



Reclamation of Saline-Sodic Soils Using Calcium Compounds

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ABSTRACT

Soil salinity, characterized by the excessive accumulation of soluble salts, is a major constraint to sustainable agriculture in Iran's arid and semi-arid regions. Saline-sodic soils, containing high levels of soluble salts and exchangeable sodium, exhibit poor physical and chemical properties that drastically reduce crop productivity. This study reviews reclamation methods for saline and saline-sodic soils, focusing on chemical amendments such as agricultural gypsum, elemental sulfur, sulfuric acid, ammonium thiosulfate, and organic fertilizers. Novel calcium compounds, including soluble calcium-sulfur solutions and organic calcium soil enhancers, are highlighted for their advantages in effectively replacing sodium with calcium, improving soil health, and enhancing plant tolerance to salinity. Efficient reclamation requires accurate soil characterization, careful amendment selection, timing of application, and safety considerations. Integrating these approaches is essential for improving soil quality, increasing agricultural productivity, and ensuring food security in salt-affected regions.

Keywords: Reclamation of Saline-Sodic Soils Using Calcium Compounds

1. INTRODUCTION

Soil salinity is a dynamic soil characteristic defined by the excessive accumulation of soluble salts within the soil profile. Beyond its negative impact on agricultural activities, this phenomenon leads to land degradation and can trigger desertification. Given Iran's climatic conditions, over 90% of the country's land area is situated in arid regions, with an average annual precipitation of approximately 253 mm. This is significantly lower than the global average of about 860 mm. Conversely, Iran's average annual evaporation is estimated at 2100 mm, more than three times the global average of roughly 700 mm. This considerable disparity between rainfall and evaporation has led to the widespread prevalence of soil salinity across much of the country, posing a major impediment to Iran's agricultural development.

Soil salinity is recognized as the third most limiting factor for agriculture in the country, following erosion and the scarcity of high-quality freshwater resources (Khorasandi & Hasheminejad, 2018). Moreover, according to a study by Wachau et al. (2010), Iran ranks third globally, after India and Pakistan, in facing the issue of soil salinity.

Efforts to address the problem of saline soils in Iran date back over a century. Early studies by Divan and Famouri (1964) reported that approximately 12.5% of the total land area consisted of saline soils. Later, Sayari and Mahmoudi (2002) estimated that 15% to 17% of the land, equivalent to 25 to 27 million hectares, was saline. Momeni (2010), using the one-millionth scale soil potential map of Iran created by Banayi (2001), estimated the extent of saline lands to be 55.6 million hectares.

Soils affected by salinity are generally classified into three primary categories: saline soils, saline-sodic soils, and sodic soils. The key parameters used for this classification include **electrical conductivity (EC)**, **sodium adsorption ratio (SAR)**, and **exchangeable sodium percentage (ESP)**. These criteria, along with physical properties such as color and texture, are fundamental for identifying the specific type of saline soil and its associated problems.

Accurate knowledge of a soil's physical and chemical properties, especially the correct identification of the salinity class, is crucial before any reclamation measures are implemented. Incorrect decisions regarding



reclamation can severely reduce the quality and productivity of agricultural land. For example, while leaching with adequate drainage is an effective method for saline soils, heavy irrigation of saline-sodic soils without prior chemical amendment can disrupt the soil structure and convert it to a sodic state. Therefore, chemical amendment should be prioritized for these types of soils (Ghanei et al., 2010).

Visually, there are often no obvious differences between saline and saline-sodic soils and non-saline soils, and they may appear similar. Common visual indicators of saline and saline-sodic soils include powdery soil surfaces, visible salt crystals in fields and on channel walls, the formation of hollow, white-walled pores within the soil, surface crusting, and the growth of halophytic plants such as *Alhagi maurorum*, *Salsola*, *Tamarix*, and *Salicornia*.

In sodic soils, additional symptoms include the formation of black layers or oily patches on the soil surface, severely reduced water infiltration, soil erosion due to low permeability, water runoff along slopes, the formation of prismatic soil columns with rounded tops, and significant shrinking and swelling during wet and dry cycles. Consequently, chemical soil tests are essential for accurately diagnosing the type of salinity and selecting the appropriate reclamation method (Khorasandi & Hasheminejad, 2018).

Soil salinity and sodicity can have a primary, inherent origin related to geotectonic and geomorphological processes, or a secondary origin resulting from human activities and improper soil and water management (Rezapour & Kalashipour, 2019). The extent of lands affected by secondary salinity and sodicity is growing, leading to substantial economic losses. In these soils, excess salts and exchangeable sodium damage the physical soil structure and negatively affect chemical properties, leading to reduced crop growth, yield, and economic viability.

The dominant class of saline soils in Iran is saline-sodic (Rezapour et al., 2021). Geographically, these soils are primarily found in the central plateau, southern coastal plains, and around Lake Urmia. The high concentration of soluble salts ($EC > 4$ dS/m) and high exchangeable sodium percentage ($ESP > 15\%$) in these soils create unfavorable physical, chemical, biological, and nutritional conditions that severely restrict their agricultural potential. The vast distribution of these soils in Iran's arid and semi-arid climate, combined with the increasing need for agricultural products, makes sustainable reclamation of these lands a necessity.

High concentrations of soluble salts and the toxicity of sodium, chloride, and boron ions cause osmotic stress and limit plant growth. Furthermore, the adverse physical effects of increased exchangeable sodium, such as reduced soil aeration and infiltration, exacerbate these problems (Dehlavi et al., 2018). Ultimately, these factors significantly reduce the ability of saline-sodic soils to produce economically viable and high-quality crops.

However, saline-sodic soils are fundamentally normal soils that have been subjected to specific conditions. If these adverse conditions (salinity and alkalinity) are corrected, they can be transformed back into fertile soils with high potential for producing a variety of crops.

Given the widespread nature and importance of saline-sodic soils in the country and the critical need for their reclamation, many efforts have been made to amend these lands. Among the most common methods are leaching and the use of chemical amendments such as gypsum, sulfuric acid, and organic materials (Singh et al., 2016).

Methods for Reclaiming Saline and Saline-Sodic Soils

Saline-sodic soils typically contain not only high levels of soluble salts but also elevated amounts of **exchangeable sodium**, which reduces aggregate stability and soil permeability. Consequently, in the reclamation process for these soils, it is essential to apply amendments before leaching. These amendments are intended to replace the exchangeable sodium with calcium, thereby improving the soil's physical properties.

Common chemical amendments include:

- **Agricultural Gypsum (Hydrated Calcium Sulfate - $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$):** Gypsum is one of the oldest and most common amendments. The calcium it provides replaces sodium at the exchange sites in the soil, and the liberated sodium is then leached from the soil with irrigation or rainwater. Proper timing and application of gypsum are crucial to prevent imbalances in calcium and avoid negative effects on soil fertility. Furthermore, uniform distribution and adherence to safety precautions are important to prevent respiratory problems.
- **Elemental Sulfur:** Sulfur is used as an acidifying agent in calcareous soils. Biological oxidation of sulfur by *Thiobacillus* bacteria produces sulfuric acid, which dissolves soil carbonates (lime),



releasing calcium. This calcium then replaces sodium, creating conditions favorable for sodium leaching. The action of sulfur is slower than that of gypsum and requires suitable temperature and moisture conditions.

- **Sulfuric Acid:** Sulfuric acid is used as a fast-acting amendment for saline-sodic soils, particularly calcareous ones. By dissolving soil lime, it rapidly releases calcium, which replaces sodium. However, due to high transportation costs and safety hazards, its use is more limited compared to sulfur. Application without prior soil testing is dangerous and is not recommended for soils lacking carbonates or with less than 5% lime.
- **Ammonium Thiosulfate and Other Compounds:** Other compounds, such as ammonium thiosulfate and polysulfides, are also used for salinity reclamation, though their application requires careful management.
- **Organic Fertilizers:** Due to their content of calcium and magnesium cations, organic fertilizers can serve as effective supplements for reclaiming saline-sodic soils and help improve soil structure and microbial activity.

Agricultural gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) is a widely used amendment. Its natural and environmentally friendly nature makes it popular among farmers. Correct application of gypsum supplies plants with essential calcium and sulfur while improving the soil's chemical and physical properties.

However, improper use without considering soil analysis can lead to calcium imbalances, phosphorus fixation, and reduced availability of certain micronutrients, resulting in decreased soil productivity and crop yields. Excessive application of gypsum can also disrupt the soil's sulfur balance and harm the soil ecosystem.

Uniform distribution of gypsum is crucial because uneven application can lead to accumulation in some areas and deficiencies in others. Consistent exposure of workers to airborne gypsum particles can cause respiratory issues, making personal protective equipment and safety protocols essential.

Acidifying Materials

Sulfur and sulfuric acid are also commonly used acidifying materials for reclaiming saline-sodic soils. The biological oxidation of sulfur by microorganisms produces sulfuric acid, which dissolves soil carbonates and releases calcium. This calcium increases the **exchangeable calcium** and replaces sodium, which is then leached to deeper soil layers, thereby reducing sodium's effects in the root zone.

Although sulfuric acid is a rapid amendment, its high transportation costs and associated hazards make it less commonly used than sulfur. The use of sulfuric acid is not recommended for soils with less than 5% calcium carbonate and less than 0.5% organic matter (Zabihi & Nouri Hoseini, 2017).

Nitrogen Fertilizers and Growth Regulators

In addition to providing essential nitrogen for plant growth, nitrogen fertilizers can increase the production and transport of plant growth regulators, such as cytokinins, from the roots to the shoots. These regulators play a significant role in enhancing plant tolerance to salinity stress. Research has shown that optimal nitrogen application can mitigate the negative effects of salinity (Khalilpour & Mozaffari, 2016).

Novel Calcium Compounds

In recent years, highly efficient soluble and organic calcium compounds have been introduced to the market, offering significant advantages over traditional amendments:

- **Calcium Sulfur Solution:** This is a combination of soluble calcium and sulfur that not only provides essential nutrients but also effectively replaces sodium with calcium in the soil. Unlike sulfuric acid and elemental sulfur, this solution has fewer application constraints and can be used during the growing season without time limitations.
- **Calcium Organic Soil Enhancer:** This compound contains soluble calcium, organic matter, and nitrogen. It not only improves soil salinity and alkalinity but also enhances plant resistance to salinity stress and promotes soil health and structure.

These compounds are considered effective options for farmers due to their lower application rates, ease of uniform distribution, and ability to be applied multiple times throughout the growing season, ultimately reducing labor and transportation costs.



Conclusion

Saline and saline-sodic soils, due to their high concentration of soluble salts and exchangeable sodium, pose significant challenges to agriculture in arid and semi-arid regions. These issues not only have a detrimental effect on the soil's physical and chemical properties but also severely limit plant growth and yield. Improving the condition of these soils through reclamation methods, particularly by replacing sodium with calcium, is crucial for increasing agricultural productivity and preserving soil resources.

The use of amendments such as **agricultural gypsum**, **elemental sulfur**, and **sulfuric acid** each has its own advantages and limitations, which are important to consider when selecting a reclamation strategy. Gypsum, as a cost-effective and natural material, is highly effective, but its improper use can lead to environmental disruptions and reduced soil fertility. Sulfur and sulfuric acid, as acidifying agents, play a crucial role in releasing calcium and reducing sodium; however, each has specific limitations that must be carefully managed.

Nitrogen fertilizers and plant growth regulators also play a complementary role in enhancing plant tolerance to salinity stress, and their intelligent use can mitigate the negative effects of salinity.

The introduction and application of novel calcium compounds, such as **Calcium Sulfur Solution** and **Calcium Organic Soil Enhancer**, offer promising, more effective, and flexible solutions for reclaiming saline-sodic soils. These compounds require lower application rates, are easy to distribute, and can be used repeatedly throughout the growing season. In addition to improving soil prop.

temperature were directly input on the software windows, and the thermo-physical parameters at high temperature can be extrapolated based on.

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