of these soils can be much higher than 8.5. With leaching of soluble salts of chlorides and sulphates of sodium, these soils behave like alkali soils.

Distribution of salt affected soils

Based on FAO / UNESCO soil map, about 952 million hectares of land in the world is under varying degrees of deterioration due to excessive accumulation of salts in the soil profile. In India about 7421000 ha are affected by salinity and sodicity.

Nature of soluble salts in saline soils

Soluble salts refer to those inorganic chemicals that are more soluble than gypsum ($CaSO_4 \cdot 2H_2O$), which has a solubility of 0.241 g per 100 ml of water at 0^oC. Common table salt (NaCl) has a solubility nearly 150 times greater than gypsum. Most soluble salts in saline soils are composed of the cations sodium (Na^+), calcium (Ca^{++}), Magnesium (Mg^{++}) and the anions chloride (Cl^-), sulphate ($SO4^{2-}$) and carbonate (CO_3^{2-}) also occur, as do many other ions. Boron may also be present in saline soils.

Characterization of saline soil

(i) Soluble salt concentration in the soil solution

In saline soils, the soluble salt concentration in the soil solution is very high and as a result, the osmotic pressure of the soil solution is also very high. Plant growth is affected due to wilting and nutrient deficiency. Salt content of more than 0.1 % is injurious to plant growth.

(ii) Osmotic pressure

Osmotic pressure of the soil solution is closely related to the rate of water uptake and the growth of plants in saline soils. It should be assessed of field capacity soil moisture regimes.

$$\text{Osmotic pressure} = 0.36 \times EC\ (dSm^{-1})$$

(iii) Electrical conductivity of the soil saturation extract

Measurement of EC of the soil saturation extract is also essential for the assessment of the saline soil for the plant growth and is expressed as dSm^{-1}.

< 2 – Salinity effects mostly negligible

2-4 – Yields of very sensitive crops may be restricted

4 –8 - Yields of many crops restricted

8-16 - Only tolerant crops yield satisfactorily

> 16 - Only a few tolerant crops yield satisfactorily

(iv) Concentration of water soluble boron

The critical limits of boron concentration for the plant growth is

Boron concentration

< 0.7 - Crops can grow (safe)

0.7 -1.5 - Marginal

> 1.5 - Unsafe

(v) Soil texture

A sandy soil with 0.1 % salt would be saline enough to injure the growth of common crops, while a clayey soil with the same amount of salt may be just a normal soil in which the yields of even sensitive crops would not be affected.

Relationship between EC and TSS

For soil solutions with EC ranging from 0.1 to 5 dSm^{-1},

- Total dissolved solids (mg / L) is EC (dSm^{-1}) x 640
- Sum of soluble cations or anions = EC (dSm^{-1}) x 10

For soil solutions with EC ranging from 3 to 30 dSm^{-1}

OP (bars) = EC (dSm^{-1}) x (-0.36)

Where OP is the osmotic potential or the negative of osmotic pressure of solution which directly measures the effect of salinity on plant growth.

Common sources of salts

1. Rocks and minerals

The salts primary originate as a result of hydrolysis, hydration, carbonation and oxidation – reduction of the easily weatherable minerals inherited from the parent materials viz., halite, gypsum, sulphides, calcite, dolomite, apatite, amphiboles, olivine, feldspars and primary layer silicates.

2. Arid and semi-arid climate

Salt affected soils are mostly formed in arid and semi-arid regions where low rainfall and high evaporation prevails. The low rainfall or precipitation in these regions is not sufficient to leach out the soluble weathered products and hence the salts accumulate in the soil.

3. Ground water

Groundwater contains large amounts of water-soluble slats which depends upon the nature and properties of the geological material with which water remains in contact. Where water table and evapotranspiration is high, salts move along with water upward through the capillary activity and the salts accumulate on the soil surface in the form of crystals.

4. Ocean or sea water

Ocean water containing 42 x 10^{15} tonnes of dissolved salts (of which 85.6 % is NaCl) is a significant direct source of salts in the soils of the low-lying coastal areas. **5. Irrigation water**

The application of irrigation water without proper management (i.e., lack of drainage and leaching facilities) increases the water table and surface salt content in the soil. Salts can also accumulate due to flooding by waters from mining shafts or by industrial effluents.

6. Atmospheric accession of salts

Atmospheric accession of salts in the soil of inland areas can occur as a result of falling dried droplets of ocean water from the atmosphere (aerosol) along with rain water or as dry salt-dust.

7. Salts blown by wind

In arid regions near the sea, appreciable amount of salts are blown by wind year after year and get deposited on the surface soil. Due to low rainfall, the deposited salts are not washed back to the sea or leached to the lower soil horizon and thereby develops salinity in the soil. The salinity of Rajasthan are mostly developed through this source.

8. Excessive use of basic fertilizers

Use of basic fertilizers like sodium nitrate, basic slag etc., may develop soil alkalinity.

9. Marine rocks and deposits

Marine rocks and evaporites developed with the upliftment of many parts of the continents from the sea / ocean are also important sources of salts in the soil. E.g. Localised concentration of salts along the lower Himalayas and the Shiwaliks, and a large part of the present Indo-Gangetic Plains, Western Rajasthan upto the Aravallis and Kutch in India, which may be attributed to the upliftment of these ranges during the geological periods from under the sea.

10. Salt springs

Salt springs emerging from many regions can also add considerable quantities of salts to the soil, because volcanic gases and waters from the interior of the earth contain large quantities of chlorides.

Problems of salt affected soils

- Soils are usually barren but potentially productive
- Wilting coefficient of saline soil is very high
- Amount of variable soil moisture is low
- Excessive salts in the soil solution increases the osmotic pressure of soil solution in comparison to cell sap. Thus, it is more difficult for roots to extract moisture. During a dry period, salt in soil solution may be so concentrated as to kill the plants by pulling water from them (exosmosis). Due to high salt concentration, plants have to spend more energy to absorb water and to exclude salt from metabolically active sites
- Salt toxicity – When the concentration of soluble salts increases to a high level, then it produces toxic effect directly to plants such as root injury, inhibition of seed germination etc.,

Effects of salts on plant growth

The growth of plants is suppressed when the salt concentration is low, but may entirely prevented if it is too high. Seeds fail to germinate, plants die at early stages, show stunted growth and foliage becomes characteristically bluish-green. The entire field may look barren. Plant growth is affected due to changes in proportion of exchangeable cations, soil reaction, ionic balance in plants, physical properties of the soil and osmotic and specific ion toxicity effects.

(i) Osmotic stress

Under osmotic stress, plant cells continue to divide, but do not elongate, resulting in an increase in the number of cells per unit areas which accounts of the typically dark bluish green colour of the foliage.

(ii) Toxic effect of some ion

The ions which cause specific toxicities in plants are chlorides, sulphates, bicarbonates, sodium, magnesium and boron. Excessive intrusion of these ions in the roots and their movement in the plants through transpiration stream may lead to necrosis, burning of leaf tips and margins and eventually death. Excessive alkalinity causes caustic effect on the roots of plants.

(iii) Nutritional imbalances

Salinity induced cationic and nutritional imbalances occur within the plants. Examples include excessive absorption of Na^{+} ions leads to decrease in the absorption of Ca^{2+}, Mg^{2+} and K^{+} ions. High concentration of bicarbonates in soil solution can induce iron chlorosis and micronutrient deficiencies. Increase in soil salinity and alkalinity can also adversely affect soil biology, mineralization of organic matter and transformations of applied fertilizer nutrients.

Management of saline soils

1. **Physical amelioration**

The commonly followed physical methods for amelioration of salt affected soils include deep ploughing, sub-soiling, sanding, profile inversion and scrapping. Reclamation by this method cannot be achieved on a permanent basis.

2. Hydrotechnical amelioration

Reclamation of salt affected soils by this method involves the removal of salts from the saline soil through the process of leaching with water and drainage. Ponding continuously with sufficient depth of good quality water on the surface of the soil and ensuring downward movement of water is the most traditional method for leaching of salts. Land leveling is an important step before initiation of the leaching process. The passage of 1 metre leaching water per metre of soil depth under continuous ponded conditions normally removes approximately 80 % of soluble salts from the soil. Basin furrow method of leaching is considered to be more efficient.

Leaching requirement (LR) – Leaching requirement may be defined as the fraction of irrigation water that must be leached through the root zone to control soil salinity at any specified level.

The leaching requirement is the ratio of the equivalent depth of the drainage water and may be expressed as a fraction or as percent.

$$LR = \frac{D_{dw} \times 100}{D_{iw}} = \frac{EC_{iw} \times 100}{EC_{dw}}$$

LR - Leaching requirement expressed in percentage

D_{dw} - Depth of drainage water in inches

D_{iw} - Depth of irrigation water in inches

EC_{iw} - Electrical conductivity of the irrigation water in dSm^{-1}

EC_{dw} – Electrical conductivity of the drainage water in dSm^{-1}

Drainage system

The need for the development of either surface or sub-surface drains has to be worked out on the basis of the nature of the soil, ground water conditions, climate, cropping pattern, economic considerations etc.,

3. Cultivation of salt tolerant crops

Threshold salinity		
4 -8 dSm^{-1}	**2 – 4 dSm^{-1}**	**< 2 dSm^{-1}**
Date palm	Alfalfa	Turnip
Cowpea	Rice	Onion
Soybean	Tomato	Mung bean
Wheat	Cucumber	Berseem
Sorghum	Groundnut	Sugarcane
Sugarbeet		Maize
Cotton		Citrus
Barley		Potato
Cluster bean		Cabbage
		Celery

Important characteristics of salt affected soils

Characteristics	Saline soil	Non-saline alkali soil	Saline- alkali soil	Degraded alkali soil
Content in soil	Excess soluble salts of sodium	Absence of soluble salt and presence of excess exchangeable sodium on the soil complex	Soils are both saline and non-saline alkali soil. It is a stage of transition. Soil contains Na-clay as well as soluble salts	Hydrogen (H^+) ions in the upper layer and sodium (Na^+) in the lower layer
Exchangeable Ca / Na	Exchangeable Ca	Exchangeable Na	--	--
Colour	White	Black	--	Black in lower layer
Dominant salts	Sulphates, chlorides and nitrates of sodium	Sodium carbonate	--	Sodium carbonate in lower layer
Sodium adsorption ratio (SAR)	Less than 13	More than 13	More than 13	Less than 13 in the surface and greater than 13 in the lower horizon
Exchangeable sodium percentage (ESP)	Less than 15 of total CEC	More than 15 of total CEC	More than 15 of total CEC	Usually more than 15 of total CEC
Soil pH	Less than 8.5	8.5-10.0	Less than 8.5	pH about 6.0 in the surface soil and 8.5 in the lower layer constituting the

				main soil body
Physical condition of the soil	Flocculated condition, permeable to water and air. Soil structure optimum	Deflocculated condition, permeability to water and air is poor. Very poor soil structure	Flocculated or deflocculated depending upon the presence of sodium salts and Na-clay	Compact, low infiltration and permeability. Develops columnar structure
Morphological character	White crust on the soil surface	Silica gels and humus produces hard pan in the sub-soil	----	----
Organic matter content	Less than normal soils	Very low. These soils are almost barren (Usar)	Variable	Low
Total soluble salt content	More than 0.1 % High osmotic pressure to prevent absorption of moisture and plant nutrients from such soils.	Less than 0.1 %	More than 0.1 %	Less than 0.1 %
Soluble boron	Causes problem in this soil Safe: <0.7 ppm Marginal :0.7 – 1.5 ppm Unsafe: > 1.5 ppm			
Electrical conductivity of the saturation extract	> 4 dSm^{-1}	< 4 dSm^{-1}	> 4 dSm^{-1}	< 4 dSm^{-1}

Lecture 11

Cause reclamation and management of Sodic Soils

Introduction

The chief characteristic of sodic soils from the agricultural stand point is that they contain sufficient exchangeable sodium to adversely affect the growth of most crop plants. For the purpose of definition, sodic soils are those which have an **exchangeable sodium percentage (ESP) of more than 15**. Excess exchangeable sodium has an adverse effect on the physical and nutritional properties of the soil, with consequent reduction in crop growth, significantly or entirely. The soils lack appreciable quantities of neutral soluble salts but contain measurable to appreciable quantities of salts capable of alkaline hydrolysis, e.g. sodium carbonate. The **electrical conductivity** of saturation soil extracts is, therefore, likely to be variable **but are often less than 4 dS/m at 25 °C**. The pH of saturated soil pastes is 8.2 or more and in extreme cases may be above 10.5. Dispersed and dissolved organic matter present in the soil solution of highly sodic soils may be deposited on the soil surface by evaporation causing a dark surface which is why these soils have also been termed as black sodic soils.

Under field conditions after an irrigation or rainfall, sodic soils typically have convex surfaces. The soil a few centimetres below the surface may be saturated with water while at the same time the surface is dry and hard. Upon dehydration cracks 1-2 cm across and several centimetres deep form and close when wetted. The cracks, generally, appear at the same place on the surface each time the soil dries unless it has been disturbed mechanically.

The principal cause of alkaline reaction of soils is the hydrolysis of either the exchangeable cations or of such salts as $CaCO_3$, $MgCO_3$, Na_3CO_3, etc. Hydrolysis of the exchangeable cations takes place according to the following reactions

$$\text{clay micelle}\,^{Na}_{Na} + H_2O \Leftrightarrow \text{clay micelle}\,^{Na}_{H} + Na^+ + OH^-$$

In this reaction H^+ is inactivated by exchange adsorption in place of Na^+. The displaced Na does not combine with, or inactivate OH^- ions which results in an increase in the OH^- ion concentration and increased soil pH. The extent to which exchangeable cations hydrolyse depends on their ability to compete with H^+ ions for exchange sites. Ions such as Na^+ are unable to compete as strongly as the more tightly held ions such as Ca^{2+} and Mg^{2+}. For this reason exchangeable Na^{+2} and K^{+2} are hydrolysed to a much greater extent and produce a higher pH than do exchangeable Ca^{2+} or Mg^{2+}. Hydrolysis of exchangeable Ca^{2+} and Mg^{2+} ions, in fact, is so limited that it results in a soil having only by a mildly alkaline reaction. Hydrolysis of compounds like $CaCO_3$, and $MgCO_3$, takes place according to the reaction:

$$CaCO_3 + 2H_2O \Leftrightarrow Ca^{2+} + 2\,OH^- + H_2CO_3$$

Causes and Mechanisms of Soil Sodification

Sodium salts predominate, soils tend to become alkaline in reaction and develop sodicity. Saline soils with good drainage lose a substantial portion of soluble salts resulting in a high Na^+: Ca^{2+} ratio after leaching or rainfall. Subsequently, sodium clays hydrolyze to form free sodium hydroxide causing deflocculation of the colloidal particles followed by clay movements to lower depths and formation of a hard clay pan. The factors responsible for sodicity development and found that specific topographic conditions, weathering of rocks, anaerobic reduction of sulphate ions and irrigation with carbonates (CO_3^{2-}) & bicarbonates (HCO_3^-) rich groundwater induces excessive Na^+ accumulation on the soil exchange complex (SEC). Various causes of sodification may broadly be categorized into natural and anthropogenic factors.

Natural causes

High intensity rainfall in a relatively short duration causes repeated flooding of low lying areas and causes depressions subjecting the soils therein to rapid cycles of wetting and drying favourable to the release and dissociation of alkali salts leading to Ca^{2+} displacement, Na^+ saturation and high pH (≥8.4).

Anthropogenic causes

- In addition to natural factors, anthropogenic activities also contribute to soil sodification; often at an accelerated rate. Intensive irrigation with marginal quality water is the major human action responsible for sodicity development in the cultivated soils.
- Aquifers pumping sodic water are found in many parts of north-western India.
- In the absence of reliable fresh water supplies, farmers are compelled to irrigate their crops with such water putting the soils at risk of sodification.

Sodic Soil – Characteristics, Gypsum Requirement and Management

Exchangeable sodium percentage

Sodium saturation in the soil is expressed as exchangeable sodium percentage (ESP) and as sodium adsorption ratio (SAR) in the soil solution, because of their significance in deteriorating physico chemical properties of the soil and adversely affecting the growth of plants.

$$ESP = 100 \text{ (Exchangeable } Na^+ \text{ ions) / (CEC)}$$

(all cations and CEC in C mol (P^+) / kg soil)

The value of SAR i.e. the relative proportion of Na^+ ions with respect to Ca^{2+}, Mg^{2+} ions in the soil solution as calculated by the Equation

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

ESP = 100 (ESR) / (1+ESR), where ESR is the Exchangeable Sodium Ratio

Alkali soils

Soils have sufficient sodium saturation and alkalinity to adversely affect plant growth and crop productivity. Carbonates (CO_3^{2-} + HCO_3^-) of sodium are the dominant salts. The concentration of neutral salts (Cl^- and SO_4^{2-}) is much lower. Sparingly soluble gypsum, which may be present in many saline soils, is nearly absent in alkali soils. Alkali soils are characterized by pH more than 8.5, ESP more than 15 and EC lower than 4 dSm^{-1} at 25^oC.

Black alkali soils

In alkali soil, because of high pH and Na_2CO_3 the finally decomposed organic matter is dissolved along with the water that imparts a dark black or brown colour to the soil.

Effects of alkali soils

(i) Dispersion of soil colloids

Under alkali conditions, the damage is not due to salt concentration. The sodium ion adsorbed by clay colloids causes deflocculation and dispersion of clay which results in a loss of desirable soil structure and helps for the development of compact soil.

(ii) Other physical properties

Due to dispersion and compactness of soil, aeration, hydraulic conductivity, drainage and microbial activity are reduced.

(iii) Caustic influence

It is due to the high sodicity caused by sodium carbonate and sodium biacarbonate

(iv) Concentration of hydroxyl ion

High hydroxyl ion has a direct detrimental effect on plants. Damage from hydroxyl ions occurs at pH 10.5 or higher.

(v) Specific ion effect

The presence of excess sodium may induce deficiencies of cations like calcium and magnesium due to exclusion of calcium and magnesium from the adsorption sites.

Physical amelioration

Profile inversion can be adopted only under conditions where surface soil is good but the soil below some depth is sodic, saline or has undesirable characteristics. This is a very cumbersome method and is generally not followed by farmers.

Chemical amelioration

Alkali / sodic soils contain Na_2CO_3 and $NaHCO_3$, which upon hydrolysis produce alkalinity. The common amendments used for reclamation of alkali soils is

Amendment	Soil Conditions
Gypsum	Saline and alkali soils having pH upto 9.0
Sulphur, Iron Sulphate, Iron pyrite	Saline and alkali soils having pH from 8.0 -9.0

The chemical amendments can be broadly grouped into

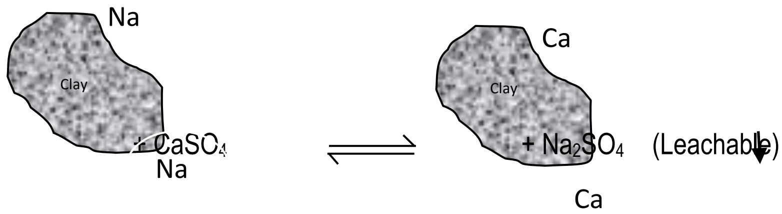
(i) Soluble sources of calcium – Gypsum, Calcium chloride, Phosphogypsum
(ii) Sparingly soluble calcium salts – Calcite
(iii) Acids or acid – formers – Sulphur, Sulphuric acid, Sulphates of iron and aluminium, pyrites, lime-sulphur.

Chemical Reactions involving reclamation of alkali soils

(i) Gypsum ($CaSO_4.2H_2O$)

When gypsum is applied to sodic soils, loss of exchangeable sodium occurs and calcium takes the place of sodium on the exchange complex.

$$Na_2CO_3 + CaSO_4 \rightleftharpoons CaCO_3 + Na_2SO_4 \quad \text{(Leachable)}$$



(ii) Sulphur

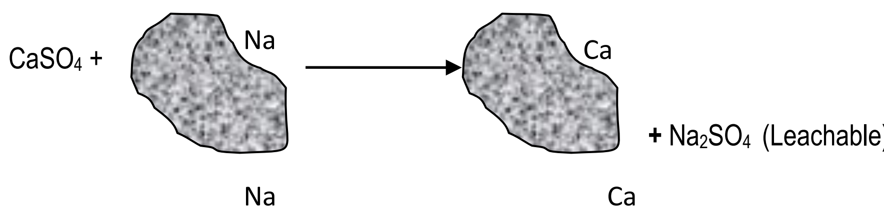
$2S + 3O_2 \longrightarrow 2SO_3$ (By the action of sulphur oxidizing bacteria)

$SO_3 + H_2O \longrightarrow H_2SO_4$

$H_2SO_4 + Na_2CO_3 \longrightarrow CO_2 + H_2O + Na_2SO_4$ (Leachable)

On calcareous alkali soil

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

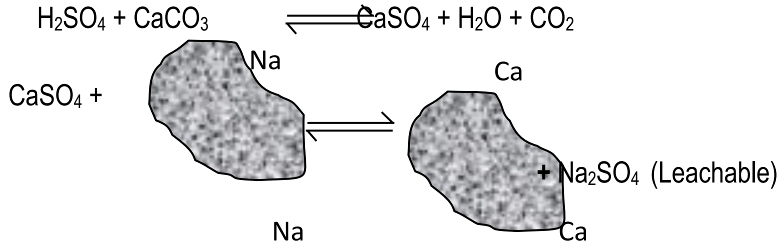


(iii) Iron pyrite (FeS_2)

$FeS_2 + O_2 + H_2O \rightleftharpoons FeSO_4 + H_2SO_4$

$FeSO_4 + 2H_2O \rightleftharpoons H_2SO_4 + Fe(OH)_2$

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



(iv) Iron Sulphate ($FeSO_4$)

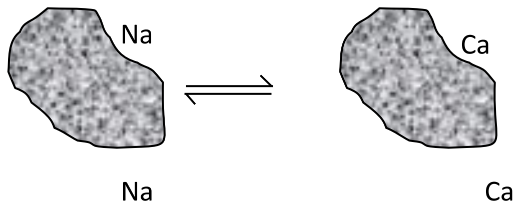
When iron sulphate is applied to the soil, the following chemical reaction will occur.

$$FeSO_4 + 2H_2O \rightleftharpoons H_2SO_4 + FeO$$

On calcareous alkali soil

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

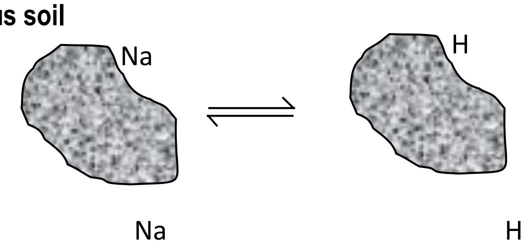
$CaSO_4$ +



+ Na_2SO_4 (Leachable)

In non-calcareous soil

H_2SO_4 +



+ Na_2SO_4 (Leachable)

(v) Lime Sulphur (CaS_5)

When lime sulphur is applied to soils, the following raction takes place.

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

Then the reactions are similar as that of iron sulphate in calcareous and non-calcareous alkali soils. **Other methods -Salt precipitation**

The elimination of salts and exchangeable sodium from soils by leaching is presently practiced but the leached salts have been washed into ground waters or streams resulting in ground water pollution. A new concept in managing the soils is by precipitation of salts. Instead of leaching the salts completely away, they can be leached to only 0.9 -1.8 m deep (3-6 ft), where much of the salt would form slightly soluble gypsum or carbonates during dry periods and not react any longer as soluble salts.

Gypsum Requirement

The main principle for the reclamation of sodic or alkali soils is to replace exchangeable Na by another action calcium (Ca^{2+}). Gypsum is considered the best and cheapest for the reclamation purpose. In India, the resources of gypsum are estimated to be more than 1000 million tones. Calcium (Ca^{2+}) solubilized from gypsum replaces sodium leaving soluble sodium sulphate (Na_2SO_4) in the water, which is then leached out. Gypsum requirement is expressed as me of Ca^{2+} per 100 g of soil.

Gypsum Requirement (GR) is the calculated amount of gypsum necessary to add to reclaim the soil. Gypsum requirements depends upon exchangeable sodium content to be replaced, exchange efficiency and the depth of soil to be reclaimed. This determination includes Ca^{2+} required to replace the exchangeable Na^{+} ions plus that required to neutralize the alkalinity.

$$\text{Gypsum requirement i.e.,} \quad = \frac{\text{ESP (Initial)} - \text{ESP (Final)}}{100} \times \text{CEC meq of } Ca^{2+} / 100 \text{ g soil}$$

ESP (initial) is obtained from the analysis of soil before reclamation or application of gypsum; ESP (final) is usually kept at 10 and CEC is the cation exchange capacity in C mol (p^{+}) kg^{-1} of the soil. Gypsum requirement obtained from the calculation should be multiplied by the purity factor of gypsum to arrive at the field requirement.

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

Amendment	**Tonnes equivalent to 1 tonne of gypsum**
Gypsum ($CaSO_4 . 2H_2O$)	1.0
Sulphur	0.18
Lime - Sulphur	0.75
Sulphuric acid	0.57
Iron sulphate ($FeSO_4 .7H_2O$)	1.62
Aluminium sulphate	1.27
Limestone ($CaCO_3$)	0.58

- Gypsum should be broadcasted and incorporated in the surface 0-10 cm soil by discing or by using a cultivar
- Mixing of gypsum in deeper soil decreases its effectiveness, as a fraction of gypsum reacts with soluble carbonates to precipitate Ca as $CaCO_3$
- Mined gypsum ground to pass through 2 mm sieve is cost effective and efficient.

Biological Amelioration

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

Addition of crop residues and other organic materials have got a tremendous influence on maintaining soil physical, chemical & biological properties of soils. Organic amendments like straw, rice husk. Ground nut & safflower hulls, compost, poultry droppings, green manures, tree leaves & saw dust. They produce CO_2 (carbonic acid) & organic acids, they increase the solubility of calcite and lower the ESP.

Crop selection

Relative tolerance of crops to alkalinity or sodicity.

ESP (range)	Crop
2 -10	Deciduous fruits, nuts, citrus, avocado
10-15	Safflower, Blackgram, Peas, Lentil, Pigeonpea
16-20	Chickpea, Soybean
20-25	Clover, Groundnut, Cowpea, Onion, Pearl Millet
25-30	Linseed, Garlic, Cluster bean
30-50	Oats, Mustard, Cotton, Wheat, Tomatoes
50-60	Beets, Barley, Sesbania
60-70	Rice

Industrial by products as Amendments:

Phospho-gypsum	Used to provide soluble Ca directly/indirectly by dissolving soil lime
Press mud	
Molasses	
Acid wash	
Effluent from milk plants	

Lecture 12

Cause reclamation and management of Acid and acid sulphate Soils

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Acid soil is a base unsaturated soil which has got enough of adsorbed exchangeable H^+ ions so as to give soil a pH lower than 7.0.

Genesis of acid soils

(i) Leaching due to heavy rainfall

Acid soils are common in all regions where rainfall or precipitation is high enough to leach appreciable amounts of exchangeable bases (Ca^{2+}, Mg^{2+}, Na^+ and K^+) from the surface soils and relatively insoluble compounds of Al and Fe remains in the soil.

$$CO_2 + H_2O \longrightarrow H_2CO_3$$

$$H_2CO_3 + CaCO_3 \longrightarrow Ca(HCO_3)_2 \text{ (Leachable)}$$

(ii) Acidic parent material

Some soils developed from acidic parent materials like granite and gneiss may develop soil acidity.

(iii) Acid forming fertilizers and soluble salts

The use of acid forming fertilizers like ammonium sulphate $(NH_4)_2SO_4$ and ammonium nitrate NH_4NO_3 increases soil acidity.

$$(NH_4)_2SO_4 \rightleftharpoons 2\,NH_4^+ + SO_4^{2-}$$

$$2\,NH_4^+ + SO_4^{2-} + Ca\,\boxed{\text{Clay}} \longrightarrow {}^{NH_4}_{NH_4}\boxed{\text{Clay}} + CaSO_4 \text{ (Leached out)}$$

$$\begin{matrix} NH_4 \\ \boxed{\text{Clay}} \\ NH_4 \end{matrix} + 3O_2 \xrightarrow{\text{Nitrification}} \begin{matrix} H \\ \boxed{\text{Clay}} \\ H \end{matrix} + 2HNO_3$$

Acid soil

Similarly sulphur also produces acid forming sulphate ion through oxidation.

(iv) Humus and other organic acids

Decomposition of organic matter releases weak organic acids, which is capable of solubilizing bases resulting in increased acidity.

(v) Aluminosilicate minerals

At low pH values most of the aluminium (Al) is present as the hydrated aluminium ions (Al^{3+}) which undergoes hydrolysis and release hydrogen (H^+) ions in soil solution.

$$Al^{3+} + H_2O \rightleftharpoons Al\,(OH)^{2+} + H^+$$

$$Al(OH)^{2+} + H_2O \rightleftharpoons Al\,(OH)_2^{+} + H^+$$

$$Al(OH)^{3+}_{2} + H_2O \rightleftharpoons Al\,(OH)_3^{+} + H^+$$

$$Al(OH)^{4+}_{3} + H_2O \rightleftharpoons Al\,(OH)_4^{+} + H^+$$

(vi) Carbon dioxide (CO_2)

CO_2 evolved from root activity and microbial metabolism combines with H_2O to form H_2CO_3 resulting in soil acidity.

(vii) Hydrous oxides

The oxides of iron and aluminium under favourable conditions undergo stepwise hydrolysis with the release of hydrogen (H^+) ions in the soil solution and develop soil acidity.

(viii) Aluminium and iron polymers

The Al^{3+} ions displaced from clay minerals by cations are hydrolysed to monomeric and polymeric hydroxyl aluminium complexes as shown below. Hydrolysis of these forms liberate hydronium ion thus lowering the soil pH.

$$Al(H_2O)_6^{3+} + H_2O \rightleftharpoons Al(OH)(H_2O)_5^{2+} + H_3O^+$$

$$Al(OH)(H_2O)_5^{2+} + H_3O^+ \rightleftharpoons Al(OH)_2(H_2O)_4^{+} + H_3O^+ \text{ (pH : 4.7 – 6.5)}$$

$$Al(OH)_2(H_2O)_4^{+} + H_3O^+ \rightleftharpoons Al(OH)_3(H_2O)_3^{0} + H_3O^+ \text{ (pH : 6.5 – 8.0)}$$

$$Al(OH)_3(H_2O)_3^{0} + H_3O^+ \rightleftharpoons Al(OH)_4(H_2O)_2^{-} + H_3O^+ \text{ (pH : 8.0 – 11.0)}$$

Similarly,

$$Fe(H_2O)_6^{3+} + H_2O \rightleftharpoons Fe(OH)_4(H_2O)_5^{2+} + H_3O^+$$

(Reaction occurs under more acidic conditions than Al)

Kinds of Soil Acidity

Soil acidity may be of the following two kinds

(i) Active acidity

It is defined as the acidity that develops due to hydrogen (H^+) and aluminium (Al^{3+}) ions in the soil solution. The magnitude of this acidity is limited.

(ii) Exchange acidity

It is defined as the acidity that develops due to adsorbed hydrogen (H^+) and Aluminium (Al^{3+}) ions on the soil colloids. The magnitude of this acidity is very high. It is also called potential / reserve acidity.

(iii) Total acidity

The summation of active and exchange acidity is called total acidity.

Total acidity = Active acidity + Exchange acidity.

Distribution of acid soils

Out of 157 m.ha of cultivable land in India, 49 m.ha are acidic, of which 36 m.ha have soil pH less than 5.6 and the rest 13 m.ha have soil pH in the range of 5.6 to 6.5. In Tamil Nadu, acid soil occupies nearly 2.6 M.ha, predominantly found in the hilly areas of Nilgris and Kodaikanal, high rainfall zone of Kanyakumari districts and parts of Pudukottai, Sivagangai, Cuddalore and Vilupuram districts.

Broadly acid soils of India can be classified into seven distinct groups viz., (i) Laterite (ii) Laterite and Lateritic red (iii) Mixed red, black and yellow (iv) Ferruginous red (v) Podsolic brown forest and forest soil (vi) Foot hill soils and (vii) Peat soils.

Problems of soil acidity

(i) Acid toxicity

The acid toxicity includes toxicities of acidic anions as well as H^+ ions.

(ii) Toxicity of nutrient elements

a. Iron and Manganese

The concentration of these two ions (Fe^{2+} and Al^{3+}) in soil solution depends upon the soil reaction. The nutrient elements viz., Mn^{4+} and Fe^{3+} reduce to Mn^{2+} and Fe^{2+} respectively and their concentration is increased to toxicity levels. Due to such toxic effects, a physiological disease of rice is found in submerged soils which is popularly known as *browning disease*.

b. Aluminium

The toxicity of aluminium tends to decrease with an increase in concentration of other cations such as calcium. Aluminium toxicity is a problem in both upland and lowland soils. Aluminium toxicity in soil affects plant growth in the following ways as

- It restricts the root growth
- It affects various plant physiological processes like cell division, formation of DNA and respiration
- It restricts the absorption and translocation of important nutrient elements from the soil to the plants like P, Ca, Fe, Mn etc.,
- It causes wilting of plants
- It also inhibits the microbial activity in the soil.

(iii). Nutrient availability

a. Non specific effects –It causes inhibition of root growth and thereby affects the nutrient availability.

b. Specific effects

- **Exchangeable bases:** Due to complementary ion effect, exchangeable bases are released preferentially in a fractional exchange. Deficiency of bases like Ca^{2+} and Mg^{2+} are found in acid soils
- **Nutrient imbalance**
  * Phosphorus reacts with iron, aluminium and manganese and produces insoluble phosphatic compounds rendering phosphorus unavailable to plants
  * Availability of phosphorus is reduced due to fixation of phosphorus by hydrous oxides of iron and aluminium or by adsorption
  * Molybdenum is very limited and is unavailable to plants
  * Availability of boron is also reduced due to adsorption on sesquioxides, iron and aluminium hydroxyl compounds.
  * Nitrogen, potassium and sulphur become less available in a soil with pH less than 5.5.

(iv). Microbial availability

Bacteria and Actinomycetes function better in soils having moderate to high pH values. They cannot function at a pH below 5.5. Nitrogen fixation in acid soils is greatly affected by lowering the activity of *Azotobacter* spp. Besides these, soil acidity also inhibits the symbiotic nitrogen fixation by affecting the activity of Rhizobium sp. Fungi can grow well under very acidic conditions and causes various diseases like root rot of tobacco, blight of potato etc., However potato scab (caused by Actinomycetes) is not prevalent under acidic environment.

Soil acidity is the result of excessive accumulation of H+ ions over OH- ions in the soil solution. Acid sulphate soils are soils with a pH below 4 that is directly or indirectly caused by sulphuric acid formed by oxidation of pyrite. Potential acid sulphate soils are poorly drained soils with a high content of pyrite. The pH of the soil will be neutral or slightly acid in the field. Upon drainage, the soil becomes strongly acidic, which directly affects the growth of plants as a result of aluminium and iron toxicity, and indirectly decreases the availability of phosphorus and other nutrients. In India, approximately 390000hectare lands are found for acid sulphate soils. In general the area covered in 0.26 million hectare. Acid sulphate soils are unproductive or low productivity, it may be due to one or more of the unfavourable factors i.e. soil acidity, salinity, aluminium toxicity, iron toxicity, low content of major nutrients, low base status, and hydrogen sulphide toxicity. Acid sulphate soils are the major problem and require suitable reclamation and management practices, which useful for enhancing agricultural productivity.

Acid sulphate soil

Acid sulphate soil is a name given to soils or sediments containing iron sulphides. Iron sulphides are micro-crystalline minerals such as pyrite that have formed naturally in soils where long-term water-logged conditions occur such as estuaries, wetlands and shallow groundwater in deep sands. Soil minerals containing sulfides (mainly pyrite) that become very acid on drying have been recognized for many yields. Because of their pale yellow colour and infertile nature, Dutch farmers named them as Kattakali meaning *Cat Clays*. Chenery (1954) introduced the term Acid Sulphate Soils that have been drained, have adsorbed sulphate and pale yellow colour of Jarosite and usually have low pH (< 4.0) when in water. If the soils are drained or exposed to air by a lowering of the water table, the sulphides react with oxygen and form sulphuric acid.Undrained soils with sulfides also occur in situations where some forms of reclamation have been attempted. These are termed as Potential Acid Sulphate Soils.

Distribution of acid sulphate soils:

They occur in coastal areas under the influence of saline or brackish water or permanent fresh water swamps formerly brackish and in Pleistocene terraces as also in high water swamps

with adjacent source of sulphur. In India these soils occur in extensive areas in coastal saline soil zone of West Bengal commonly known as Sunderbanr, Andman Nicobar Islands and in coastal areas of Kerala formed from deltic alluvium of four rivers namely Meenachil, Manimala, Achencoil and low laying area of Vemband lake. In general the area covered in 0.26 million hectare (Mohsin *et al.*, 1995). In India, approximately 390000 hectare lands are found for acid sulphate soils.

Genesis of acid sulphate soils:

The formation of acid sulphate soils consists of two main processes: formation and oxidation of pyrite. The accumulation of pyrite is brought about by the combined effect of somewhat unique conditions that occur in tropical coastal areas. The sulphur in pyrite is derived from the sulphate in sea water, which is biologically reduced to sulphide in the anaerobic mud. An energy source is necessary for bacterial sulphate reduction, and organic matter is usually readily available as a result of abundant plant growth in these coastal areas. Iron, sulphur and sometimes sea water plays an important role. Pyrite (FeS2) and murcasite are the main source of iron. Sulphur is contributed by brackish and sea water (> 800 mg kg-1 SO4 2- sulphur), sediments containing large amount of sulfides and biological materials like algae and diatoms. Also, ferrous iron (Fe2+) must be available, and it is usually derived from the reduction of insoluble ferric compounds that result from the weathering of clay. Thus the combination of sulphate from sea water, organic matter from plant growth, anaerobic conditions caused by exclusion of atmospheric oxygen by the excess water, and the presence of Fe2+ result in the formation and accumulation of pyrite in tropical coastal wetlands (Figure 1). Ferrous sulfide is usually an important ingredient which is developed due to chemical reactions such as :

$$4Fe(OH)3 + 4CaSO4 + 9CH2O\ 4Fes + 4Ca(HCO3)2 + CO2 + 11\ H2O$$

Where, CH_2O represents organic matter which is used as an energy source by microorganisms which bring about the reaction. This iron sulfide accumulates as ferrous sulfide or as iron polysulfide. The sulfide bearing soils usually have pH values near neutrality as long as anaerobic conditions prevail upon drainage, however, the sulfides are oxidized to sulphates due to combination of chemical and microbiological reactions (Somani, 1994).

$$2FeS_2 + 2H_2O \rightarrow FeSO_4 + H_2SO_4$$

Thiobacillus ferro oxidans

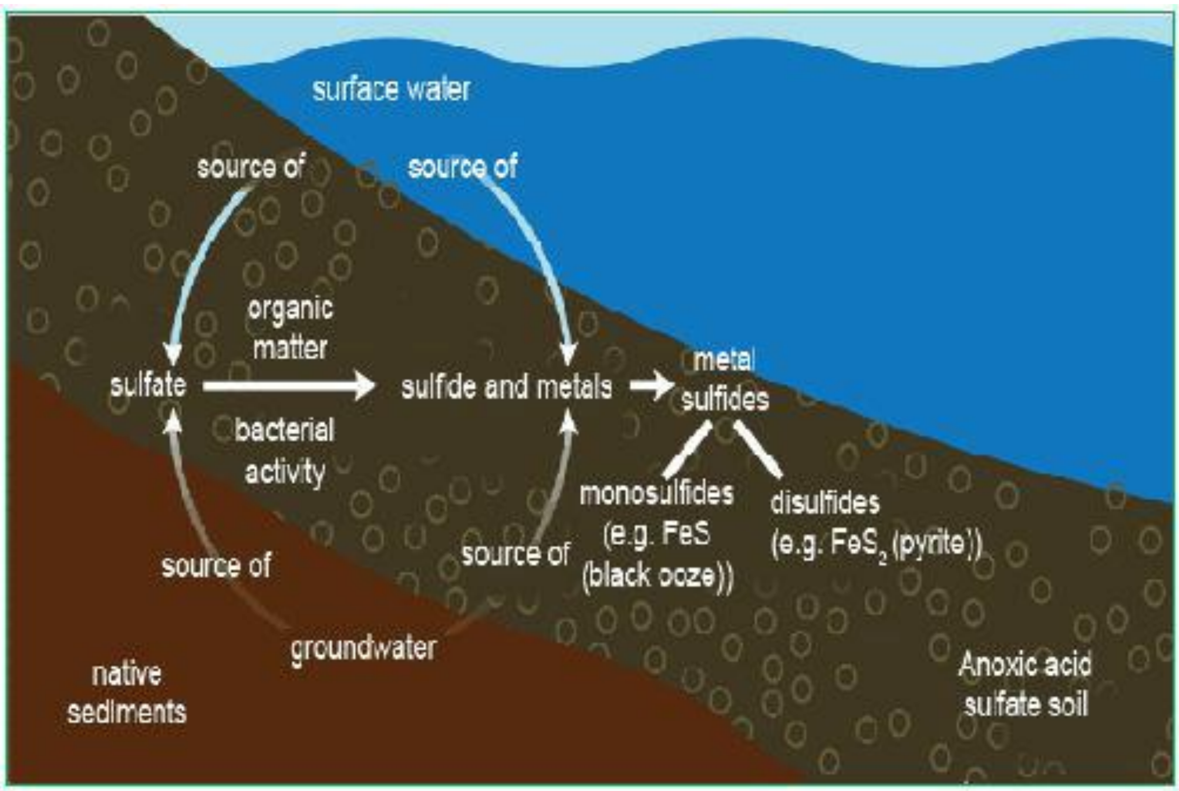
4FeSO4 + O2 + 2H2SO4 → 2Fe2(SO4) + 2H2O

$$4FeSO_4 + O_2 + 2H_2SO_4 \rightarrow 2Fe_2(SO_4) + 2H_2O$$

Thiobacillus thio oxidans

$$Fe_2(SO_4)_3 + FeS_2 \rightarrow 3FeSO_4 + 2S$$

$$2S + 3O_2 + H_2O\ 2H_2SO_4$$



Causes of low productivity in acid soils :

- Low productivity of these soils is due to -
- Injury of hydrogen ions.
- Low pH causing

- Impaired availability and absorption of plant nutrients.
- Increased solubility of iron, aluminum and manganese resulting in toxicity.
- Decreased availability of phosphorus and molybdenum.
- Low base saturation due to leaching.
- Abnormal biotic factors causing impaired mycorrhiza and virulence of plant diseases.
- Salt injury.
- Telicity due to hydrogen sulphide (H_2S).
- Production of organic acids.

- Plant roots are directly injured due to high concentration of hydrogen ions particularly if the pH is < 4.0. But plants can tolerate concentration of hydrogen ions (H^+) if concentration of polyvalent cations is less. It causes suppressed root growth and root branching because of adverse effect on cell cytoplasm and cell permeability. Numbers of plant roots are less, thick and dull grey to brown in colour. Nutrient absorption capacity of root is reduced. If the pH is around 4.0 rubber, oil palm, coconut, cassava and banana can be grown. Paddy can also be grown under submergence as, it can tolerate high concentration of aluminum (1.2 to 25 mg kg^{-1}) if supply of other nutrients can be maintained because concurrent increase in pH due to continuous submergence lowers the concentration of aluminum. The concentration of aluminum which was 74.5 mg kg^{-1} at pH 3.11 is reduced to 0.3 mg kg^{-1} at pH 4.0. This may be because ferric hydro oxide is reduced to ferrous hydro oxide and the OH released causes the precipitation of aluminum.

$$Fe(OH)_3 \; Fe(OH)_2 + OH Al^{3+}$$

$$+ OH^- \; Al(OH)^{++}, Al(OH)_2$$

$$^+ \text{ and } Al(OH)_3$$

- Paddy can also tolerate high concentration of Fe^{2+} (200 mg kg^{-1}). But excess of H_2S present in this range causes Akiochi disease as a result of which respiratory activity of root is reduced, plants become deficient in K, N, Si and bases, iron content in the plant increases to toxic levels and plants are infected with Helminthosporium which causes wide spread damage. H_2S can also cause suffocation disease which can be corrected by application of nitrate nitrogen. Another disease called Brusone also develops which is caused by *Piricularia oryzae* and the plant suffers.

- High concentration of aluminum makes the plant roots brittle, devoid of branching with thick root tips and brown lateral roots. Aluminum is attached to phosphate in the DNA structure which inhibits cell division and protein synthesis. It also causes precipitation of nucleic acids and increases the water potential of plants.
- High concentration of manganese decreases translocation of calcium to leaves and increases oxidation of Indole Acetic Acid (IAA) and hence growth of plant tops is affected. Activity and functioning of Mn activated enzyme system is reduced. Excess of Mn causes marginal chlorosis of young leaves and necrotic spots on leaves. However, since considerable quantities of Mn is lost during formation of these soils (due to leaching) very few of these soils suffer from Mn toxicity.
- Organic acids, such as acetic acid, n-butyric acid and propionic acid accumulate in these soils. These acids are phytotoxic.
- The concentration of soluble salts also increases particularly when pyritic soils undergo oxidation and drying. The electrical conductivity (EC) may be as high as 10 dSm-1. Periodic flooding of acid sulphate soils with sea water may further accelerate the salt problem. Because of these reasons the productivity is low and –

1. Lower yield of crops
2. Lower chances of increasing yields due to fertilizer application
3. Further complications arising out of dry spells accentuating the soil acidity.
4. Drains are blocked due to ochre.
5. Inundation due to sea water.
6. Continuous water logging causing H2S toxicity.

Soil quality problems of acid sulphate soils :

In general, acid sulphate soils are unproductive or low productivity, it may be due to one or more of the unfavourable factors i.e. soil acidity, salinity, aluminium toxicity, iron toxicity, low content of major nutrients, low base status, and hydrogen sulphide toxicity.

- **Soil Acidity :** The acid sulphate soils may be due to the direct effect of hydrogen (H+) ions,especially below pH 3.5 to 4. However, aluminum toxicity is probably more important in this pH range.

- **Soil Salinity :** Acid sulphate soils in tidal areas are often affected by salinity. Salinity shows the toxicity, by weakening the plants and increasing iron and aluminium concentration in solution.
- **Aluminium Toxicity :** One cause of stress on the growth of certain plant species is aluminium toxicity. A high Al level affects cell division, disrupts certain enzyme systems,and hampers uptake of phosphorus, calcium and potassium. Most plants grown on acid sulphate soils which have a pH below 4 suffer from Al toxicity.
- **Iron Toxicity :** Dissolved iron in excess of 300-400 mg kg-1 is toxic to rice crop.
- **Low Nutrient Contents :** In the absence of iron and aluminium toxicity and harmful salinity, phosphorus deficiency is the most important problem of acid sulphate soils. Supply of nitrogen increases the phosphate response.
- **Low Base Status :** During the formation of acid sulphate soils, bases are removed as sulphate and most of the exchange complex is occupied by aluminium. Therefore, acid sulphate soils are likely to be deficient in Ca and K.
- **Hydrogen Sulphide Toxicity :** Hydrogen sulphide has been shown to be toxic to the rice plant through its suppression of the oxidizing power of the roots.

Reclamation and management of acid sulphate soils :

Various important factors which govern reclamation and improved use of these soils are :the degree of acidity developing upon the drainage, depth of non acid top soil covering acid and potential acid sulphate soil horizon buried below, case of controlling water table during dry season besides intensity of dry season.

1. Prolonged submergence.

2. Leaching with rain water, sea water or in succession with these.

3. Addition of lime and manganese dioxide.

4. Ridging, growing of tolerant crops, deep ploughing to mix calcareous horizons, liming fertilizer application and water table control.

5. Improvement of drainage and leaching out of soluble salts repeatedly.

Lime Requirement

Lime requirement of an acid soil is defined as the amount of liming material that must be added to raise the pH to some prescribed value. This value is usually in the range of pH 6.0 to 7.0, since this is an easily attainable value within the optimum range of most crop plants. Shoemaker et al. (1961) buffer method is used for the determination of lime requirement of an acid soil.

Principles of Liming Reactions

Lime reactions in soils depends upon the nature and the fineness of the liming materials. Lime is applied to soils in the form of ground limestone. Limestones can be classified as calcitic ($CaCO_3$), dolomite ($CaMg(CO_3)_2$) or a mixture of the two. Both are sparingly soluble in pure water but become soluble in water containing carbon di oxide.

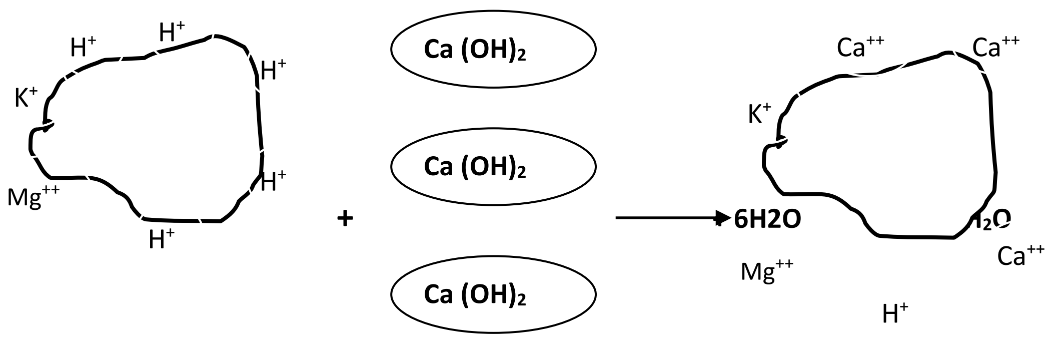
$$CaCO_3 + H_2O + CO_2 \longrightarrow Ca(HCO_3)_2$$

$$Ca(HCO_3)_2 \longrightarrow Ca^{2+} + 2HCO_3^- \downarrow$$

$$\underset{\text{(soil solution)}}{H^+} + \underset{\text{(from lime)}}{HCO3^-} \longrightarrow H_2CO_3 \rightleftharpoons H_2O + CO_2$$

In this way hydrogen ions (H^+) in the soil solution react to form weakly dissociated water and calcium (Ca^{2+}) ion from limestone is left to undergo cation exchange reactions. Acidity of the soil is thus neutralized and the percent base saturation of the colloidal material is increased.

The process of changing pH by the addition of lime ($Ca(OH)_2$) is illustrated below.



Acidic clay **Lime** **Neutral clay** **water**

Factors affecting liming reactions

(i) Moisture

Greater the moisture content, more rapid is the rate of reaction. As moisture increases, oxygen content decreases, CO_2 increases resulting in an increased rate of reaction.

(ii) Temperature

Lime and liming materials react more rapidly at high than at low temperatures. This effect is probably related to diffusion rates of end products away from the reaction sites.

(iii) Amount of exchange acidity

The amount of exchange acidity present in the soil affects reaction rate.

Liming materials

These are called *Agricultural liming materials*.

Gypsum is not considered as a Liming Material

Gypsum is not considered as a liming material because on its application to an acid soil, it dissociates into calcium (Ca^{2+}) and sulphate (SO_4^{2-}) ions.

$$CaSO_4 \rightleftharpoons Ca^{2+} + SO_4^{2-}$$

The accompanying anion is sulphate and it reacts with soil moisture produces mineral acid (H_2SO_4) which also increases soil acidity instead of reducing soil acidity.

$$SO_4^{2-} + H_2O \longrightarrow H_2SO_4$$

Besides this, calcium (Ca^{2+}) in the gypsum after dissociation will result in replacement of adsorbed aluminium (Al^{3+}) in a localized soil zone with a significant lowering of soil pH. Hence gypsum does not qualify as a liming material.

Kinds of Liming Materials

Various kinds of liming materials are used for the correction of soil acidity. They are as follows.

(i) Oxides of lime

It is normally called burned lime or quick lime.

$$CaCO_3 + Heat \longrightarrow CaO + CO_2 \uparrow$$

Limestone

$$CaMg(CO_3)_2 + Heat \longrightarrow CaO + MgO + 2CO_2 \uparrow$$

(ii) Hydroxides of lime

It can be produced by adding water to burned lime and is called *slaked lime*.

$$\underset{\text{(Burned lime)}}{CaO + H_2O} \longrightarrow \underset{\text{(Slaked lime)}}{Ca(OH)_2 + CO_2}$$

It is more caustic than burned lime (CaO). If it is kept open in the moist air, then combination of calcium hydroxide occurs as follows.

$$Ca(OH)_2 + CO_2 \longrightarrow CaCO_3 + H_2O$$

$$Mg(OH)_2 + CO_2 \longrightarrow MgCO_3 + H_2O$$

(iii) Carbonates of lime

The two important minerals found are calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$).

(iv) Slags

These are generally three types of slags that are found important.

a. **Blast furnace slag** – It is a by- product of the manufacture of Pig iron. As a liming material, this behaves as calcium silicate. The neutralizing value of blast furnace slags ranges from about 75-90%.

b. **Basic slag** – It is a by-product of the basic open hearth method of making steel from pig iron, which in turn is produced from high phosophorus iron ores. Impurities in the iron, including silica and phosphorus are fluxed with lime and the basic slags are produced. Its neutralizing value ranges from 60-70%.

c. **Electric furnace slag** – This is produced from the electric furnace reduction of phosphate rock during preparation of elemental phosphorus. This product is largely calcium silicate and is used as a liming material.

d. **Other liming materials** – Coral shell, chalk, wood ash, press mud, by-product material of paper mills, sugar factories, fly ash and sludge etc., are considered as liming materials and also used for the amelioration of soil acidity.

Efficiency of liming materials

The efficiency of liming materials can be judged on the basis of following important factors because of varying neutralizing capacity of different liming materials.

(i) Neutralizing value (N.V) or Calcium Carbonate Equivalent (CCE) –Calcium carbonate equivalent (CCE) is defined as the acid neutralizing capacity of an agricultural liming material expressed as a weight percentage of calcium carbonate.

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

Liming materials	Neutralizing value of CCE (%)
Calcium oxide (CaO)	179
Calcium hydroxide ($Ca(OH)_2$)	136
Dolomite ($CaMg(CO_3)_2$)	108.7
Calcite ($CaCO_3$)	100
Basic slag ($CaSiO_3$)	86

(ii) Purity of liming materials – More pure the liming material, higher will its effectiveness for the amelioration of soil acidity.

(iii) Degree of fineness of liming materials – Finer materials increases the surface contact with the soil and the rate of reaction is high. The amount of finer fraction of liming materials will be required much less as compared to coarser fractions of the material to achieve a certain pH. The fineness is measured in terms of the ability of a material to pass through a sieve having 60 holes of equal size in one linear inch (60 mesh sieve).

Percent Effective Calcium Carbonate (ECC) or (Neutralizing Index)

The effective calcium carbonate (ECC) rating of a limestone or liming material the product of the calcium carbonate equivalent (CCE) and the fineness factor. The fineness factor is the sum of the product of the percentage of material in each of the three size fractions (60 mesh sieve, 20 mesh sieve and 8 mesh sieve) multiplied by the appropriate effectiveness factor.

Percent ECC or N.I = CCE x Fineness factor.

Relative tolerance of crops to soil acidity

Crops	**Optimum pH range**
Cereals	
Maize, sorghum, wheat, barley	6.0-7.5
Millets	5.0-6.5
Rice	4.0-6.0
Oats	5.0-7.7
Legumes	
Field beans, soybean, pea, lentil etc.	5.5-7.0
Groundnut	5.3-6.6
Others	
Sugarcane	6.0-7.5
Cotton	5.0-6.5
Potato	5.0-5.5
Tea	4.0-6.0

Liming Factor

Liming Factor may be defined as the factor by which the actual amount of lime can be calculated from the estimated theoretical amount of lime. This factor varies from 1 to3, depending on rate of limestone solution, plant uptake and leaching during the reaction period.

Methods of applying lime

The application of small amounts of lime of soil every year or twice a year is effective. Lime should be applied well ahead of the crop cultivation by broadcasting and should be mixed with the whole plough layer soil so that liming reaction can occur in a faster rate. When both the surface and subsurface soils are strongly acidic e.g. ultisols, incorporation upto a depth of about 30 cm (12 inches) is required.

Effects of overliming

When excessively large amount of lime is applied to an acidic soil, the growth of plants is affected due to the following causes.

(i) Deficiency of ion, copper and zinc
(ii) Phosphorus and potassium availability will be reduced
(iii) Due to high OH^- ion concentration, root development will be inhibited in association with tip swelling brought about by hydrations. Due to dehydrating properties of boron, it acts as a protective agent for excess OH^- ion concentration
(iv) Boron deficiency occurs
(v) Incidence of diseases like scab in root crops

All these effects can be reduced with the application of large amount of organic manures like well rotten farmyard manure, green manure crops, compost, phosphorus, boron or a mixture of micronutrient fertilizers to the soil.

Liming on Plant Nutrition

Direct Benefits

(i) Reduction in toxicity of aluminium and manganese. Reduced uptake of calcium (Ca^{2+}) and magnesium (Mg^{2+}) in the soil solution can also be alleviated with the application of lime.

(ii) Removal of hydrogen (H^{+}) ion toxicity which damages root membranes and causes detrimental effect for the growth of microbes like bacteria.

Indirect Benefits

(i) Phosphorus availability – At low pH values and at high pH values, phosphorus availability is greatly reduced due to precipitation as iron and aluminium phosphates, calcium or magnesium phosphates respectively. Liming programme should be planned so that the pH can be kept between 5.5 -7.0 inorder to derive maximum benefit from the applied phosphatic fertilizer.

(ii) Micronutrient availability – The toxic effect of most of the micronutrients like Fe,Mn,Cu,Zn,B (except Mo) can be prevented by the application of lime.

(iii) Nitrification – Nitrification is enhanced by a liming to a pH of 5.5 to 6.5. Most of the organisms responsible for the conversion of ammonia to nitrates require large amount of active calcium.

(iv) Nitrogen fixation – The process of nitrogen fixation both symbiotic and non-symbiotic is favoured by adequate liming.

(v) Soil Physical Condition – The structure of fine textured soil may be improved by liming. This is the result of an increase in the organic matter content and to the flocculation of calcium-saturated soils. Liming decreases the bulk density of soils, increases infiltration and percolation rates of water. Liming checks soil erosion.

(vi) Diseases - The amelioration of soil acidity by liming helps to control certain plant pathogens. Club root disease of cole crops can be reduced with the application of lime.

(vii) Efficiency of fertilizers – Liming increases the efficiency of different fertilizers especially nitrogenous and phosphatic fertilizers by modifying the soil reaction favourably.

Lecture 13

Cause reclamation and management of Laterite soils

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Laterite soil

- The word laterite is derived from Latin word "later" which means "**brick"**
- The main reason of laterite soil is formed due to intense leaching
- Leaching happens due to high tropical rains and high temperature
- Theses soils are poor in organic matter, nitrogen, phosphate and calcium, while iron oxide is in excess
- Nearly all laterites are of rusty-red coloration, because of high iron oxide content and aluminum.
- Laterite soil is quite acidic and the pH level of the soil is quite low. The pH level of laterite soil is mostly found to be around **4.5 - 6.5**. Soil pH is to be more precise is a measure of the acidity or alkalinity in soils

Formation

- They develop by intensive and prolonged weathering of the underlying parent rock
- The weathering process of laterite soil formation is called as **Laterization**
- As a result of high rainfall, lime and silica are leached away. And soils rich in iron oxide and aluminium compound are left behind
- Laterites are formed from the leaching of parent rock
- Sedimentary rocks - sandstones, clays, limestones
- Metamorphic Rocks - schists, gneisses, migmatites
- Igneous Rocks - granites, basalts, gabbro, peridotites
- Which leaves the more insoluble ions, predominantly iron and aluminium. The mechanism of leaching involves acid dissolving the host mineral lattice, followed by hydrolysis and precipitation of insoluble oxides and sulfates of iron, aluminium and silica under the high temperature conditions of a humid sub-tropical monsoon climate.
- An essential feature for the formation of laterite is the repetition of wet and dry seasons
- The mineralogical and chemical compositions of laterites soils are dependent on their parent rocks.
- Laterites consist mainly of quartz, zircon, and oxides of titanium, iron, tin, aluminium and manganese, which remain during the course of weathering.

Distribution

- These soils are developed on the summits of hills and uplands
- They cover most of the land area between the tropics of Cancer and Capricorn; areas not covered within these latitudes include the extreme western portion of South America, the southwestern portion of Africa, the desert regions of north-central Africa, the Arabian Peninsula and the interior of Australia.
- In India these soils are abundant in area along the edge of the plateau in the east covering small parts of the states of Kerala, Karnataka, Tamil Nadu, Maharashtra, Chhattisgarh and hilly areas of Orissa and Assam

The chemical composition of Lateritic Soils

- Laterite soils are rich in bauxite or ferric oxides.
- They are very poor in lime, magnesia, potash, and nitrogen.
- Sometimes, the phosphate content may be high in the form of iron phosphate.
- In wetter places, there may be higher content of humus.

Soil related constraints

The soil can be formed in humid tropical belt characterized by high rain fall and temperature conditions. The distinct altitudinal variations and undulating topography has a modifying effect on the various factors of the soil formation. Different combinations of the soil forming factors have resulted in the development of a variety of soils and soil related constrains which have a direct bearing on crop production. The major soil related constraints from the point of view of soil health are:

Soil Physical constraints

i. **Steep slopes and erosion**

- Hilly and undulating topography with wide range of slope classes.
- The high precipitation and undulating topography especially in the mid land laterite region with high erodibility has accelerated water erosion with substantial losses of top soil and available nutrients.
- In the laterite terrain exposure of the laterite bed by erosion and its prolonged drying and dehydration causes the formation of stone/petro plinthite.

ii. **Root zone limitation**

- This is the outcome of severe water erosion causing removal of surface soils and exposure of the laterite beds.
- The laterite pan is soft when under a column of soil, but hardens on exposure causing plant root penetration and workability, difficult.

- Dehydration of plinthite brings out an increase in bulk density making root penetration difficult

iii. **Gravel content and hard pans**

- The gravel content in laterite soils are ranges from 15 to 70 per cent.
- The gravelliness factor depending on the soil texture increases the bulk density which adversely affects the foraging capacity of plant roots for nutrients.
- The decrease in soil volume also leads to poor inherent soil fertility, lesser available water capacity and other hydrological properties.
- The low water holding capacity of the low activity clays also brings about water stress in the root zone during summer months.

iv. **Poor drainage and hydrology**

- Poor drainage conditions are consequent on high water erosion and water logging in the lower landscape positions resulting in flooding. Water logging is a characteristic feature of the lands which have topographic disadvantage of lying below sea level.

v. **Drought stress**

- The low available water capacity as a result of gravelliness of the laterite soils, presence of laterite pans and consequent reduced soil volume has been responsible for intense moisture stress in the root zone leading to drought.
- The erratic monsoon rains also contribute to severe drought stress

Soil Chemical constraints

i. **Soil acidity**

- These soils are developed from acidic parent rocks under the humid tropical environment, characterised by high rainfall and temperature conditions which are conducive to rapid removal of bases from the soil.

ii. **Acid sulphate soils**

- Waterlogged area of lands have ultra acid soils with pH less than 3.5.
- These soils are developed mainly from sulphur rich sediments of marine origin and in some areas occur below sea level and are ill drained.
- Oxidation of these sediments under aerobic situation experienced during summer months causes extreme acidic conditions leading to the formation of acid sulphate soils.
- These soils also require acidity amelioration through regular liming and special management methods.

iii. **Aluminium and iron toxicity**

- These soils are rich in iron and aluminium oxides and strongly acid with pH less than 5.5 resulting in high levels of soluble Al which accumulates in the root tip and causes injury and inhibits root growth. Aluminium toxicity occurs in the potential acid sulphate soils.
- Under aerobic conditions, pyrities mineral get oxidized to jarosite which is hydrolyzed to iron hydroxide and sulphuric acid causing drastic reduction in pH values.
- In the laterite region, the sub soil layers of the profile with pH less than 5.5, the clay minerals are solubilized bringing into solution K, Mg, Fe and Al. Concentration of Fe and Al increases to toxic levels in soils.
- Iron toxicity is often encountered in flooded anaerobic situation especially in rice ecosystem.
- The reducing conditions bring about solubilisation of oxides of iron, which compete with other cations like $K^{+,}$ Ca^{2+}, Mg^{2+} and Zn^{2+}, leading to deficiency of these elements.
- High concentration of soluble Fe also causes precipitation of soluble P into insoluble forms making it unavailable to plants.
- Toxic levels of Fe are also harmful to the roots. Iron toxicity is more observed under poorly drained conditions and in soils with low cation exchange capacity.

iv. Subsoil acidity

- The subsoil layers of the laterite soil are often very strongly acid (pH 4.5 and less) resulting in solubilisation of exchangeable Al and deficiency of Ca and Mg.
- Exchangeable Al in toxic levels inhibits root growth and the target is the root apex causing stunting of primary roots and growth inhibition of the lateral roots.
- Combined application of gypsum ($CaSO_4{\bullet}2H_2O$) and dolomitic limestone is recommended to neutralize exchangeable Al levels in subsoil and alleviate deficiency of Ca and Mg.
- Gypsum and its combination with liming materials enables substantial movement of Ca and Mg to lower levels due to the presence of stable and mobile SO_4^{2-} ion.

v. Low nutrient reserves and retention

- In general, these soils are highly weathered and dominated by low activity clays with acidic pH, very low cation exchange capacity (CEC) and base saturation, low nutrient reserves and low water holding capacity.
- The high rainfall conditions result in intense leaching leading to further decrease in nutrient status. The dominance of low activity clays with low CEC and poor carbon reserves contribute to poor nutrient retention in soils.
- Low organic matter content of the soil is another factor responsible for the poor nutrient and water holding capacity of soils.

- Regular application of organic manures and green manuring helps in improving carbon reserve and thereby improving nutrient and water holding capacity

vi. High phosphorus fixation

- The important factor controlling the availability of P in soils is the maintenance of soil pH between 6.0 and 7.0.
- Acidic soil and rich in sesqi-oxides with resultant P fixation to the tune of 90 -95 %.
- This is indicative of the high doses of applied P fertilizers which get fixed initially in the colloidal fraction of the soil and subsequently getting solubilised resulting in high P levels in soils.

vii. Secondary and micro nutrient status

- Extensive deficiencies of secondary nutrients (Ca and Mg) and micro nutrient (boron) have been observed laterite soils.
- Application of liming materials such as dolomite, calcium carbonate and magnesium sulphate are recommended for alleviating deficiency of Ca and Mg.
- Application of copper sulphate, zinc sulphate and borax are recommended for correcting deficiencies.

Biological constraints

- The soil micro flora utilizes organic matter as source of energy and high levels of organic matter are often conducive to intense biological activities.
- The high temperature and destruction of vegetative cover has accelerated the oxidative process due to exposure leading to depletion of the organic carbon stock.
- Recycling of organic matter in crop lands are not sufficient to compensate for the oxidative losses.
- Soils are strongly acidic, alleviation of soil acidity through liming has to be a regular practice for sustaining the soil biological balance.
- Maintenance of soil organic matter at satisfactory level is also an equally important management requirement for sustaining the biological bio diversity of the soil.

Advantages

- Laterite soils are light and porous.
- They are easily tillable.
- They are red in colour due to the presence of large amounts of iron oxide.

Disadvantages

- These Soils are formed by leaching, therefore consists of less minerals and organic materials.
- They are acidic in nature as alkalis are leached.
- They are not at all fertile

Management of Laterite soil

Application of lime

- Spreading lime remains the most effective remedy for soil acidity.
- It is the only cost-effective option for acidic agricultural soils.
- Liming may result in substantial crop yield responses for several year

Application of enriched rock phosphate

- Recommended quantity of FYM enriched rock phosphate and zinc sulphate to be applied for different crops to enhance the phosphorous and zinc use efficiency and maintain the soil quality.

Green manuring

- Pre monsoon sowing of green manures and incorporation at flowering stage will enhance the nitrogen availability and reduce surface crusting problem by creating favourable soil physical environment.

Application of organic manures

- Farmyard manure, composted coirpith or pressmud at 25 t ha^{-1} per year conserves soil moisture, adds micronutrients, enhances aeration and improves the physical properties of the soil

Reduce leaching of Nitrogen

- Use split application of nitrogen fertilizers along with phosphorus and Zn for maximizing the crop yield; use lower rates of less acidifying fertilizers; avoid acidifying fertilizers such as mono ammonium phosphate or sulphate of ammonia.
- Crop Rotation Growing Legume crops tend to take up more cations in proportion to anions.
- As a consequence, H^+ ions are excreted from their roots to maintain the electrochemical balance within their tissues. This leads to a rise in soil acidification. Hence crop rotation with cereals crop is mandatory.

Suitable crops

- Soil has to be well manure and irrigated, some laterites are suitable for growing plantation crops like tea, coffee, rubber, cinchona, coconut, areca nut, etc.
- Plant fast-growing plant or tree in the area where its slope is more than 12%. Varieties of plant suitable are eucalyptus, bamboo, rain tree, Leguminosae, genus Cassia.

Lecture 14 and 15

DIAGNOSIS AND MAPPING OF LAND DEGRADATION USING RS AND GIS TOOLS

and

MONITORING LAND DETERIORATION BY FAST ASSESSMENT AND MODERN TOOLS

Information on geographical location, aerial extent and spatial distribution of wastelands is essential for their effective management and sustainable development. Among the new technologies emerged for studying natural resources, remote and Geographical Information System (GIS) are effective technologies for detecting, assessing, mapping, and monitoring the wastelands. Space borne multispectral data, by virtue of providing synoptic views of fairly large areas at regular intervals, have been found to be very effective in providing the necessary information on salt-affected soils and waterlogged areas in a timely and cost-effective manner.

In the visual interpretation of satellite data, high soil moisture and surface waterlogged areas are identified as deep dark grey to light black in color described that areas with high water logging risk. To study the spatial dynamics of wastelands, and to evaluate the utility of high resolution satellite data for wasteland mapping, the IRS P6 satellite data(23.5x 23.5 m) and topographical maps are generally used (Scale = 1:50000). The dynamic nature of wasteland categories warrants the uses of multi-season satellite data for their accurate delineation. Hence, such images need to be geo-referenced in a common coordinate and projection system. The Planning Commission of India has recognized GIS as "an invaluable planning tool in land use and wasteland development for identifying treatment areas and models, making trade-off calculations in choosing from competing land uses, and carrying out simulations and impact assessments. The management of "wastelands" is a priority area in the context of national development. In 1991, the Ministry of Environment and Forest (MoEF) embarked upon an ambitious project to apply GIS technology for wasteland management. This was based on prior work carried in 1986 when the Department of Science (DoS) under the National Wasteland Identification Project developed detailed wasteland maps of 147 districts in the country with a 1:50,000 scale. In this project, a Task Force was identified to evolve a suitable wasteland classification system. The classification system evolved and approved by the Planning Commission comprises of the following categories (NWDB, 1987):

i. Gullied and/or ravenous land
ii. Upland with or without scrub
iii. Waterlogged and marshy land

iv. Land affected by salinity/alkalinity(coastal or inland)
v. Shifting cultivation area
vi. Sandy (desert or coastal)
vii. Mining/industrial wastelands
viii. Under-utilized/degraded notified forest land
ix. Degraded pasatures/grazing land
x. Degraded land under plantation crops
xi. Barren rocky/stony wastes/sheet-rock areas
xii. Steep-sloping areas, and
xiii. Snow covered and/or glacial areas

The application of remotely sensed data in mapping degraded lands space borne sensors started with the launch of the first Earth Resources Technology Satellite (ERTS-1 / Landsat-1). However, the satellites Landsat-TM, SPOT and Indian Remote Sensing (IRS) Satellites with better spatial and spectral resolution, enabled to map and monitor degraded lands more 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.

Remote sensing imagery is vital for the understanding of land cover change, and thus forms an essential element of any effort to track land degradation and desertification trends. Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times. Change detection is an important process in monitoring and managing natural resources and urban development because it provides quantitative analysis of the spatial distribution of the population of interest. These studies may be helpful for the planners and stack holders in the process of overall sustainable development of the study area. For detection of temporal changes in the wastelands, two period data sets i.e., IRS, Linear Imaging Self-Scanning (LISS III) are used. The geodatabase generated using Arc GIS and on screen digitization techniques, shows the type, extent and spatial distribution of different wasteland categories present in the area. The procedure involved in wasteland mapping using satellite data consists of input data, preparatory work and methodology. The methodology normally adopted for mapping at any scale consists of preparation of base map, on –line visual interpretation of satellite data, development of legend, ground truth collection, analysis of soil samples, classification of degradation classes and finalization of maps in light of field information and analytical data. Thus, geocoded FCC products on 1:50000 scale are used for visual interpretation. The image characteristics, such as colour, tone, texture, pattern, shape, size, location and association enable one to identify and delineate different types of wastelands. These delineations, however, are tentative and subject to confirmation in the field. Therefore, ground truth forms a vital input to mapping with remote sensing data. The key for interpretation is subject to changes depending upon the season, scale and resolution of the imagery. Certain categories of wastelands like salt-affected land, water-logged/ marshy land and sandy areas can be easily delineated by virtue of their spectral separability, pattern and location; whereas gullied or ravenous land, shifting cultivation etc. can be delineated with moderate success. However, undulating upland with or without scrub cannot be easily delineateddue to similar reflectance pattern with fallow land. The issue can be resolved to some extent using multidate images.

Using space-borne multi-spectral data, maps, showing extent, spatial distribution and magnitude of eroded lands, salt-affected soils, waterlogged areas, shifting cultivation, to name a few, at 1:250,000 and 1:50,000 scales have been generated. The saline soils appear in different shades of white tone with fine to coarse texture on the False Colour Composite (FCC) prints of the satellite data, owing to presence of the salts, and are recognizable under normal crop growth. For assessing these soils, the National Remote Sensing Agency has prepared maps on1 : 250,000 scale using satellite data from Landsat Thematic Mapper (TM)/IRS sensors in association with other central and state government organizations. A digital atlas for India has been prepared. This information is being used for planning land reclamation and soil conservation programmes. Estimated area of wastelands in the country stands at 63.85 million hectares. Each maps shows village, forest compartment and micro watershed boundaries.

Image interpretation keys - Colour / Tone

White: Objects that reflect more light- Saline soil, sandy soil

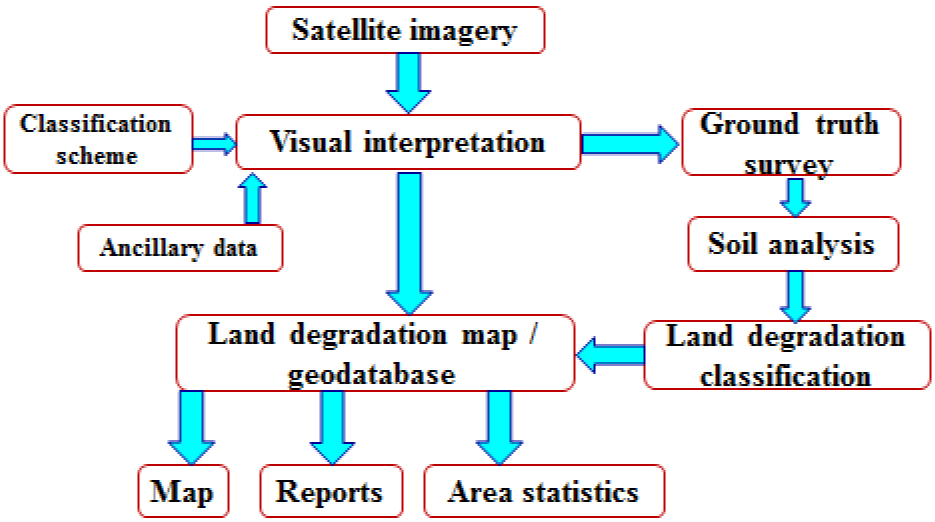
Black: Objects that reflects less light- Black soil, fire affected forest area

Green: Objects of red colour nature- Red soil

Red: Objects of green colour nature- Agricultural land, grasslands, forests

Blue: Objects of blue colour nature - Water bodies

Land degradation mapping using remote sensing and GIS approach



Land degradation assessment by remote sensing is carried out bases on the spectral reflectance of the surface soils. Degraded soils exhibits distinct spectral reflectance that are different from normal soils. This helps identification degraded soils easily from normal soil with remote sensing approaches. Eroded soils reflects more in the visible and NIR region. Saline soil exhibits bright white reflectance during summer but which is absent in monsoon season. Acid soil produces slight yellowish orange tone owing to higher iron content in soil samples. Surface ponding can be identified by the blue tone in imageries in different seasonal images continuously. Mining areas can be identified by the presence of blue tone in monsoon images (as similar to ponds) owing to stagnation of water during monsoon season. This can be confirmed by the landform and related information.

Sodic and calcareous soil do not produce distinct reflectance and hence it is difficult to delineate these degradation while visual interpretation. These soils are usually delineated with the help of previous soil maps and further ground truth verification. The factors such as vegetation cover, management, tillage practices, etc. alters the reflectance value of the soil thus by hinders mapping degrade land precisely.

Procedures

Study area map and multi-seasonal satellite imageries of summer, monsoon and post monsoon season is essential requirement for assessing degraded lands. Degraded lands exhibits different colour/tone in satellite imageries and hence comparing multi-seasonal image is must. Multi seasonal data helps to identify the non- vegetated areas, agricultural areas and saline soils clearly as it compares the different seasonal images of the study area.

In addition to this, ancillary information such as topographical map, vegetation map, previous soil map, climatic map is also required to arrive concrete conclusion on degradation.

First prepare the study area vector map. Then multi seasonal images need to be visually interpreted on-screen by considering Survey of India toposheets, soil map, physiography map, land use / land cover map and waste land map available at specific scale (not more than 1:50,000 scale). The various degraded lands are delineated through this visual interpretation and preliminary map is generated suitably.

Field Service to be carried out towards confirmation the interpretation through ground verification. Soil samples are to be collected from the respective ground truth points information such as location, landform, current land use, cropping pattern, source of irrigation etc. is also observed. Physical degradation can be directly confirmed throw field observation

The collected soil samples were analysed in the laboratory with respected to chemical properties. Based on chemical characterization, chemical degradation is confirmed. Further the severity or degree of Degradation is able to assess from the laboratory analysis which is not possible with visual interpretation of satellite imageries alone.

The information gathered through ground truth survey and soil analysis is transferred to the initial interpretation map. From this transferred information, final degradation map is to generated using suitable colour coding process at specific scales.

Mapping of sodicity, calcareousness, subsurface ponding and industrial effluent affected areas is not possible only with satellite data interpretation. It can be found out through more ground truth data along with soil analysis. Assessment of land degradation in small patches is relatively difficult. But this can be overcome by using high resolution satellite data.

Geodatabase on land degradation is very useful for planning conservation and rehabilitation of natural resources in the context of food security and environmental safety.

In Remote Sensing studies, Normalized Differential Vegetation Index (NDVI) is widely used for assessing vegetation cover. Landsat TM/ETM imageries are useful for this analysis.NOAA AVHRR data is useful for study on dry land areas using NDVI. Analysis such as linear regression analysis, distributed lag models, multiple stepwise regression and dynamic factor analysis is useful in land degradation assessment Global Land Degradation Information System (GLADIS) provides information on land degradation with your spatial resolution of 8 km x 8 km.

Lecture- 16

Land use policy, incentives and participatory approach for reversing land deterioration

The concept of land degradation neutrality (LDN) was introduced into the global dialogue to stimulate a more effective policy response to land degradation. LDN was adopted as target for Sustainable Development Goal 15, and building capacity to achieve LDN is a primary goal of the United Nations Convention to Combat Desertification (UNCCD, 2016).

LDN is defined as "a state whereby the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems" (UNCCD, 2016). The concept was raised to galvanise effort around a concrete target of "no net loss" and it aims to maintain the world's resource of healthy and productive land through a dual-pronged approach of measures to avoid or reduce land degradation, combined with measures to reverse existing degradation, such that losses are balanced by gains. The LDN target is a global goal and countries have been invited to commit voluntarily to LDN at the national level.

The UNCCD Science-Policy Interface (SPI) was requested by the UNCCD's Conference of the Parties (COP) to develop a scientific "Conceptual Framework for Land Degradation Neutrality" to provide a scientifically-sound basis for understanding and implementing LDN, and to inform the development of practical guidance for pursuing LDN and monitoring progress towards the LDN target. While the scope of the UNCCD is limited to drylands, the LDN conceptual framework is applicable across all land types, land uses, and ecosystem services. LDN will underpin the achievement of multiple SDGs related to food security, environmental protection and the sustainable use of natural resources.

Land Degradation Neutrality provides a great opportunity for the IUCN conservation and development sectors to address one of the most fundamental challenges to conservation and sustainable development. It is an ambitious target that will allow countries to track progress towards environmental sustainability across their entire terrestrial area. LDN is an aspiration that all conservation actors should support.

1. Integrated ecosystem management approaches should be central to achieving LDN. The conservation sector already provides a wide range of options to deliver LDN, through restoration, sustainable management, and conservation approaches which are gender responsive. Integrated ecosystem management approaches must be central to achieving LDN to ensure sustainability at all levels and to avoid unwanted trade-offs.

2. Natural resource governance should be strengthened to enable equitable LDN outcomes. This includes governance by resource users at a local level, governance by the state at local and national levels, and international agreements to govern issues at the transboundary, regional and global levels. It is important to recognise that not all resource users are in an equal position to participate fully and actively in the governance process and efforts will be needed to promote the empowerment of women, indigenous peoples, and other marginalised groups.

3. LDN should proceed on the basis of adequate evidence and monitoring, without evidence collection becoming a barrier to attaining the LDN goals. An appropriate balance is required to ensure that LDN progress can be tracked, unwanted externalities can be monitored, and the impact of actions in restoration and sustainable management can be assessed for their impact on biodiversity and on social outcomes.

4. Achieving LDN should build on the synergy with other conservation approaches and targets. LDN should not be seen as an additional burden, but as an opportunity for greater value-addition through the most integrative approaches. LDN should be recognised as a crucial framework for many environmental goals and should be given much greater prominence at the centre of conservation, sustainable development and climate change discourse. It is recommended that LDN build on existing National Action Programmes to Combat Desertification, which have been revised in line with the UNCCD 10 Year Strategy, which in turn has ensured greater alignment of the Convention with the UNFCCC and the CBD.

5. Innovative funding should be developed to support implementation of action towards LDN. Important efforts are needed to explore how synergies between conservation and sustainable development LDN actions can be financed through national and international financial flows, justified by ecosystem benefits that accrue to society at the national and global levels, in the form of Payment for Ecosystem Services.

Lecture-17

Global issues for twenty first century

1. Genetic modification of crops

Environmental issues caused by man-made chemicals are becoming clearer. For example, there has been a 90% reduction in the Monarch butterfly population in the United States that can be linked to weed killers that contain glyphosate. There is also some speculation that genetically-modified plants may leak chemical compounds into soil through their roots, possibly affecting communities of microorganisms.

2. Desertification

Desertification is a type of land degradation in drylands in which biological productivity is lost due to natural processes or induced by human activities whereby fertile areas become increasingly more arid. It is the spread of arid areas caused by a variety of factors, such as through climate change (particularly the current global warming) and through the overexploitation of soil through human activity

When deserts appear automatically over the natural course of a planet's life cycle, then it can be called a natural phenomenon; however, when deserts emerge due to the rampant and unchecked depletion of nutrients in soil that are essential for it to remain arable, then a virtual "soil death" can be spoken of, which traces its cause back to human overexploitation. Desertification is a significant global ecological and environmental problem with far reaching consequences on socio-economic and political conditions.

3. Soil degradation

Soil degradation is the physical, chemical and biological decline in soil quality. It can be the loss of organic matter, decline in soil fertility, and structural condition, erosion, adverse changes in salinity, acidity or alkalinity, and the effects of toxic chemicals, pollutants or excessive flooding. Soil degradation causes include agricultural, industrial, and commercial pollution; loss of arable land due to urban expansion, overgrazing, and unsustainable agricultural practices; and long-term climatic changes.

4. Waste production

The average person produces 4.3 pounds of waste per day, with the United States alone accounting for 220 million tons per year. Much of this waste ends up in landfills, which generate enormous amounts of methane. Not only does this create explosion hazards, but methane also ranks as one of the worst of the greenhouse gases because of its high global warming potential.

5. Population growth

Many of the issues listed here result from the massive population growth that Earth has experienced in the last century. The planet's population grows by 1.13% per year, which works out to 80 million people. This results in a number of issues, such as a lack of fresh water, habitat loss for wild animals, overuse of natural resources and even species extinction. The latter is particularly damaging, as the planet is now losing 30,000 species per year.

6. Water pollution

Fresh water is crucial to life on Earth, yet more sources are being polluted through human activities each year. On a global scale, 2 million tons of sewage, agricultural and industrial waste enters the world's water every day. Water pollution can have harmful effects outside of contamination of the water we drink. It also disrupts marine life, sometimes altering reproductive cycles and increasing mortality rates.

7. Deforestation

The demands of an increasing population has resulted in increasing levels of deforestation. Current estimates state that the planet is losing 80,000 acres of tropical forests per day. This results in loss of habitat for many species, placing many at risk and leading to large-scale extinction. Furthermore, deforestation is estimated to produce 15% of the world's greenhouse gas emissions.

8. Urban Sprawl

The continued expansion of urban areas into traditionally rural regions is not without its problems. Urban sprawl has been linked to environmental issues like air and water pollution increases, in addition to the creation of heat-islands. Satellite images produced by NASA have also shown how urban sprawl contributes to forest fragmentation, which often leads to larger deforestation.

9. Overfishing

It is estimated that 63% of global fish stocks are now considered overfished. This has led to many fishing fleets heading to new waters, which will only serve to deplete fish stocks further. Overfishing leads to a misbalance of ocean life, severely affecting natural ecosystems in the process. Furthermore, it also has negative effects on coastal communities that rely on fishing to support their economies.

10. Acid rain

Acid rain comes as a result of air pollution, mostly through chemicals released into the environment when fuel is burned. Its effects are most clearly seen in aquatic ecosystems, where increasing acidity in the water can lead to animal deaths. It also causes various issues for trees. Though it doesn't kill trees directly, acid rain does weaken them by damaging leaves, poisoning the trees and limiting their available nutrients.

11. Ozone layer depletion

Ozone depletion is caused by the release of chemicals, primarily chlorine and bromide, into the atmosphere. A single atom of either has the potential to destroy thousands of ozone molecules before leaving the stratosphere. Ozone depletion results in more UVB radiation reaching the Earth's surface. UVB has been linked to skin cancer and eye disease, plus it affects plant life and has been linked to a reduction of plankton in marine environments.

12. Ocean acidification

Ocean acidification is the term used to describe the continued lowering of the pH levels of the Earth's oceans as a result of carbon dioxide emissions. It is estimated that ocean acidity will increase by 150% by 2100 if efforts aren't made to halt it. This increase in acidification can have dire effect on calcifying species, such as shellfish. This causes issues throughout the food chain and may lead to reductions in aquatic life that would otherwise not be affected by acidification.

13. Air pollution

Air pollution is becoming an increasingly dangerous problem, particularly in heavily-populated cities. The World Health Organization (WHO) has found that 80% of people living in urban areas are exposed to air quality levels deemed unfit by the organization. It is also directly linked to other environmental issues, such as acid rain and eutrophication. Animals and humans are also at risk of developing a number of health problems due to air pollution.

14. Lowered biodiversity

Continued human activities and expansion has led to lowered biodiversity. A lack of biodiversity means that future generations will have to deal with increasing vulnerability of plants to pests and fewer sources of fresh water. Some studies have found that lowered biodiversity has as pronounced an impact as climate change and pollution on ecosystems, particularly in areas with higher amounts of species extinction.

15. Nitrogen cycle

With most of the focus being placed on the carbon cycle, the effects of human use of nitrogen often slips under the radar. It is estimated that agriculture may be responsible for half of the nitrogen fixation on earth, primarily through the use and production of man-made fertilizers.Excess levels of nitrogen in water can cause issues in marine ecosystems, primarily through overstimulation of plant and algae growth. This can result in blocked intakes and less light getting to deeper waters, damaging the rest of the marine population.

16. Natural resource use

Recent studies have shown that humanity uses so many natural resources that we would need almost 1.5 Earths to cover our needs. This is only set to increase as industrialization continues in nations like China and India.Increased resource use is linked to a number of other environmental issues, such as air pollution and population growth. Over time, the depletion of these resources will lead to an energy crisis, plus the chemicals emitted by many natural resources are strong contributors to climate change.

17. Transportation

An ever-growing population needs transportation, much of which is fueled by the natural resources that emit greenhouse gases, such as petroleum. In 2014, transportation accounted for 26% of all greenhouse gas emissions. Transportation also contributes to a range of other environmental issues, such as the destruction of natural habitats and increase in air pollution.

18. Polar ice caps

The issue of the melting of polar ice caps is a contentious one. While NASA studies have shown that the amount of ice in Antarctica is actually increasing, these rises only amount to a third of what is being lost in the Arctic.There is strong evidence to suggest that sea levels are rising, with the Arctic ice caps melting being a major contributor. Over time, this could lead to extensive flooding, contamination of drinking water and major changes in ecosystems.

19. Climate change

The majority of the issues previously listed contribute or are linked to climate change. Statistics created by NASA state that global temperatures have risen by 1.7 degrees Fahrenheit since 1880, which is directly linked to a reduction in Arctic ice of 13.3% per decade. The effects of climate change are widespread, as it will cause issues with deforestation, water supplies, oceans and ecosystems. Each of these have widespread implications of their own, marking climate change as the major environmental issue the planet faces today.