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Research Article

Gypsum and Water Level Effects on Central Rift Valley Sodic Soils of Ethiopia

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Abstract

Background and Objective: There are vast areas of Sodic soils in the world. In Ethiopia, many of the low lands are affected by sodicity and need reclamation for better agricultural productivity. The efficiency of two amendments in reclaiming sodic soil using gypsum and water for better agricultural productivity was investigated. Sodic soils of Adami Tullu Kombolcha were used for the study.

Materials and Methods: Gypsum and the different levels of water were applied to packed sandy clay loam soil columns. Gypsum was mixed with topsoil before leaching at application rates of 0, 50, 100 and 150% of the Gypsum Requirement (GR), whereas 1, 2, 3 and 4 Pore Volume (PV) of water were also used to leach the sodium in the soil. **Results:** Gypsum and water application reduce sodium to an acceptable range for plat production. Exchangeable sodium percentage was reduced by 66.8 and 53.38% for the highest rate of application of water and gypsum respectively. Results indicated that during cation exchange reactions most of the sodium was removed.

Conclusion: Both amendments efficiently reduced soil salinity and sodicity. Gypsum at 150% of the GR can be used as an efficient amendment and leaching with 2 PV of water could be recommended to reclaim the studied soil.

Key words: Sodic, gypsum requirement, reclamation, saline, leaching, pore volume water

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Salt-affected soils are a widespread problem in arid and semiarid regions. More than 62% of the total land of the earth in more than 100 countries is saline-sodic or sodic¹. Therefore, the management of soil salinity requires special approaches to maintain their productivity².

According to the different researches, the reclamation process involves the application of calcium (Ca^{2+}) to replace sodium ions (Na^+) from exchange sites²⁻⁴. In the reclamation process to avoid re-sodification, replaced Na^+ has to be removed away from the root zone with an adequate amount of water. The most commonly used chemical amendments are gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$), calcium chloride ($\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$) and sulfuric acid (H_2SO_4). Gypsum and calcium chloride provides a direct source of Ca^{2+} to replace Na^+ , while sulphuric acid increases calcite dissolution⁵. Several studies indicate that of the different amendments gypsum is preferred for reclaiming sodic soils because high electrolyte concentrations overcome the dispersing effect of sodium and its availability^{3,6}.

In Ethiopia, the naturally salt-affected areas are normally found in the arid and semiarid lowlands and in Rift valley areas that are characterized by higher evapotranspiration rates concerning precipitation. The arid and semi-arid agro-ecologies which account for nearly 50% of the country's land area are regarded as marginal environments for crop production mainly due to soil and water salinity. Low levels of annual rainfall and high daily temperatures have led to high water evaporation rates and consequently contributed to high concentrations of soluble salts in this lowland areas⁷. In Ethiopia, about 44 M ha (36% of the total land area) is potentially susceptible to salinity problems of which 11 M ha have already been affected by different levels of salinity and mainly concentrated in the Rift valley. Ethiopia ranked on 7th number in the world in terms of percentage of the total land area affected by salinity⁷. Soil sodicity results in high pH

(alkaline) as a consequence of the high content of sodium in the soil. It is estimated that about 425,000 ha of land of Ethiopian soils are sodic, mainly in the warm, semiarid to sub-humid climates⁸.

The main objectives of this study were to determine the reclamation efficiency of gypsum and leaching water and to determine the optimum gypsum and amount of water required to reduce soil sodicity and salinity to levels promoting good crop production.

MATERIALS AND METHODS

Description of the study sites: Between June-August, 2019, the study was conducted in the central Rift Valley area called Adami Tullu Jiddo Kombolcha. Adami Tulu, Jiddo Kombolcha is located in the Oromia region between geographical coordinates of $07^\circ 34' 06''$ to $8^\circ 03' 06''$ N latitude and $38^\circ 23' 57''$ to $38^\circ 55' 28''$ E longitude. The study site Algae receives annual rainfall between 750 and 1200 mm with a mean annual temperature varying from $8-28^\circ\text{C}$.

General properties of soils of the study area: The general physical and chemical properties of the soils before the application of the treatments are presented in Table 1. Soils are loam with pH 9.28. Moreover, the Exchangeable Sodium Percentage (ESP) was 39.44 where the soil can be categorized as sodic soil. According to Alka *et al.*⁹, pH and ESP solubility and availability of most nutrients could be strongly affected. The available phosphorus content is also low indicating the fixation of phosphorus to unavailable sites.

Soil sampling and analysis: Soil samples were collected from 0-30 cm depth by soil auger using a random sampling technique from representative crop fields. For the remediation, a pot study with 4 kg of soil was crushed to pass through a 2 mm sieve and was placed in plastic

Table 1: Chemical and physical properties of used soil

| Property | Value | Method |
|--|-------|---|
| pH | 9.28 | 1:2.5 soil water ratio |
| ECe (dS m^{-1}) | 4.80 | |
| Sand (%) | 50.00 | Hydrometer method |
| Silt (%) | 26.00 | |
| Clay (%) | 24.00 | |
| Bulk density (Mg m^{-3}) | 0.91 | BSI, 1975 (https://shop.bsigroup.com/ProductDetail/?pid=000000000010017095) |
| Organic carbon (%) | 2.21 | Nelson and Sommers ¹⁰ |
| Na^+ (cmol kg^{-1}) | 16.32 | 1 N NH_4OAc at pH 7.0 |
| Ca^{2+} (cmol kg^{-1}) | 15.20 | |
| CEC (cmol kg^{-1}) | 41.38 | |
| ESP | 39.44 | |
| Ava. P (ppm) | 3.70 | Murphy and Riley ¹¹ |

pots. The treatments were arranged in a Completely Randomized Design (CRD) with 5 replications. The Gypsum Requirement (GR) was calculated using standard laboratory techniques⁴ and was found to be 11.2 t ha⁻¹. Four rates of gypsum (0, 50, 100 and 150% of GR) and 4 rates of Pore Volumes (PV) of water (1, 2, 3 and 4 PV of water) were used for leaching. To determine the pore volume of water, the soil in the plastic pots were saturated with a measured amount of water from the bottom of the pot until indicated by water appearing on the top of the soil¹². After application, the pots were kept at field capacity for a week with irrigation water to facilitate exchange reaction. After a week, the saturated pots were leached by applying the predetermined amounts of the pore volume of water.

Column experiments: Plastic pots (25 cm height and 20 cm internal diameter) were packed with 3 kg of air-dried soil (less than 2 mm). Columns were packed with subsamples of the same soil. The gypsum consisted mainly of CaSO₄·2H₂O Gypsum was mixed with the entire soil in the plastic pot before leaching at application rates of 0, 50, 100 and 150% of the gypsum requirement. Leaching water was supplied to attain soil hydraulic conductivity value similar to that in the field so that the chemical reaction will be held for one week.

Four different PV of water (1, 2, 3 and 4) were allowed to pass through soil columns and leachates were analyzed. Soil samples were taken out from columns, dried and analyzed for chemical properties. Data per each percolated PV were graphed against PV. Significance was tested using two-way ANOVA between treatments with subsequent mean separation by LSD test at 0.05 using Statistics 8 program.

RESULTS AND DISCUSSION

Relative sodium removal in the leachate: Sodium concentration in the effluent (Na) relative to total Na in the system was presented in the breakthrough curve and expressed as (Na/Na₀) and plotted against PV of collected effluent in Fig. 1. The ratio of (Na/Na₀) at 1 PV of water was very low indicating the low amount of sodium removal. With the increase in both PV of water and the amount of gypsum, there is a significant difference in the removal of sodium. According to Gharaibien *et al.*¹³, this can be attributed to the tendency of leaching water to move mostly through the larger pores at lower PV of water and to a lesser extent through the smaller ones. Consequently, the fluid in small pores cannot be removed completely and therefore, the effluent will not be displaced. A similar finding was reported by Qadir *et al.*¹⁴, where the Na⁺ leached from each treatment revealed a

superiority of the highest application over other treatments. The increased displacement of exchangeable Na⁺ by Ca²⁺ was from the added gypsum and/or dissociation of CaCO₃ and subsequent leaching of replaced sodium¹⁴⁻¹⁶.

Results indicated that the total amount of sodium in effluent significantly increased with increasing amendment rate and PV of leaching water. The highest Na removal was observed for the highest (150%) gypsum application at 4PV of water followed by 100% GR at 4 PV of water expressed in Fig. 2. Relative Na removal showed significant differences with increasing application rates of PV of leaching water and percent gypsum requirement. No significant differences were observed between 100 and 150% of GR. This could be attributed to the uniformity of ionic strength of gypsum solutions during leaching stages, whereas gypsum produces higher ionic strength solutions during the early stages and would decrease at later ones.

Soil reclamation: The effect of increased application rate on soil ECe and ESP shown in Fig. 3. Soil ECe and ESP significantly decreased with increasing application rates. The highest decrease in EC was observed with the highest rate of gypsum application. Concerning leaching water 3 and 4 PV, water produces a significantly lower amount of EC. A Salinity level of 2.1 and 2.5 dS m⁻¹ was achieved with application rates of 150% GR and 4 PV of water, respectively.

The application of both water and gypsum produced significant benefits on ESP and ECe. However, amendments greater than 3 PV of water have no additional significant benefits on ECe. On average ECe decreased from 4.22-2.19 and 3.92-2.54 dS m⁻¹ for gypsum and PV water application respectively in Fig. 3a and b. The decrease in ECe could be attributed to the flocculation of soil particles as a result of increased Ca²⁺ which in turn increases soil permeability and hence the leaching of soluble salts¹⁶. On the other hand, the average decrease in ESP was from 26.47-12.34 and 31.83-10.56 for gypsum and PV water increased respectively (Fig. 3a and b). The significant reduction in ESP could be due to the removal of sodium as a result of gypsum application followed by leaching^{16,17}.

The reduction in soil salinity (desalination) in all treatments could be attributed to the leaching of soluble salts⁶. Due to the high content of sand in reclaimed soils; up to 3 PV of leaching water and gypsum application of 100 and 150 GR was needed to reach an acceptable salinity level for all crop production (<2 dS m⁻¹). Such soils mainly have macro-pores that allow water to move through quickly, therefore the contact time between soluble salts and percolating water will be short.

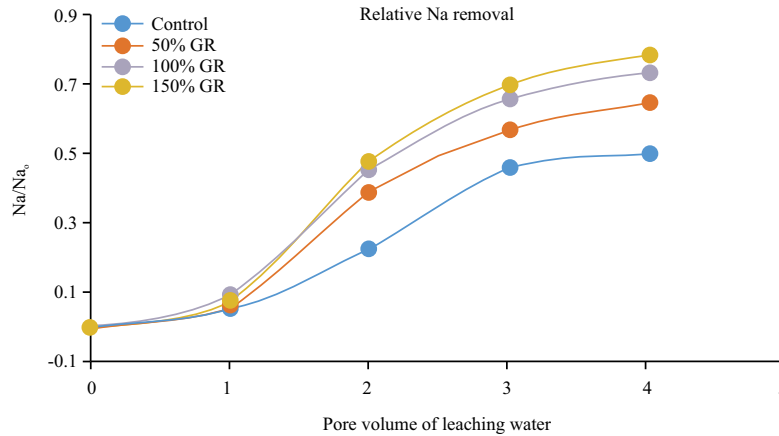


Fig. 1: Effect of amendment rates (Mg ha^{-1}) and volumes of leaching water (PV) on relative Na removal (Na/Na_0)

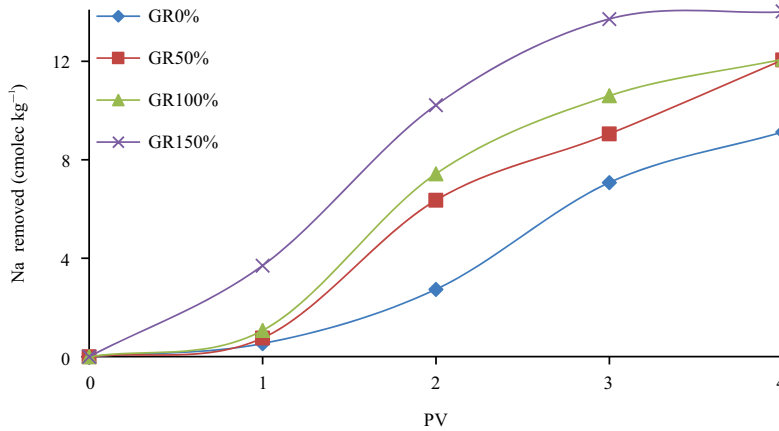


Fig. 2: Effect of amendment rates (Mg ha^{-1}) on exchangeable sodium removed (cmolec kg^{-1})

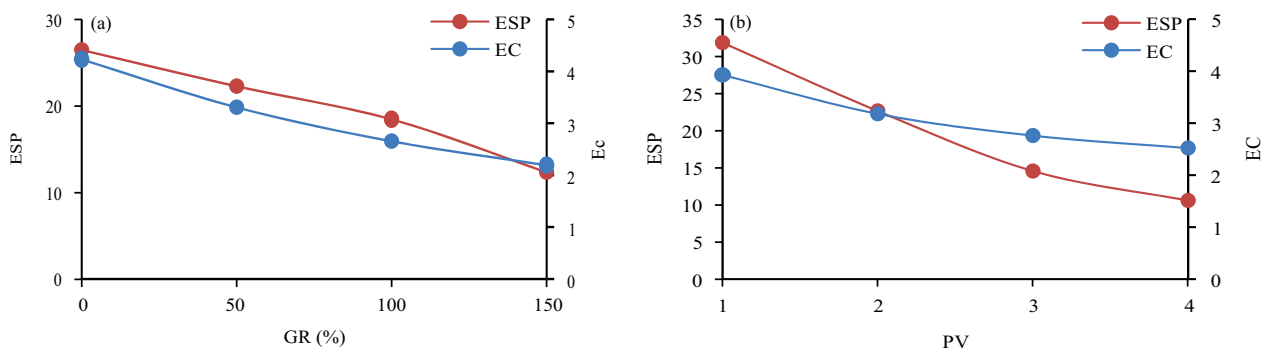


Fig. 3(a-b): (a) Effect of Gypsum on final exchangeable sodium percent (ESP) and soil salinity (ECe) and (b) Effect of Water on final exchangeable sodium percent (ESP) and soil salinity (ECe)

Significant reductions in ESP (desodification) were also observed with an increasing application rate in Fig. 4. Statistical analysis results indicated that ESP was reduced below 15% by application of gypsum and water. Accordingly, at 50% GR with 4 PV of water, 100% GR with both 3 and 4 PV

of water and 150% GR with 2, 3 and 4 PV ESP was found below 15%. It is worthwhile to mention that soils with ESP above 10 often have unstable aggregates and exhibit low infiltration rates that can cause damage to crops³. Accordingly, 100% GP with 4 PV and 150% GR both with 3 and 4 PV water have ESP

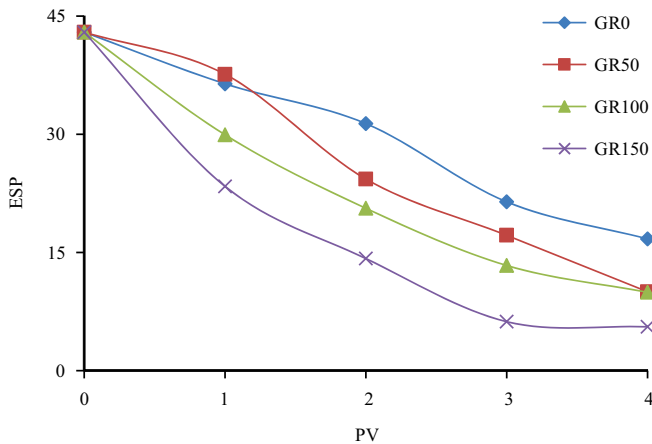


Fig. 4: Effect of amendment rates (Mg ha^{-1}) and volumes of leaching water (PV) on exchangeable sodium percent (ESP)

less than 10%. The decrease in ESP could be attributed to the addition of gypsum that increased the exchange reactions with calcium ions in the system to displace sodium in the soil¹⁶. Simple leaching (control) decreased ESP and this may be attributed to the valence dilution. Results were similar to those of Koo *et al.*¹⁵ and Gharaibeh *et al.*¹⁶, who reported a decrease in ESP using water alone (control) due to the dilution of the soil solution “Valence dilution” which favours the adsorption of divalent cations at the expense of monovalent cations. This finding was in agreement with earlier works of Mufeed¹⁷.

CONCLUSION

Chemical reclamation of sodic soils is the best option and has recently become an efficient way of reclamation for farmers and therefore efforts have been made to know the amount of gypsum and leaching water to be applied for reclamation. This research showed that amelioration of a calcareous sodic soil can be achieved efficiently both by applying gypsum and leaching the Na from the soil so that crop productivity can be increased. It can be concluded that the utilization of agricultural drainage water in the preliminary stages of soil leaching for sodic soil can save more than 60% of freshwater requirements for soil reclamation. Likewise, adding gypsum to sodic soil reduced the amount of water needed for leaching. The drop in EC and ESP with gypsum-amended soil was relatively faster than the control one because of the flocculation of soil particles, which is a distinctive phenomenon with the use of gypsum. A sharp decrease in exchangeable Na^+ and total sodium removed for all treatments was also noticed with an increase in both

treatments. Overall, the three leaching treatment scenarios were able to reduce soil salinity to less than 4 dS m^{-1} which conformed to the study’s purpose. Moreover, as gypsum is a relatively inexpensive material to purchase in large quantities, the research pointed out that using both leaching water and gypsum might be a potential reclamation material for saline-sodic soils on a large scale in arid and semiarid environments.

SIGNIFICANCE STATEMENT

This study has discovered combined methods for reclamation of sodic soils using different levels of gypsum followed by application of the different amount of leaching water to leach the excess salts. It is a simplified, very quick method, with accessible materials, which are affordable for the management of sodic soils. The study will help farmers to reclaim their soils and become productive. It will also help the researcher think of site-specific management options with easily available materials. Thus, different rates and materials will be developed for different soil types.

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