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Sodic soil in India: Concept, status and management

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Abstract
Sodic soil, characterized with high ESP (Exchangeable Sodium Percentage) (>15%), SAR (Sodium Adsorption Ratio) (>13) and pH (8.5-10) is considered as one of the important soil constraints causing reduced crop productivity. Out of the estimated 2.8 million hectares of sodic soils, about 2.5 million hectares occur in the Indo-Ganga plains. There are three distinct stages in the evaluation of sodic soils viz. salt accumulation, salinization and finally alkalization. Productivity of sodic soil is severely jeopardized by dispersion of soil colloid leading to slow infiltration, low permeability, water logging, poor soil tilth, cracking behaviour, soil crusting and poor microbial activities etc. The reclamation of sodic soil is an important step to increase the productivity of agricultural lands which includes chemical methods like application of gypsum, iron pyrite (FeS_2), sulphur, etc.; biological methods like application of organic wastes, mulching, crop rotation etc.; cultural methods like proper drainage, deep ploughing, frequently irrigation, land labelling and physical methods like proper tillage operation, flushing, scraping etc. Further research is required in this field to bring back more areas under cultivation from the menace of soil sodicity to sustain productivity and to ensure food security.

Keywords: Sodic soil, characteristics, impact, management

1. Introduction

The degradation of substantial land areas worldwide has been attributed to the presence of salt-affected soils. These soils are classified as problematic due to their detrimental impact on agricultural productivity. Saline soil is characterized by a high concentration of soluble salts, which hinder its fertility. Similarly, sodic or alkali soil is identified by the abundant presence of exchangeable sodium, which adversely affects its agricultural potential. This type of soil is also referred to as black alkali soil due to its elevated sodium carbonate content. When the soil's pH level increases, it causes the dissolution and upward movement of soil organic matter to the surface, resulting in salt deposits and a brown to black coloration. Sodic soil emerges when approximately 15% of all cations in the soil are bound to clay particles, leading to structural issues. The level of sodium in the soil, quantified as Exchangeable Sodium Percentage (ESP), serves as a critical measure of sodicity. High pH levels (exceeding 8.5) and elevated sodicity are the primary factors contributing to reduced soil productivity. Sodium carbonate is the predominant soluble salt in sodic soils, accompanied by a high Sodium Absorption Ratio (SAR). In such soils, clay particles swell and obstruct soil pores, causing reduced permeability to water and air (Kumar *et al.*, 2022) [6]. In India, regions with mean annual rainfall ranging from 55 to 90 cm are more susceptible to the presence of sodic soil. These soils typically occur in flat terrains with inadequate natural drainage, where weathering by products accumulate during the wet season. Extensive evaporation during the post-rainy season leads to soil solution concentration, resulting in elevated SAR, sodium levels, and pH values (Kumar *et al.*, 2020) [5]. Approximately 2.5 million hectares of the estimated 2.8 million hectares of sodic soil in India are located in the Indo Ganga plains of Uttar Pradesh, Haryana, and Punjab. The remaining sodic soil can be found in regions such as Bihar, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan, and Tamil Nadu (Sharma *et al.*, 2016) [10].

2. Formation of Sodic Soil

The mechanisms responsible for the formation of sodium carbonate in soils which characterize sodic soil have been discussed in several standard works -

- Groundwater containing carbonate and bicarbonate is one of the chief contributing factors in the formation of sodic soils in many regions (Sharma *et al.*, 2016) [10].
- Reduction of sulphate ions under anaerobic conditions and in the presence of organic matter was reported to result in formation of sodium carbonate.

Salt accumulation represents the initial stage in a sequential process (Fig 1) that is common to the family of salt-affected soils, predominantly occurring in regions characterized by a mean annual rainfall ranging from 55 to 90 cm and featuring low-lying areas with insufficient drainage. The formation of sodic soil is a consequence of cation exchange within the soil solution and the exchange complex of the soil itself (Paz *et al.*, 2023) [9].

The cations found in the solution phase of salts maintain equilibrium with those associated with the soil colloids. Conditions leading to an increase in the Sodium Adsorption Ratio (SAR) of the soil solution subsequently give rise to the development of sodic soil. There are three distinct stages involved in the evolution of alkali soils, namely:

1. Salt accumulation
2. Salinization
3. Alkalization, which includes desalination and the intense formation of alkali soil

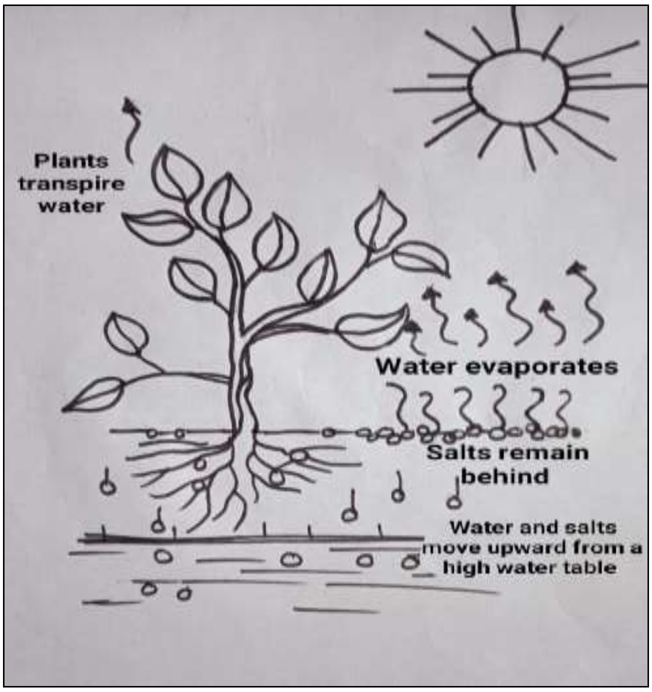

Fig 1: Formation of Sodic Soil

2.1. Salt accumulation: It is the first stage of the formation of sodic soil. It is the result of exchange of cations in soil solution [especially Na^+] with those present on the exchange complex of the soil (Paz *et al*., 2023) [9].

$$[Clay]\,[Ca^{2+}] + 2Na^+ = [Clay]\ \text{i.}[Na],\ \text{ii.}[Na] + [Ca^{2+}]$$
$$[Ca^{2+}]\,[Clay] + 2Na^+ = \sum clay\ \text{i.}[Na^+]\ \text{ii.}[Na^+] + [Ca^{2+}]$$

2.2. Salt salinization: It occurs through the accumulation of salts from irrigated water or fertilizers. Irrigated water contains dissolved salts & as this water evaporates out of the soil, the remain left in the topsoil. It is an excessive accumulation of water-soluble salts. (Katkar *et al*., 2019) [4]

Cause

1) Dry climates & low precipitation
2) High evaporation rate
3) Poor drainage
4) Removal of deep – rooted vegetation

$$[Ca^{2+}]\,[Clay] + [Na^+]\,[salt] = [Na^+]\,[clay] + [Ca^{2+}]\,[salt]$$

2.3. Alkalization: It results from the concentration & precipitation of water-soluble salts such as chlorides sulphates & carbonates of Na, Mg or Cl on the surface or in the subsurface of soil.

In arid regions as the soil solution becomes concentrated through evaporation or water absorption by plants, the solubility limits of $CaSO_4$, $CaCO_3$, $MgCO_3$ often exceeded in which case they are precipitated with a corresponding increase in sodium concentration. Under this condition the exchangeable Ca^{2+}, and Mg^{2+} is replaced by Na^+ resulting alkali or sodic soil.

3. Major Problems of Sodic Soil

The physical and chemical characteristics of soils are impacted by excessive concentration of exchangeable sodium in alkali soils. Major issues with sodic soils include:

- **Concentration of hydroxyl (OH^-) ion**: There is no doubt that high hydroxyl (OH-) ion concentration directly hampers plant growth. At pH 10.5 or higher, hydroxyl ions cause damage.
- **Slow water infiltration capacity:** Alkali soils have very low infiltration and permeability, which causes water logging and inadequate ventilation that affects root respiration. As a result, plants die after a few days of water stagnation (Kumar *et al*., 2022) [6].
- **Caustic Influence**: High sodicity is the outcome of caustic influences that comes from sodium carbonate (Na_2CO_3) and sodium bicarbonate ($NaHCO_3$).
- **Decreasing availability of plant nutrients:** The availability of many plants nutrients, including P, Ca, N, Mg, Fe, Cu, and Zn are significantly reduced by the high pH of alkaline or sodic soils.
- **Very poor soil tilth:** Due to high pH and ESP, the soil tilth in alkali soils is quite weak that makes tillage operation very difficult for the farmers (Mandal *et al*., 2022) [7].
- **Crust Formation:** When wetted by rain or irrigation water, sodic soils have little structural stability; it scatters and slakes, and may form a hard crust when the surface dries. The emergence of seedlings is severely hampered by this reason.
- **Cracking Behaviour:** Due to their high ESP, soils are widely scattered, which causes them to soften when wet and harden when dried. This results in formation of soil cracks in the surface.
- **Inhibits plant growth:** A sufficient amount of ESP in the soil has a detrimental effect on plant growth and also inhibits plant growth by specifically toxicating sodium-sensitive plants. (Mandal *et al*., 2023) [8]
- **Poor Microbial Activities:** Reduced microbial activity can be caused by changes in pH, dissolved organic carbon, high sodium ion [Na^+] concentration, poor hydraulic conductivities.

4. Management of Sodic Soil

The main issue behind poor productivity of sodic soil is high ESP. The fundamental idea behind reclaiming these soils is to implement procedures that allow exchangeable sodium to be replaced by calcium and released as sodium salt that leaches out of the root zone.

4.1. Chemical Methods

Different types of chemical amendments:

a) Soluble calcium salts e.g.
- Calcium chloride ($CaCl_2.2H_2O$)
- Gypsum ($CaSO_4.2H_2O$)
- Calcium sulphate (CaSO4)

b) Acid or acid formers e.g.
- Sulphur (S)
- Sulphuric acid (H_2SO_4)

- Iron sulphate ($FeSO_4.7H_2O$)
- Aluminium sulphate [$Al_2(SO_4)_3.18H_2O$]
- Lime sulphur (calcium poly sulphide (CaS_2)
- Pyrites (FeS_2)

Chemical reactions involving reclamation of sodic soil

4.1.1. Gypsum: Gypsum has been utilized frequently and extensively as an amendment for reclamation due to its low cost and ease of availability. When gypsum is added to soil, the following reaction will take place and lose of exchangeable sodium (Na^+) occurs and calcium replace the sodium on the exchange complex.

$Na_2CO_3 + CaSO_4 === CaCO_3 + Na_2SO_4 \downarrow$ Leachable
Clay] Na + $CaSO_4$ === Ca [clay + $Na_2SO_4 \downarrow$ Leachable

4.1.2 Sulphur: When Sulphur is applied to sodic soil the following reactions takes place-

$2S + 3O_2 = 2SO_3$ (By the action of sulphur oxiding bacteria in soil)
$SO_3 + H_2O = H_2SO_4$
$H_2SO_4 + Na_2CO_3 = CO_2 + H_2O + Na_2SO_4 \downarrow$ Leachable

4.1.3. Iron pyrite (FeS_2): Use of pyrite and FYM decrease the soil pH and ESP through-

$FeS_2 + 3\ ½O_2 + H_2O === FeSO_4 + H_2SO_4$
$FeSO_4 + H_2O === H_2SO_4 + Fe(OH)_2$
$H_2SO_4 + CaCO_3 === CaSO_4 + H_2O + CO_2$
$CaSO_4$ + Na[Clay === Ca [clay + $Na_2SO_4 \downarrow$ Leachable

4.2. Biological Methods

4.2.1 Organic waste and components: Bulky organic manures, green manures, and crop residues that produce weak organic acids aid in reclaiming land by briefly producing an acidic environment. (Katkar *et al*., 2019) [4]. The physical and chemical characteristics of the soil are improved by applying FYM and poultry manures. Enhanced soil from sheep and chicken manures exhibited higher cation buildup, such as Ca^{2+}, Mg^{2+}, and K^{2+}, and increased leaching of Na^+ to low ESP.

4.2.2 Using Pressmud: Application of Pressmud, a byproduct of sugar factory, improve N, P and K content and decrease Na^+ saturation (Sharma *et al*., 2016) [10]

4.2.3 Mulching: Mulching enhances organic carbon, the production of water-resistant aggregates, and water retention. Mulching minimizes the impact of raindrops and hence reduces soil erosion brought on by runoff. Mulching as it covered the soil surface decreased the loss of water due to evaporation. (Sharma *et al*., 2016) [10].

4.3. Cultural Methods

- Providing proper drainage to the standing crops already sown in sodic soil may provide relief from waterlogging related stress.
- Good quality of irrigation should be given.
- **Use of acidic fertilizes:** In saline soil acid fertilizers such as ammonium sulphate should be used
- **Use of organic manures:** When sufficient amount of manures are added the water holding capacity of soil increases and as a result the electrical conductivity of the soil solution decreases.
- **Ploughing and leveling of the land:** Ploughing increases the infiltration and percolation rate. Therefore, salts present in soil leached down to the lower depths.
- **Reducing water evaporation:** Mulching with crop residues or plastic sheet helps in decreasing evaporation rate of water from soil surface.

4.4. Physical Methods

This does not actually remove sodium from exchange complex but improve physical condition of soil through improvement in infiltration and aeration. The commonly followed physical methods include:

- **Deep ploughing:** The cement-like hard soil layer is destroyed by deep plowing (1-2 m) or tearing, which typically results in a long-term improvement of the soil's structure and physical characteristics.
- **Tillage and Sub-soiling:** Tillage is able to break down soil plows, enhance total porosity (particularly macro-porosity), decrease bulk density, and thereby encourages root development into deep soil layers, all of which can assist in rehabilitation of sodic soil (Mu *et al*. 2016). However, due to deep tillage, subsoil comes out to surface which sometimes leads to logging and infiltration problems. In this case, an alternative approach with use of ridges may be helpful.
- Sanding and profile inversion
- Land levelling
- **Scraping:** By mechanical means, salt is removed which accumulated on the soil surface
- **Flushing:** Washing away the surface accumulated salts by flushing water over the surface is sometimes used to desalinize soils having surface salt crusts.

4.5. Growing Tolerant Crops and Varieties

- The right crop selection, adoption, and application of the most appropriate cultural and crop management strategies are crucial for managing sodic soils. Crops that can tolerate high exchangeable sodium levels can be grown to assure reasonable returns in the first year of reclamation.
- Rice and Dhaincha appear to be tolerant to sodic conditions, wheat and bajra are only moderately tolerant and legume crops like mash and lentil are relatively sensitive to excess exchangeable sodium.
- Crops like wheat, cotton, barley, tomatoes, etc. were rated as tolerant.
- Crops that are able to withstand excess moisture conditions resulting in short-term oxygen deficiencies are also more tolerant of sodic conditions.

4.6. Water Management

- The application of the ameliorants must be followed by leaching with water of acceptable quality, or with low SAR. Even salinity-low SAR water can be used.
- Frequently irrigation with small quantities of water is considered as most the successful irrigation management practice in sodic soils.
- In some cases, it may be necessary to restore the soil to

greater depths to obtain adequate drainage and root penetration.

5. Conclusion
Sodic soils are one of India's biggest challenges to agriculture and soil productivity. Due to their high level of sodium ions, these soils are found in many parts of the country. In particular, they are found in arid and half-arid areas, making them a major problem for farmers and for the environment. One of the main problems with sodic soil is that it reduces crop yield and causes poor plant growth. This is due to the negative effects that sodium has on the structure of the soil and the availability of nutrients. A variety of solutions have been developed and implemented to address these issues. Soil amendment techniques, such as adding gypsum to the soil, have been shown to be effective in reducing the amount of sodium in the soil and improving its structure. Crop rotations and precision farming methods have also helped to improve the water and nutrient efficiency of sodic soils. With the help of modern research and mapping technologies, soil management strategies can be more precise and targeted interventions can be made for sodic soils reclamation. There is hope for the future of sodic soils management with the right combination of innovative solutions and sustainable practices. By adopting these strategies and embracing new technologies, India can mitigate the negative impacts of sodic soils, safeguard its agricultural future, and ensure food security for its growing population.

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