ISBN: 978-81-973427-5-2

11. Problem Soils: Distribution, Characterization and Reclamation

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Abstract:

India's diverse climatic zones foster a variety of soil types, but many possess inherent limitation that restrict plant growth and makes the soil problematic. These problematic soils are significant challenge for agricultural productivity and global food security.

This chapter explores the various types of problematic soils found in varied regions of India, their formation, distribution, characterization, impact on productivity and specific reclamation methods to enhance their fertility and supports sustainable agricultural practices.

Keywords:

Problem soils, reclamation, soil, sustainable

11.1 Introduction:

Problem soils are defined as the soils which possess specific characteristics that make the soil uneconomical or unproductive for the cultivation of crops without adopting any proper reclamation measures. This problem of soils are mainly caused due to constraints in physical and chemical properties of the soil. These limitations in the soil physical properties such as infiltration, bulk density, hydraulic conductivity, porosity, aggregate stability etc., leads to physical problem soils. Less rate of infiltration leads to formation of water-logged soils, while excessively permeable soils formed as a result of high infiltration rate, surface crusted soils characterized by high bulk density etc., Constraints in soil chemical properties such as Soil pH, Electrical conductivity (EC), Sodium Adsorption Ratio (SAR), Exchangeable Sodium Percent (ESP) etc., leads to problem soils related to acidity and alkalinity.

Acid soils formed due to weathering, heavy rainfall, laterization and podzolization. Acid-sulphate soils formed due to formation and subsequent oxidation of pyrites. Saline soils formed due to salinization. Sodic soils are characterized by excess of sodium ion concentration and combined characteristics of saline and sodic soils leads to occurrence of saline sodic soils. It is estimated that out of the 329Mha of total geographical area in the country, the total Acid soils accounts for an area of 49Mha and Acid sulphate soils for 0.39Mha. The saline and Sodic soils occupy an area of 29.5Mha and 37.7Mha respectively.

11.2 Acid Soil:

Acid soils are simply defined as soils whose pH value tend to decrease below the neutral normal range i.e., 7. In acid soils, the concentration of free or unbound hydrogen ions increases, that leads to the acidic soil conditions. Soils having pH range less than 5.5 can be considered as problematic soils due to significant decrease in nutrient elements such as Ca, P, Mg, Mo and their availability, which gives rise to severe deficiencies of the elements in these types of soils. Acid soils not only contribute to the unavailability of essential nutrients but also remarkably increase the level of aluminium in the soil solution, as in acidic conditions aluminium which is already present in the soil gets dissolved and transforms into ionic forms leading to Al toxicity. Soil orders such as Spodosols, Alfisols, Inceptisols, Histosols, Ultisols and Oxisols with udic and ustic moisture regimes belong to acidic soil orders. Kaolinite, hydrous mica, illite clay minerals are dominant in acidic soils. Acid soils are highly base unsaturated soils. The typical base saturation of acid soils falls between 20-25%.

A. Formation of Acid soils:

Acid soils develop due to the natural processes such as weathering, heavy rainfall, laterization and podzolization. These processes remove essential nutrients from the soil, leaving it concentrated with H^+ ions. Acid soils are formed mainly due to acidic parent materials (granite), use of acid forming fertilizers such as ammonium sulphate, ammonium nitrate, etc.

Table 11.1: Class of Acid Soil

Class of soil acidity	pH value
Extremely acidic	<4.5
Very Strongly acidic	4.5-5.0
Strongly acidic	5.1-5.5
Moderately acidic	5.6-6.0
Slightly acidic	6.1-6.5
*USDA (1957)	

Colloidal compounds such as Humus can also contribute to soil acidity as they contain functional groups such as carboxylic, phenolic groups which are capable of attracting and dissociating H^+ ions in the soil also influences soil pH. Aluminosilicate minerals under low pH takes part in hydrolysis reactions and release H^+ ions in the soil solution leading to soil acidity.

B. Distribution of Acid soil:

Out of the 3950Mha of land with acidic soil globally, 49Mha are located in India. Of this 26Mha have a pH less than 5.6 and 23Mha have a pH range of 5.6-6.5.

Around 2Mha of cultivable land in West Bengal are acidic in nature due to varying climatic conditions across the districts. Arunachal Pradesh, Manipur, Sikkim, Tamil Nadu, Kerala, Chhattisgarh, Nagaland, Tripura, and Assam have the most extensive areas of strongly acidic soil. Moderately acidic soils are found in Kerala, Assam, Chhattisgarh, Nagaland, Mizoram, and Meghalaya. It is found that acidic soils are heavily concentrated in the Northeastern region which accounts for at least 95% of the total area of the region with nearly two-third classified as strongly acidic. Other states have less than 1100ha under this classification. Apart from these states, acid soils can also be found in various other states including Himachal Pradesh, Jammu and Kashmir, Uttar Pradesh, Bihar, Pockets in the Indo-Gangetic plains, Coastal Andhra Pradesh and Parts of Karnataka and Maharashtra.

Types of Soil Acidity:

a. **Active acidity:** H^+ ions in the soil solution and Al^{3+} ions that release H^+ ions through hydrolysis contribute to active acidity. Active acidity influences the solubility of many substances by affecting the chemical form they take, making them more or less available for plant uptake. The expanse of active acidity can also be determined by the extent of clay and organic matter present in the soil. Since, soil with greater quantity of clay and organic matter act as a natural buffer as they hold onto H^+ ions, restricting their free movement and becoming too concentrated in the soil solution.
b. **Exchangeable acidity:** Adsorption of H^+ and Al^{3+} ions on the negatively charged surfaces of soil colloids creates exchangeable acidity. These ions are loosely bound and can be easily replaced by other cations, making exchangeable acidity a dynamic contributor to the overall soil acidity. Comparing to the active acidity the magnitude of exchangeable acidity in the soil is very high which leads to moderate to strong acidity. Soils rich in smectite type of clay generally have higher magnitude of exchangeable acidity compared to kaolinite clays due to their differential structural orientation. As a result, this type of clays shows higher CEC (Cation exchange capacity) and can therefore hold more H^+ and Al^{3+} ions than kaolinite.
c. **Residual Acidity:** Residual acidity develops due to aluminium hydroxide ions ($Al(OH)^{3-}$) and H^+ and Al^{3+} ions tightly bound to organic matter and silicate clays. This form of acidity is not readily released but represents a large potential source of acidity that can slowly contribute to soil acidity over time due to release of H^+ ions by weathering process. Therefore, residual acidity has very slight to minimal impact on plant growth in the short term. Residual acidity can be found in soil even after active and exchangeable acidity is neutralized.

Characterization of Acid soils:

- **Physical:**

a. **Light textured soil:** Acid soils mostly occur in region receiving good amount of rainfall. Rainfall causes leaching of the clay particles, which are smallest and denser to lower horizons of the soil profile leaving behind the larger sand and silt particles, resulting in lighter overall texture.
b. **High permeability:** Since acid soils are overall light textured containing more sand and silt particles than clay, they allow movement of water more easily due to presence of

larger pore spaces. Therefore, this type of soil has poor water holding capacity and high permeability.

c. **Poor organic matter content:** Acidic environments lead to slower decomposition of organic matter due to low microbial activity.

- **Chemical:**

a. **Base unsaturation:** Acidic soils are prone to leaching as because they occur in regions which receive larger to moderate amount of rainfall or precipitation. As a result an appreciable amount of bases (Ca^{2+} and Mg^{2+}) tends to wash away from the surface of the soil.

b. **Aluminium toxicity:** As pH declines, aluminium ions become more soluble and mobilize freely in the soil solution. These free aluminium ions are highly toxic to plant roots which significantly impact the nutrient uptake and root function of plants.

c. **Iron and Manganese toxicity:** Reduced products of these elements ($Fe^{3+}$to Fe^{2+} and Mn^{4+} to Mn^{2+}) arises in low pH conditions. Iron and manganese are essential elements for plants physiological function but due to their increased uptake can lead to toxicity.

d. **Nutrient imbalances:** In acid soils, increased solubility of iron and aluminium ions leads to their interaction with phosphate, which further results in formation of insoluble complexes which limit the phosphorus activity in soil. Also due the dominance of H^+ ions in acidic soils, they tend to react with phosphate ions converting them into insoluble forms and reduce their availability. Elements like boron and molybdenum are found in lesser amounts in acid soils due to their adsorption on sesquioxides.

- **Biological:**

a. **Microbial activity**: Most bacteria and actinomycetes operates in neutral to slightly alkaline pH (around 7-8). Therefore, at low pH conditions, bacterial population shows a sharp decline. Fungi can grow very well under acidic conditions and therefore their population rises. This results in various diseases like root rot of tobacco, blight of potato etc.

b. **Lower decomposition rates:** Rate of decomposition of biological material, mineralization and nitrification are reduced when acidity level in the soil environment rises. Since decomposition slows down in acidic conditions, there is less readily available organic matter for mineralization to occur. Acidic conditions also lower the level of essential nutrient such as Mo which directly affects the process of nitrification to occur.

C. Reclamation of Acid Soils:

a. **Lime Application:** Overtime, liming has proven to be the best for amelioration of acid soils. Applying lime to soil lowers the exchangeable acidity and therefore raises the pH. Liming also significantly boost the base saturation, reduces the toxicity of Al, Fe, &Mn and also reduces P fixation. It can also stimulate microbial activity by creating a more favorable pH environment for many microbes, leading to increased mineralization of organic matter. Some sources of lime are limestone, dolomite, calcite, slag etc.,

b. **Management of micronutrients:** In acid soils, deficiency of micronutrients such as B, Zn can be seen. For correcting B deficiency, application of borax, boric acid etc., can be done depending on the severity of the deficiency. Zinc sulphate can be a good measure for correcting zinc deficiency. Fe toxicity can be managed by providing intermittent drainage as it helps by allowing oxygen back into the soil. The oxygen helps converting excess Fe^{2+} to less toxic form Fe^{3+} that plants can readily absorb.

c. **Integrated Nutrient Management:** This approach reduces the dependency on the use of chemical fertilizers for correcting acid soils. Chemical fertilizers, integrated with lime and organic manures has shown high nutrient use efficiency in comparison to inorganic fertilizers alone. Organic manures act as a slow-release source of nutrients and lime helps in adjusting the soil pH.
d. **Growing suitable crops:** Crops grown in acidic soils are mainly, rice, cassava, certain fruits crops such as pineapple, mango etc.,
e. **Other management practices:** For management of subsoil acidity, gypsum can be used as it displaces Al^{3+} ions in subsoil which are harmful to plant roots. The sulphate (So_4^{2-}) component of the gypsum additionally reacts with the displaced Al^{3+} ions reducing its toxicity. Phosphorus management in acid soils can be carried out by using rock phosphate.

11.3 Acid Sulphate Soil:

Soils naturally rich in iron sulfide minerals, like pyrite (FeS_2) are called as acid sulphate soils. Acid sulphate soils are commonly found in low-lying areas like estuaries and wetlands, where waterlogged conditions prevail. Dutch farmers referred acid sulphate soils as Cat-clays due to their pale yellow colour which is obtained from yellow mottles of jarosites and infertile nature.

The pH of acid sulphate soils are found below 4 if drained. Prior to drainage, acid sulphate soils may have neutral to near neutral pH and are called potential acid sulphate soils. They are harmless in this undisturbed state but when exposed to air, the sulfides react with oxygen and form sulfuric acid which create acidic conditions in the soil and needs to be reclaimed for cultivation purposes.

Acid sulphate soils are generally grouped under Inceptisol and Entisol soil orders. *Sulphaquepts, sulphihemists, sulphohemists and sulphaquents* are the great groups which come under this soil.

A. Formation of Acid sulphate soils:

Acid sulphate soils develop through two main processes:1) Formation of pyrites under waterlogged conditions and 2) The subsequent oxidation of pyrite when exposed to air. The tropical coastal areas often have high content of sulphate in water due to factors such as salt water intrusion. These sulphates combine with iron to form pyrites. The sulphates are also biologically reduced to sulfides under aerobic conditions.

The source of iron may be found due to the reduction of insoluble ferric compounds resulting from weathering of clay. Upon drainage and exposure to aerated conditions, sulfide is oxidized to sulphates. This oxidation can be driven by both biological activities (e.g. *Thiobacillus*) and chemical reactions to form sulfuric acid which results in low pH.

B. Distribution of Acid sulphate soils:

Acid sulphate soil is estimated to occupy an area of 50Mha globally (Sullivan et al.). India accounts for an area of 0.39Mha under acid sulphate soils. These are mostly found near coastal areas of Kerala, Orissa, West Bengal, Andhra Pradesh and Tamil Nadu. Acid sulphate soils cover approximately 0.11Mha area in Kerala. In west Bengal, nearly 0.28Mha area comes under acid sulphate soils and is mainly spread over sunderban region.

Kerala and the Andaman and Nicobar group of islands together contributes 0.26Mha area for Acid sulphate soils.

C. Characterization Acid Sulphate Soils:

a. Presence of Sulfuric horizon: Acid sulphate soils are characterized by an extremely acidic layer of soil, often reaching a pH below 3.5. This layer is termed as sulfuric horizon. This layer is mostly rich in sulfides, which react with oxygen to form sulfuric acid when the soil is drained or disturbed.

b. Elemental toxicity: The extreme acidic conditions result in the release of toxic metals like aluminium and iron which are harmful for crop growth.

c. Reduced Nutrient availability: Essential Nutrients like Phosphorus become bound to Al and Fe released by the acidic soil conditions making them unavailable for plant uptake.

d. *Akiochi* disease: *Akiochi* disease is caused by hydrogen sulfide toxicity. This gas thrives in lowland rice soils under highly reduced conditions where there is little oxygen. This disease prevents the rice plant roots for the uptake of essential nutrients from the soil.

D. Reclamation of Acid sulphate soils:

a. Minimum disturbance: Acid sulphate soils should be left undisturbed to avoid creating acidic runoff. After thorough characterization of the acid sulphate sites, strategies can be made out to minimize their disturbances.

b. Flooding: Keeping the acid sulphate soils flooded will restrict the oxidation of the soils and helps in keeping them in anaerobic conditions. This will reduce the formation of acidic environments.

c. Controlling water table: Sometimes, there is a presence of non-acidifying layer, like clay or peat, which act as a barrier, preventing the upward movement of sulfuric acid formed in the lower sulfuric horizon. In that case drainage can be implemented to lower the water table just enough to expose the upper portion of soil profile for desired land use, while keeping the sulfuric horizon submerged. This minimizes oxygen exposure and further acidification to take place.

d. Hydraulic separation: This approach is mainly followed in sandy soils rich in iron sulfide. Mineral separation techniques such as sluicing or hydrocycloning can be adapted to hydraulically separate the sulfides from the bulk sandy materials.

e. Sea water re-flooding: Sea water is denser than freshwater, and hence when the acid sulphate soils are re-flooded with seawater, they form a dense layer below the freshwater containing the acid leachate.

This density difference act as a barrier, hindering the upward movement of the acidic leachate toward the surface limiting its export. This method is simple and cheap but has occurred as a short-term solution.

f. Bioremediation: Bacteria, particularly sulphate reducing bacteria are incorporated in the soil. They consume dissolved SO_4^{2-} ions and convert them to sulfide minerals (e.g. pyrite) under oxygen limiting conditions. By utilizing sulfate ions these bacteria effectively reduce the key component needed for sulfuric acid production.

g. Growing suitable crops: The best suited crop which can be grown in this type of soil is rice. This will raise the pH of the soil and reduce the Aluminium and iron toxicity.

h. Deep soil mixing: Hollow flight auger with mixing paddles is used to drill holes to the substrate. Lime, cement or other binding agents mixed with soil slurry are then poured into these holes and allowed for cementation. This will provide with solid supporting columns in the soil.

i. Liming: In any type of acid soils, liming is a primary reclamation method followed. But due to the strong acidic nature of the acid sulphate soils, requirement of lime is huge which is practically and economically not feasible. Therefore, liming in acid sulphate soils is generally not recommended.

11.4 Salt Affected Soils:

Salt-affected soils (SAS), encompassing saline, sodic and saline - sodic types, are found across diverse climatic regimes, posing a significant threat to global agricultural productivity. Globally, vast areas of 932.2Mha are classified as SAS, with an additional 6.74Mha in India alone. Despite of reclamation efforts, only 2.1Mha of salt affected land has been successfully restored in India. SAS are distributed across 14 Indian states and the Andaman and Nicobar Islands. They are predominantly found in the Indo-Gangetic plains including Uttar Pradesh, Bihar, Haryana, Punjab, and West Bengal. Interestingly, SAS also extends to arid and semi-arid regions, as well as coastal areas exposed to seawater inundation. Salt - affected soils majorly includes saline (high soluble salts) and sodic (high sodium) subtypes, with saline-sodic soils exhibiting characteristics of both. Classified as intrazonal halomorphic soils, SAS pose a significant threat to national economy due to their widespread presence. Cost effective and scalable reclamation strategies are crucial for remediation efforts.

11.4.1 Saline Soils:

A. Distribution of saline soils:

The distribution of saline soils in India exhibits significant spatial heterogeneity. Across the globe, a substantial area of 351.2Mha is characterized by saline soils. An estimated 29.5Mha of saline soils are distributed across 12 states and one union territory in India. Gujarat, Andhra Pradesh, West Bengal, Odisha, Tamil Nadu, and the Andaman and Nicobar Islands exhibit prominent areas of saline soils with varying salinity levels. These soils can be broadly categorized into inland saline soils (1.75Mha) and coastal saline soils (1.2Mha). Inland saline soils are typically found in arid and semi-arid regions with poor groundwater quality. In contrast, coastal saline soils occur in areas experiencing frequent seawater inundation.

B. Characterization of Saline Soil:

Saline soils are distinguished by high EC > 4 dS/m which indicates accumulation of soluble salts. SAR < 3 and ESP < 15. pH of the soil is usually < 8.5. Saline soils are characterized by the presence of neutral soluble salts and these salts are composed of cations like Na^+, Ca^{2+}, Mg^{2+} and anions like Cl^- and SO_4^{2-}. While small amounts of K^+, NH_4^+, NO_3^{2-} and organic carbon may also be present. Chlorides and sulphates of Na^+, Ca^{2+} and Mg^{2+} are the dominant soluble salts in saline soils. Saline soils are characterized by a white surface encrustation and these soils correspond to Hilgard's white alkali soils and to the Solanchalks of the Russian soil scientist. While the organic matter content is slightly lower than usual, this soil has a higher concentration of soluble salts, exceeding 0.1%. This salinity keeps the soil particles flocculated, resulting in permeability equal to or even greater than non-saline soils.

C. Formation of Saline Soils:

The process of salinization leads to the formation of saline soils. In humid regions, persistent rainfall facilitates the leaching of soluble salts into groundwater, ultimately transporting them to streams and oceans. Consequently, saline soils are exceptionally rare in these areas, except in instances where intrusion of sea water occurs. This phenomenon is particularly evident in coastal regions. In arid environments, scarce precipitation and high evaporation rates lead to a buildup of salts in soil and surface water. This process is further intensified by a high-water table or low soil permeability, which restricts drainage and exacerbates salinization. The accumulation of salts in soil, can occur naturally due to factors like chemical weathering of rocks, climatical changes in arid and semi-arid regions, dissolved salts in groundwater and seawater inundation. Human activities such as improper irrigation, excessive use of fertilizer can also accelerate this process.

D. Problems Encountered in Saline Soils:

- High salt levels in soil increases osmotic pressure and make it difficult for plants to absorb water and can also hinder nutrient uptake, harming plant health.
- High salt concentrations harm plants by injuring roots, hindering seed germination and overall growth. Additionally, high salt levels can lead to toxicity of chloride and bicarbonates and disrupt calcium uptake by interfering with magnesium or its salts.
- Soils are potentially productive, but they are usually barren.
- Wilting Coefficient is very high.
- Available moisture content is very low.

E. Reclamation of Saline Soils:

a. Physical methods:

- Construction of the bunds to prevent intrusion of sea water.
- Proper drainage network establishment.

- Another simple method for removing surface salt accumulation is Scraping, which offers only a temporary solution. While it can improve crop growth in the short term, it doesn't address the underlying source of the salt or prevent it from returning.
- Soil conditioners like sand, ash, manure and synthetic polymer like Polyvinyl acetate (PVAC) and Polyacrylamide (PAM) improves soil health.

b. Hydrological methods:

- **Surface flushing:** Surface irrigation with runoff is a technique for removing salts from soil with very poor infiltration rates. This approach is appropriate when subsurface drainage methods are impractical due to soil limitations.
- **Leaching:** Reclamation of saline soils involves applying large volumes of irrigation water having low to moderate salinity. This facilitates the downward movement of salt beyond the root zone. The leaching frequency is influenced by soil texture, water table depth and season. Ideally, leaching should be carried out during the dry periods when the soil moisture content is low. However, leaching throughout the cropping season may be necessary to prevent salt accumulation from irrigation water exceeding tolerance levels for cultivated crops.
- **Drainage Systems:** Drainage refers to the removal of excess water from the soil profile, categorized as surface drainage and subsurface drainage. The Central Soil Salinity Research Institute (CSSRI) of the Indian Council of Agricultural Research (ICAR) recommends standardized subsurface drainage techniques for agricultural land. These techniques involve installing underground pipes at specific depths and intervals to intercept floodwater and seepage. Additionally, vertical disposal drains are constructed within the field and connected to natural drainage channels to facilitate the removal of excess water.
- **Continuous and intermittent ponding:** A large volume of standing water is applied continuously until the salts are flushed from the root zone. Water quantity depends on soil types and initial salinity while in intermittent ponding, smaller water applications are done in cycles followed by period of dry down. This wetting - drying process effectively leaches salts from small pores, especially efficient in low evaporation winters.

c. biological methods:

- **Selection of suitable crops:** Choosing the right crops for saline soils is crucial. Among field crops barley, sugar beet, and wheat are highly tolerant. For forage wheatgrass, crested wheatgrass, wildrye, or alkali grass can be grown. Date palms are the most tolerant fruit crop, while pomegranate, fig, olive, and grape show moderate tolerance. In vegetables, kale, asparagus, and spinach thrive in saline conditions, while tomato, broccoli, cabbage, black pepper, cauliflower, lettuce and potato have moderate tolerance.
- **Single and double row bed furrow irrigation:** This technique involves the alternate wetting and drying cycles to manage soil salinity. Irrigation water pushes salts to the dry side of the furrow, but heavy rain or accidental irrigation can reverse this process which affects the plant growth.

d. Chemical methods:

- Limestone ($CaCO_3$) is used for reclamation of saline soils having pH less than 8 and gypsum ($CaSO_4.2H_2O$) for soils having pH upto 9.

11.5 Sodic Soils:

A. Distribution:

Sodic soils, also known as black alkali soils or solonetz, encompass a vast area of 581Mha globally, impacting agricultural productivity. In India, these soils cover approximately 37.7Mha, primarily distributed across the Indo-Gangetic Plain (47%), arid and semi-arid regions of western and central India (35%), and the peninsular region of southern India (18%). The specific states most affected within each region include Uttar Pradesh, Haryana, Punjab, and Bihar in the Indo-Gangetic Plain, Gujarat, Rajasthan, Madhya Pradesh and Maharashtra in the arid and semi-arid regions, and Tamil Nadu, Andhra Pradesh, and Karnataka in the peninsular region. It is crucial to note that the severity of sodicity can vary significantly within these regions.

B. Characterization of Sodic Soils:

Sodic soils / alkali soils, exhibit specific characteristics that challenge agricultural productivity. These soils typically have an EC > 4 dS/m, SAR > 13, and a pH ranging from 8.5 to 10. They are distinguished by an excess of ESP > 15 on the soil colloid complex. Sodium carbonate (Na_2CO_3) and bicarbonate ($NaHCO_3$) are the dominant salts, while the total soluble salt content remains relatively low (< 0.1%). Sodic soils are prevalent in arid and semi-arid regions.

The name black alkali soil stems from the deposition of dispersed and dissolved organic matter on the soil surface during evaporation, causing a darkening effect. Clay dispersion is a hallmark feature, leading to its downward movement within the soil profile. This clay accumulation in the lower layers coincides with a coarsening of texture at the surface, as coarse soil fractions get deposited there. The process involves hydrolysis of sodium clay, resulting in the formation of silica gels. These gels along with humates, act as cementing agents, fostering the development of a hardpan in the subsoil. Due to this deflocculated state, sodic soils suffer from poor air and water permeability, significantly hindering their overall structural integrity. Notably, the absence of gypsum during drainage and leaching of saline-alkali soils paves the way for the formation of these characteristics.

C. Formation of Sodic Soils:

In arid regions, Ca and Mg are the primary cations found in normal soil. However, an excess of soluble salts can lead to sodium dominance. This occurs when evaporation or plant water uptake concentrates the soil solution, the solubility limits of calcium sulphate ($CaSO_4$), calcium carbonate ($CaCO_3$), and magnesium carbonate ($MgCO_3$) are often exceeded and they get precipitated with a corresponding increase in sodium concentration.

Under such condition, Na replaces Ca and Mg on the soil exchange sites. This process results in the formation of alkali or sodic soils.

D. Problems of sodic soils:

- **Dispersion of soil colloids:** High sodium adsorption leading to the dispersion and deterioration of soil structure. This translates to reduced pore space, hindering air and water movement essential for plant growth.
- **Chemical deterioration:** The presence of soluble salts like sodium carbonate and bicarbonate increases soil pH, creating a caustic environment. This disrupts nutrient uptake and hinders plant growth.
- **Hydroxyl ion toxicity:** At extremely high pH (above 10.5), the concentration of hydroxyl (OH^-) ions becomes detrimental to plants. This hydroxyl toxicity can damage root membranes and limit nutrient uptake.
- **Reduced plant nutrient availability:** High pH in sodic soils restricts the availability of essential plant nutrients like P, Ca, Mg, N, Fe, Cu, Zn. This limitation arises due to various mechanisms, including precipitation, adsorption and fixation. Additionally, excess sodium disrupts cation exchange, inducing deficiencies of Ca and Mg through a phenomenon known as the complementary ion effect. These deficiencies coupled with potential micronutrient limitations, contributes to reduced crop productivity.
- **Impaired physical properties:** Dispersion and compaction of soil particles in sodic soils lead to a series of detrimental physical effects. Reduced aeration and hydraulic conductivity hinder air and water movement within the soil profile. This will restrict root respiration and uptake of nutrients. Additionally, these conditions limit microbial activity and drainage, further compromising soil health and plant growth.

E. Management:

a. Physical methods:

- Deep ploughing, subsoiling or profile inversion can help redistribute clay particles and disrupt hardpan formation.
- Land levelling, bunding and construction of field irrigation and drainage channels can improve water management and reduce soil erosion in sodic soils.

b. Hydrological methods:

- **Leaching (Salt precipitation):** It is a method of elimination of salt and exchangeable sodium ions by leaching of water. However, conventional leaching practices can lead to salinization of groundwater or surface water bodies.
  To mitigate this concern, a controlled leaching approach can be employed by strategically regulating the leaching depth (around 0.9-1.8 meters), salts can be mobilized and driven down to the soil profile.
  Under drier cycles, these salts can then precipitate as less soluble gypsum or carbonates, effectively removing them from circulation and preventing them from harming plant growth or contaminating water sources.

c. Biological methods:

- **Use of organic amendments**: Incorporating organic materials like green manure (e.g. Daincha), compost, farmyard manure, press mud, and crop residues (e.g. paddy straw) can significantly improve sodic soils. These amendments enhance soil organic matter content, promoting better soil structure, aggregation, and drainage. Green manuring with daincha, in combination with gypsum application, is a particularly beneficial practice for restoring physical soil conditions, enriching soil nitrogen content, and enhancing overall fertility. Furthermore, the application of spent wash followed by irrigation can be an effective strategy for sodic soil reclamation.
- **Selection of salt-tolerant plant species:** Planting salt-tolerant crops allows the utilization of the lands while promoting soil improvement. Moderately tolerant (ESP:30 to 50) varieties are barley, mustard, rapeseed, wheat, sunflower, sorghum and berseem whereas semi tolerant (ESP: 20 to 30) crops are linseed, garlic, sugarcane, cotton, groundnut, onion and bajra. Bengal gram, soybean, maize, safflower, peas, lentil, and pigeon pea are the sensitive crops (ESP < 20).
- **Selection of suitable cropping system:** Crop rotation hastens the reclamation process of sodic soils. Crop rotations that integrate salt-tolerant crops like rice, wheat, and green manure legumes (e.g. daincha) helps in sustained productivity and improved soil health through nitrogen fixation and organic matter addition. In highly sodic soils (pH > 10), adopting a silvipastoral model can be a viable approach for bioremediation. This system integrates trees and grasses/forage legumes. The trees help reduce surface runoff and enhance water infiltration, while the forage species contribute organic matter and improve soil health.

d. Chemical methods:

- **Gypsum technology:** Gypsum technology is a common technique for reclaiming sodic soils, developed under CSSRI in Karnal. Sulphates of Ca, Fe, Al are generally used as chemical amendments for reclamation. Acid formers like pyrite and lime sulphur are used in calcareous sodic soils, which are high in calcium carbonate. Soluble calcium salts are preferred for faster reclamation when the soils are deficient in calcium carbonate. Acid formers can be used with low solubility calcium salts, but the process is slower. To achieve effective reclamation, amendments like gypsum are generally broadcasted on the soil surface and incorporated using disc plough. However, for the amendments containing sulphur, leaching with irrigation water is recommended immediately after application to facilitate deeper penetration into soil profile.

11.6 Saline - Sodic Soils:

Saline-sodic soils present a unique challenge for agricultural management due to their combined characteristics of salinity and sodicity. These soils consist of both soluble salts and exchangeable sodium on the soil exchange complex. They are defined by specific EC exceeding 4dS/m, SAR > 13, and an ESP >15. pH can typically rise above 8.5 due to the presence of sodium and soluble salts. When the soil is dominated by excess salts (total soluble salt content > 0.1%), the properties resemble those of saline soils, often with a pH below 8.5.

However, when excess salts are leached away, a portion of the exchangeable sodium hydrolyzes to form sodium hydroxide (NaOH), which can further react with carbon dioxide (CO_2) to become sodium carbonate (Na_2CO_3). This process triggers extreme alkalinity (pH > 8.5) and dispersion of soil particles, leading to a deflocculated state. These soils are formed by the combined process of salinization and alkalization. The complex nature of saline-sodic soils necessitates a multifaceted management approach. Effective reclamation strategies require the removal of both excess salts and exchangeable sodium. The specific techniques employed depend on the dominant factor at play, drawing upon methods used for managing either saline or sodic soils.

11.7 Degraded Alkali Soils:

Extensive leaching of saline-sodic soils without a Ca and Mg source can lead to the formation of degraded alkali soils. This process involves the replacement of sodium ions on the soil exchange complex by hydrogen ions. However, this replacement results in an unstable soil structure and a slightly acidic upper layer (pH around 6). The consequence is a problematic soil, results in:

- A surface layer with acidic character (pH ≈ 6), low EC (< 4dS/m), and elevated ESP (>15) but with a SAR value < 13.
- A lower layer containing residual sodium (pH ≈ 8.5), possessing a SAR value >13 despite having low total soluble salts (<0.1%).

This uneven distribution of exchangeable cations contributes to the development of a columnar soil structure. The lower layer also acquires a characteristic black colour due to the dissolution and deposition of humic substances by sodium carbonate present in the leached solution. These degraded alkali soils become compacted, with significantly reduced infiltration and permeability, further hindering plant growth.

11.8 Calcareous Soils:

Calcareous soils are defined as the soils containing high levels of calcium carbonate affects soil properties related to plant growth, such as soil water relations and the availability of plant nutrients (Elgabaly,1973). Classified as zonal soils, they are prevalent in arid and semi-arid regions, encompassing an estimated one-third of the global land surface. The presence of $CaCO_3$ in the parent material and subsequent accumulation of lime are defining features of these soils. In some cases, $CaCO_3$ can concentrate into hardened caliche layers that impede water infiltration and root penetration. Calcareous soils share some problematic characteristics with alkali soils, particularly when Na_2CO_3 is present (calcareous-sodic soils). The pH typically ranges from 7 to 8.5, but can exceed 9 in the presence of Na_2CO_3. This higher pH is attributed to the combined effects of high pCO_2 (partial pressure of carbon dioxide) promoting the formation of undissociated carbonic acid (H_2CO_3), which reduces $CaCO_3$ hydrolysis and lower pCO_2 upon dilution leading to a rise in pH. Despite of these potential challenges, calcareous soils can be productive for various crops like forage legumes, corn, cotton, sugar beets, potatoes, and tomatoes. Notably, while these soils are rich in free lime ($CaCO_3$), they can also contain significant amounts of Fe, Al, and Mn either as individual minerals, as coatings on soil particles or complexed with soil organic matter.

11.9 Waterlogged Soils:

Soil waterlogging occurs when the soil becomes saturated with excess water, either temporarily or permanently.

This saturation leads to anaerobic conditions within the soil profile which retards vital gaseous exchange processes between soil and atmosphere.

Consequently, waterlogged soils become unproductive due to the presence of excess moisture and limited oxygen availability for plant roots and soil microbes. Waterlogging leads to poor aeration, anaerobic conditions, increased salinity, reduced soil temperature and there by retard plant and root growth.

A. Distribution:

Globally, waterlogged soils cover approximately 5 to 7% of the Earth's total land surface. The area affected by waterlogging is estimated to be 700-1000Mha worldwide.

In India, the states of Odisha, West Bengal and Uttar Pradesh experience the most significant waterlogging problems. The total waterlogged area in India is estimated to be around One Million hectares. (Planning Commission., 2011.)

B. Characterization:

These Soils are saturated with water for sufficiently long time in a year to give the soil the following distinctive gley horizons resulting from oxidation-reduction processes:

- A partially oxidized ‘A’ Horizon high in organic matter.
- A mottled zone in which oxidation and reduction alternate and
- A permanently reduced zone which is bluish green in colour. (Robinson G.W,1949.)

C. Reclamation:

- In areas prone to waterlogging, raised beds are formed during land preparation which improves aeration and helps in creation of artificial aerobic conditions for crop roots.
- Removal of excess water from the root zone by adopting proper drainage methods such as Surface drainage, Sub-surface drainage and drainage well methods based on the convenience and availability for the farmer.
- Removal of excess water from soil by using Bio-drainage method, in which water is removed by using deep rooted tree species which having high transpiration rate such as *Syzygium cumini*, *Pongamia pinnata*, *Terminalia arjuna*, *Casurina glauca*, *Eucalyptus tereticornis* which found effective for Bio-drainage purpose.
- Selection of Waterlogging tolerant crops (Rice, jute, sesbania etc.,) and varieties to reduce the huge economic losses.
- Mulching of soil surface acts as both preventive and reclamation measure which involves addition of organic matter to the topsoil.

11.10 Soil Crusting:

Soil crusting is a prevalent physical concern in arid and semi-arid regions. Soil crust is a thin, hardened layer that forms on the soil surface. It is denser than the soil below as a result of raindrop impact and subsequent drying. The thickness of the crust can vary from 1 mm to 5 cm (Evans and boul, 1968), depending on the amount of clay and silt in the soil. Soils with low organic matter (<1%) are more susceptible to crusting.

A. Causes of Soil Crusting:

- Beating action of rain drops.
- Fine soil textures which having higher amount of silt and clay content.
- Colloidal oxides of Iron and Aluminium in Alfisols.
- Excessive tillage and puddling of the soil.

B. Distribution:

India faces a substantial challenge from soil crusting, impacting approximately 10.25 Mha (3.1%) of its total geographical area (329 Mha). This phenomenon is concentrated in several states including Haryana, Punjab, West Bengal, Odisha, and Gujarat. (Brajendra and Bhadana, 2014).

C. Characteristics of soil Crust:

- Low porosity.
- High bulk density.
- Greater mechanical strength.
- Reduced infiltration rate.

D. Impacts:

- Prevents seed germination and retards root growth.
- Accelerated surface runoff as a result of poor infiltration.
- Compacted soil restricts air circulation to the rhizosphere.
- Nodule formation in leguminous crops is affected.

E. Mechanism of Crust formation:

- **Mechanical destruction of aggregates:** Low water stable aggregates gets disintegrated and dispersed by the beating action of rain drops.
- **Washing in:** The dispersed soil particles get washed into surface layer.
- **Re-orientation of the soil surface:** The dispersed soil particles clog the pores of the surface layer.
- **Compaction:** The rapid drying of soil surface causes the forces of surface tension to pull the dispersed particles together to form a thin compact soil crust. (A. K. Saha et al.,)

F. Reclamation:

- Scraping the soil surface by using implements such as tooth harrow, rotary hoe, finger type weeder, spring tooth harrow etc.,
- Mulching on the surface of the soil to avoid direct impact of rain drops to the soil surface.
- Sowing of bold grained seeds and for small, seeded crops, sow more number of seeds per hill.
- Application of artificial soil conditioners, polyanionic soil conditioners (HPAN-Hydrolyzed poly acrylo-nitrile, VAMA- Vinyl acetate maleic acid copolymer) and non-ionic soil conditioners (PVA- Poly vinyl alcohol).
- Apply lime or gypsum to the soil and spread it uniformly.

11.11 Conclusion:

The impact of problematic soils has severely affected the agricultural output. This is due to their intense ability to degrade the healthy soils. The complex interplay of natural processes (weathering, precipitation, parent material etc.) in combination with anthropogenic activities has led to their formation. By implementing the aforementioned management techniques, we can not only combat the current challenges but also enhance the inherent potential of the soil. Therefore, it is imperative for the agricultural community to embrace innovative scientific management practices alongside conventional reclamation methods to ensure sustainable agricultural productivity.

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