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Research Article

Role of Gypsum in Reclaiming Saline-Sodic Soils to Improving Soil Health and Enhancing Productivity

Asif Raza Noonari^{1*}, Barkat Ali Nindwani², Amanullah Tunio³, Ghulam Hussain Awan⁴, Sajjad Ali Halepoto⁴, Abdul Saboor Soomro⁴, Muhsin Ali Faraz Jokhio⁴, Kumail Raza Noonari⁵

¹ Department of Irrigation and Drainage system, Sindh Agriculture University Tandojam

² Department of Farm Power and Machinery, Sindh Agriculture University Tandojam

³ Department of Basic Engineering, Sindh Agriculture University Tandojam

⁴ Department of Land and Water Management, Sindh Agriculture University Tandojam

⁵ Department of Mathematics, Shah Abdul Latif University.

ABSTRACT

Salinization and sodification of soil are a widespread concern, The United Nations Food and Agriculture Organization (FAO) reported that it affected 833 billion hectares of land worldwide. Gypsum is frequently utilized to restore saline-sodic and sodic soils due to solubility, cheap cost, availability, and simplicity of handling. The experiment was conducted at the experimental station of the Department of Land and Water Management, Faculty of Agricultural Engineering, Sindh Agriculture University, Tandojam, during the year 2021- 2022. The reclamation of saline-sodic soil under the influence of varying gypsum levels was investigated in a pot experiment. The research was set up in three replicated complete randomized designs (CRD), each with a total pot size of 30 x 30 cm (900cm²). G0 = 0 gypsum requirement (control treatment), G1 = 1/2 gypsum requirement, G2 = 1/3 gypsum requirement, and G3 = 1/4 gypsum requirement were the treatments prepared. After the leaching of water, the different soil properties were tested. According to the subject study, applying gypsum with various treatments reduced soil bulk density, dry density, water holding capacity, pH, EC, SAR, and ESP. The G1 was shown to be the most effective dosage among the various treatments because it lowers the maximum soil bulk density to 1.16 g/cm³ after leaching. Likewise, the overall maximum reduction in dry density, water holding capacity, pH, EC, SAR, and ESP after leaching was 1.42 g/m³, 27.07 %, 7.88, 3.21 dSm⁻¹, 16.25 %, and 16 % for the same treatment and only increased the soil porosity to 56.22% after leaching. The application of G1=1/2 of the soil's recommended gypsum dose appears to be the most cost-effective way to recover saline-sodic soil.

Keywords: Salinization, Sodification, Gypsum, Reclamation, Saline-sodic, Sodic.



Correspondence

Asif Raza Noonari
asifrazanoonari12@gmail.com

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INTRODUCTION

Expansive soils are the type of soil that may expand in volume. These sorts of soils have several issues, including high compressibility, poor strength, and unequal settlements, which can damage roadways, cause cracks in existing structures, and impede traffic flow (Fattah et al., 2010). Salt-affected soils account for around 30% of the entire agricultural area (FAO, 2005). Saline and sodic soils made up 831 million hectares of the world's salt-affected soils (Martinez et al., 2005). Sodic and saline soils are typically located in semi-arid areas where the evaporation rates are much higher than the precipitation rate (Qadir et al., 2008). Optimizing agriculture practices and improving the yield of crops in saline-sodic soil. Gypsum (GYP) seems to be the most often utilized modification owing to its inexpensive cost (Makoi and Ndakidemi, 2007).

Gypsum was one of the first fertilizers to be used in the United States. The impact of slag-based gypsum (SBG) and conventional gypsum (CG) on maize was tested in acidic and neutral soils in this research. The effect of gypsum on the structural qualities of porous soil (Prapagar et al., 2012). Gypsum up to 8% increased the optimal moisture levels and highest dry unit mass of bentonite. That was changed with 8% lime (Aldood et al., 2014). The impacts of lime coir fiber and gypsum, on the mechanical properties of soft soils revealed that the maximum dry unit weight was decreased and instead improved with the addition of 4 percent on average gypsum and 8 percent of overall lime (Jadhav et al., 2015). Gypsum-modified geopolymer had a greater beneficial impact on monitoring swelling than lime-modified geopolymer (Khadka et al., 2020). Gypseous soil was contaminated with crude oil, and it was discovered that this pollution increased the stiffness and implosion capability of the gypseous soil by 9 percent (Abo-El et al., 2020). Furthermore, bentonite in soil attraction and expansion found that sand incorporation reduced the swelling potential of bentonite. Moreover, it was shown that when soil suction increased, the swelling potential of bentonite–sand combinations decreased (Fattah et al., 2021). Due to its solubility, accessibility, low price, and simplicity of processing, gypsum is extensively used to restore salty and sodic soils and decrease the detrimental effects of high sodium irrigation water in farming areas. It has a 19 percent sulphur concentration and a 23 percent calcium content. The calcium in the gypsum allows Na^+ to be displaced from the soil's cation exchange sites (Abdel-Fattah et al., 2012). Gypsum influence is evaluated in Pakistan in different treatments. It is reasonably priced and widely accessible (Ali et al. 2001).

MATERIALS AND METHODS

The experiment was conducted at the experimental station of the Department of Land and Water Management, Faculty of Agricultural Engineering, Sindh Agriculture University, Tandojam, during 2021-2022. The research was conducted on the reclamation of saline-sodic soil under the effect of various gypsum levels. The four levels of gypsum were used in this experiment as shown in Table 1.

Table 1. Treatment Levels of Gypsum

Sr. No.	Level of Gypsum	Description	Replications (03)
1.	Level -4	G0 = 0 gypsum requirement (control treatment)	Experimental units = 4x3 (TxR) = 12 Irrigation water: ground water
2.	Level-3	G1 = 1/2 gypsum requirement	
3.	Level -2	G2 = 1/3 gypsum requirement	
4.	Level-1	G3 = 1/4 gypsum requirement	

The experiment was conducted in small mud bowls as shown in Figure 1. The complete randomized design (CRD) with three replications, (R1, R2, and R3), with a pot size of 30 × 30 cm (900cm²) was proposed as the experimental design. (Figure 2).



Figure 1. The photograph of the experimental setup

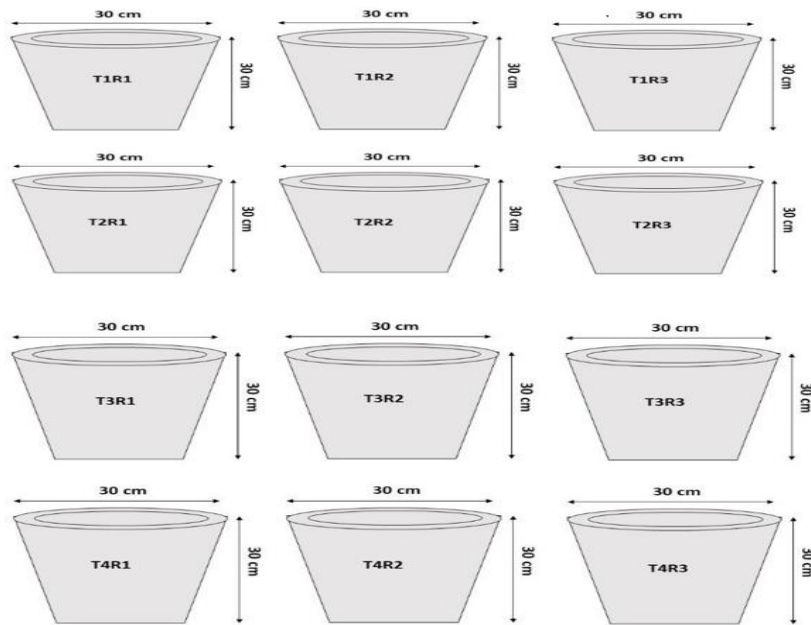


Figure 2. Design and layout of pot

Table 2 Irrigation doses on pot experiment

Sr. No	Treatments	No of pots	Irrigation interval (days)	Amount of irrigation water of each pot (lit)	Amount of irrigation water of three pot (lit)	Total number of irrigations of each treatment (times)
1	G0 (control treatment)	03	15	1.5	4.5	6
2	G1(1/2 GR)	03	15	1.5	4.5	6
3	G2(1/3GR)	03	15	1.5	4.5	6
4	G3(1/4 GR)	03	15	1.5	4.5	6

The gypsum requirement was calculated using the following formula;

$$TGR = \left[\frac{ESP \times 0.78 \text{ Tons}}{\text{Hectare}} \right] \times A$$

Where, TGR= Total Gypsum requirement, ESP= Exchangeable Sodium, Percentage A= Area

The saline-sodic soil was collected from the field wherever available and transferred to the laboratory of the Department of Land and Water Management. The composite soil was collected from the depth of 0- 10cm, 10-20 cm, 20-30 cm, and 30-40 cm, in each chamber and samples were analyzed for physical and chemical properties. The soil texture was determined using a Hydrometer by Bouyouco (Bouyoucos,1962). Table 3.2 shows the depth-wise textural class of the investigated saline-sodic soil used for the reclamation under different treatments.

Table 3. Textural class of saline-sodic soil

Depth (cm)	Soil proportions			Textural class
	Clay	Silt	Sand	
0-10	15.3	64.1	20.6	Silty loam
10-20	18.2	50.5	31.3	Silty loam
20-30	13.6	53	33.4	Silty loam
Average	16.5	55.5	28	Silty loam

The bulk density of the soil was carefully maintained under the field's specifications. To analysis the bulk density of the soil, the following equation was utilized;

$$\text{Bulk density}(\%) = \left[\frac{\text{Bulk weight of soil}}{\text{Volume of soil sample}} \right] \times 100$$

The core technique was used to measure the dry density of the soil (McIntyre and loveday, 1974) and following formula was used;

$$\text{Dry density (g/m}^3\text{)} = \left[\frac{\text{Dry weight of soil}}{\text{Total volume of soil}} \right]$$

The water situation approach (Kanwar & Chopra, 1959) was used to measure the soil porosity;

$$\text{Porosity (\%)} = \left[1 - \frac{(\rho b)}{(\rho d)} \right] \times 100$$

Where

η = porosity (%), ρb = Bulk density (g/cm³), ρd = Particle density

The following equation was used to determine, before and after the experiments, the soil's water-holding capacity;

$$\text{WHC (\%)} = \left[\frac{\text{water retained (ml)}}{\text{water added (ml)}} \right] \times 100$$

Water retained (ml) = water added (ml) – water drained (ml), The pH of the soil was tested using a 1:5 soil water extract technique (U.S. salinity laboratory staff, 1954). Electrometric technique was used to evaluate the electrical conductivity of the soil extract at a ratio of 1:5 soil water extract (Shanmuganathan and Rajendran, 2016).The following formula was used to compute the chemical characteristics such as the sodium adsorption ratio (SAR);

$$\text{SAR} = \left[\frac{\text{Na}^+}{\frac{\sqrt{\text{Ca}^{++} + \text{Mg}^{++}}}{2}} \right]$$

Where: Na^+ = Sodium, Ca^{++} = Calcium, Magnesium =Mg

Exchangeable sodium percentage (ESP) was determined according to the following formula;

$$\text{ESP} = \left[\frac{100 (-0.0126 + 0.01475 \times \text{SAR})}{1 + (-0.0126 + 0.01475) \times \text{SAR}} \right]$$

The collected data were analyzed using (ANOVA) statistical software package Statistix (version 8.1).

RESULTS

According to the results, soil bulk density frequently decreased after gypsum amendments were applied and leaching compared to the G0 (control treatment) without gypsum. However, the average soil bulk density of the soil was significantly different among the treatments (Figure 3).

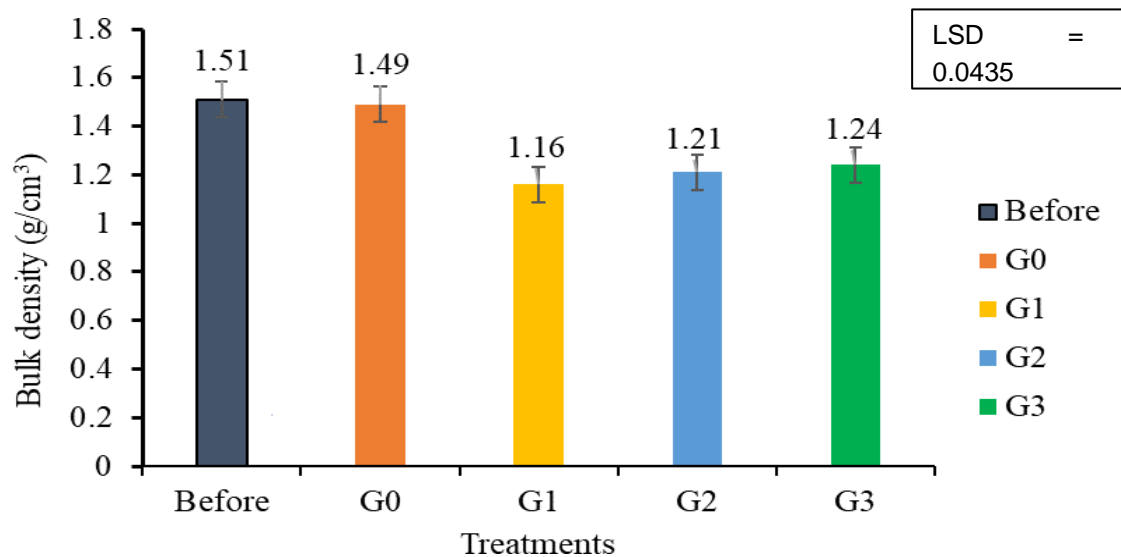


Figure 3. Effect of gypsum amendment on soil bulk density

The effect of gypsum application with or without gypsum on the dry density of soil is shown in Figure 4. Among the treatments, the gypsum combination decreased significantly when it was treated. The dry density of the soil was matched to the control soil without the combination of gypsum. The dry density of soil samples was recorded as 1.86, 1.42, 1.63, and 1.68 (g/m^3) after leaching with water in different treatments G1, G2, and G3, respectively.

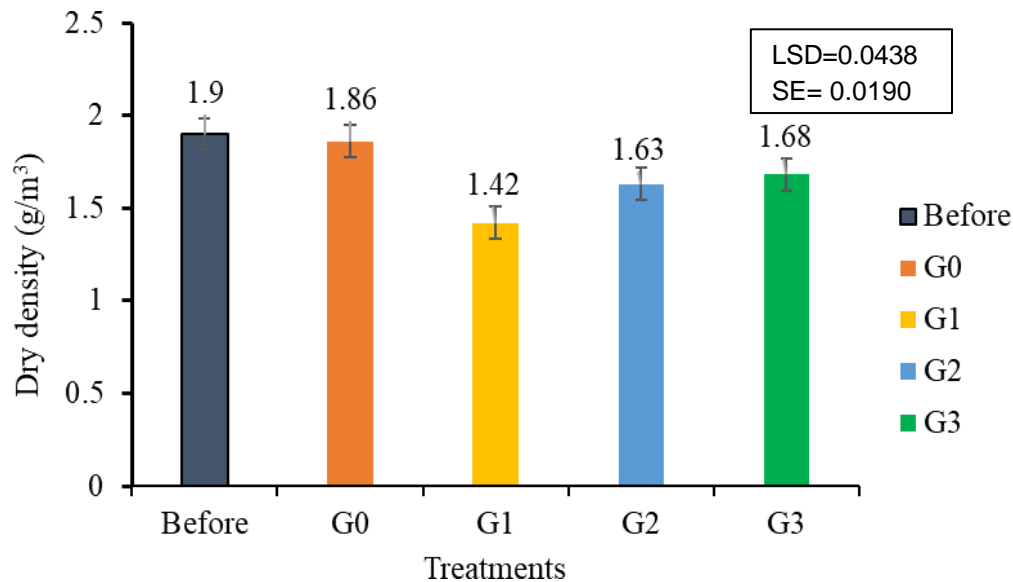


Figure 4. Effect of gypsum amendment on soil dry density

The values of soil porosity increased due to gypsum amendment. The result of soil porosity was determined as 53.86% in control soil, however, 56.22, 54.33, and 53.2% under gypsum requirement treatments G1 = 1/2 gypsum requirement, G2 = 1/3 gypsum requirement, and G3 = 1/4 gypsum requirement, respectively.

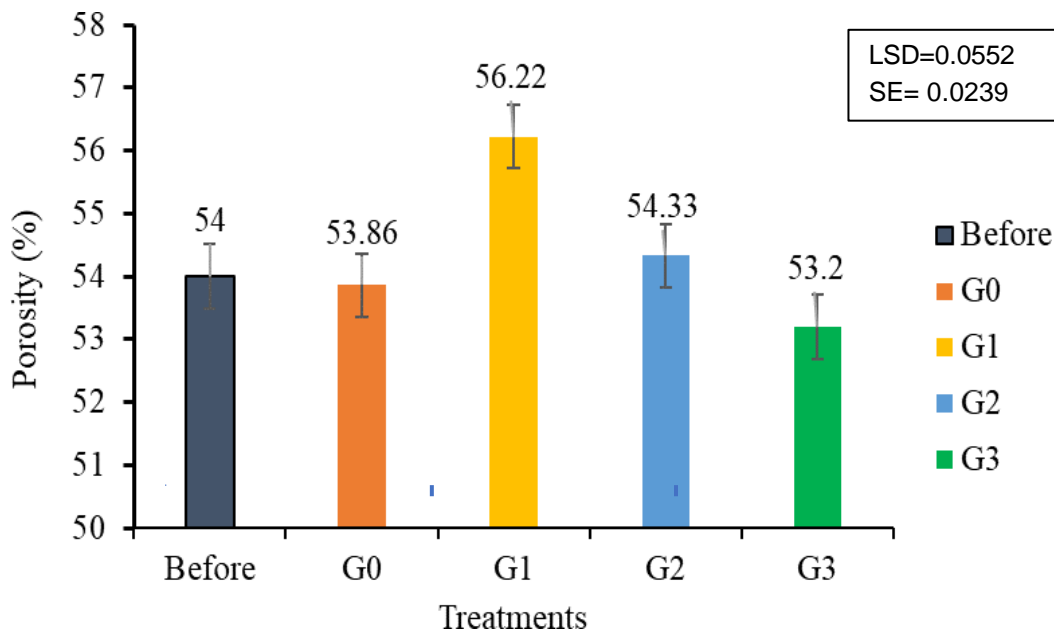


Figure 5. Effect of gypsum amendment on soil porosity

The soil water holding capacity compared to before the adoption of modifications and leaching with the control treatment (without gypsum) and gypsum requirements used in G1 = 1/2 gypsum requirement, G2 = 1/3 gypsum requirement, and G3 = 1/4 gypsum requirement, the important variations were among themselves (Figure 6).

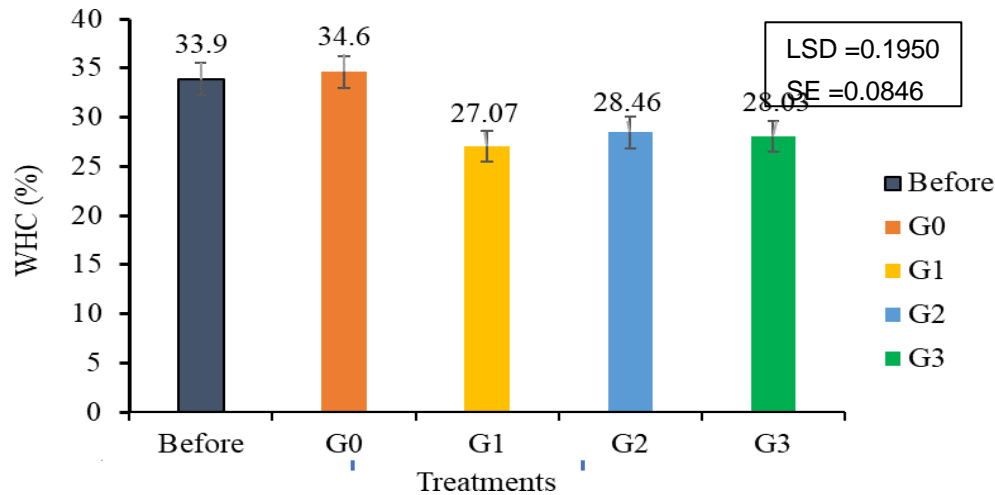


Figure 6. Effect of gypsum amendment on soil water holding capacity

The pH of the control soil was 8.66, and after the combination of gypsum, the pH of the soil samples in different treatments G0, G1, G2 and G3 was reduced to 7.88, 8.27, and 8.35, respectively after leaching with water (Figure 7).

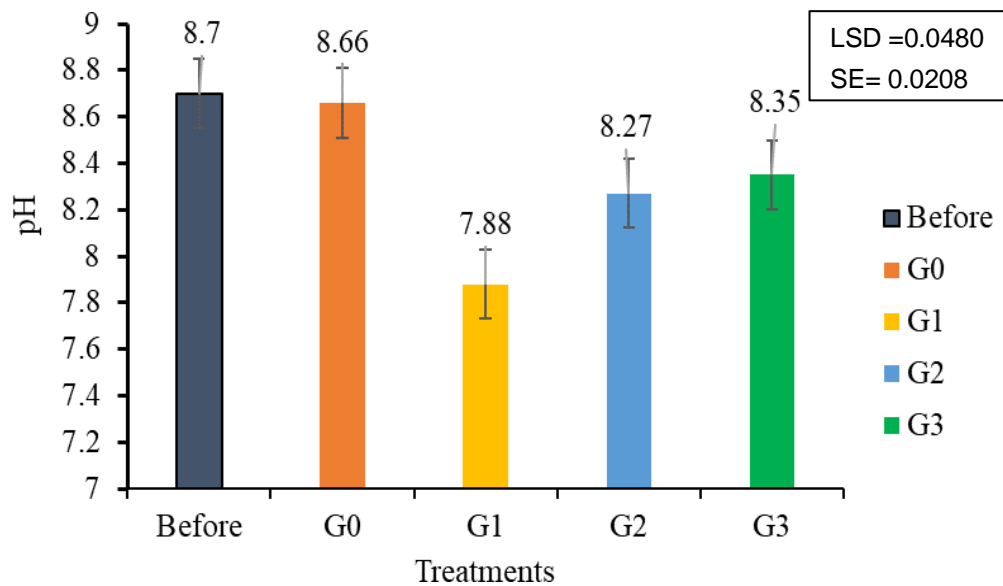


Figure 7. Effect of gypsum amendment on soil pH

Figure 7 depicts the impact of gypsum treatment on EC, in comparison to control soil (without gypsum). The gypsum combination among the treatments was more successful in lowering the EC of the soil than the control soil without the addition of gypsum. The EC of soil was slightly decreased from 12 to 3.21, 4.5, and 5.85 (dS/m) after leaching with water.

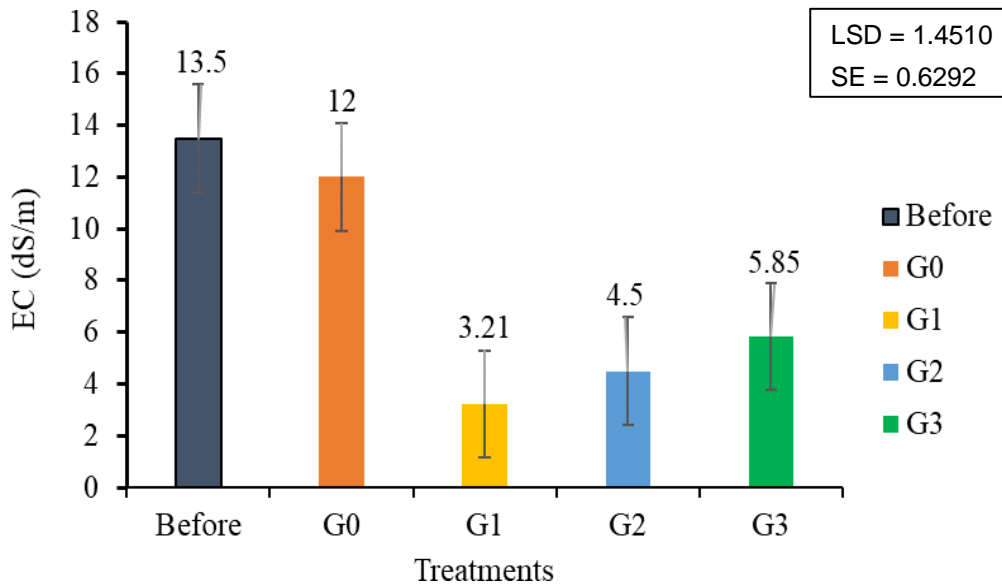


Figure 8. Effect of gypsum amendment on soil electrical conductivity

The results of various treatments on the sodium adsorption ratio (SAR) of the soil after reclamation are shown in Figure 8. The SAR decreased significantly when it was treated. The treated soils showed a substantial drop in SAR. The SAR value of 16.25 % was obtained in control soil (without gypsum) and the SAR value of 14.12, 15.08, and 15.86 % was determined under the gypsum requirement under different treatments representing G1 = 1/2 gypsum requirement, G2 = 1/3 gypsum requirement, and G3 = 1/4 gypsum requirement.

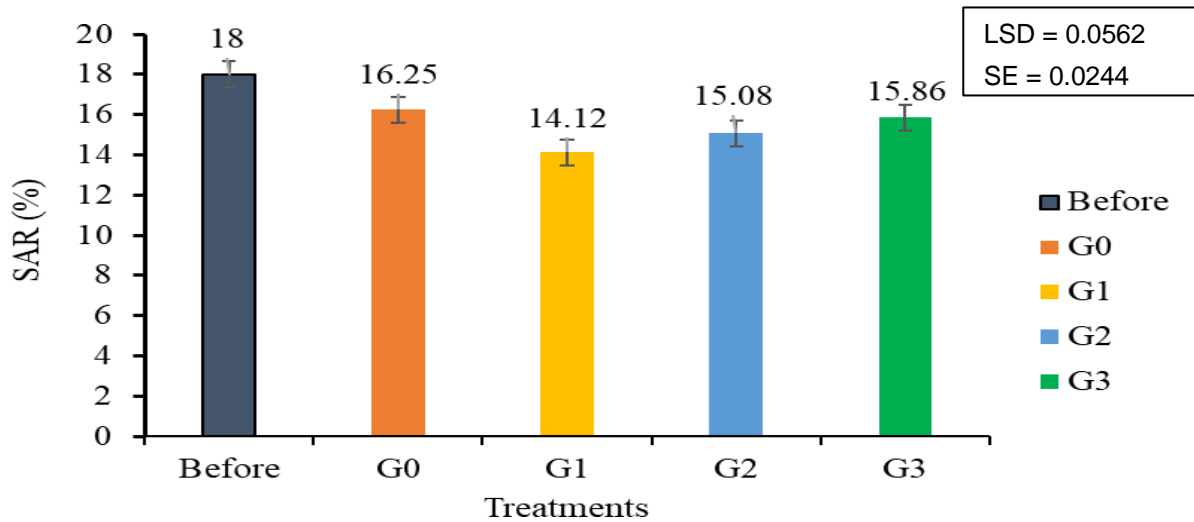


Figure 9. Effect of gypsum amendment on soil (SAR)

The soil exchangeable sodium percentage (ESP %) often reduced with the use of amendments and leaching compared to the control treatment (without gypsum) and gypsum requirement used under different treatments G1 = 1/2 gypsum requirement, G2 = 1/3 gypsum requirement, and G3 = 1/4 gypsum requirement found that the average ESP of the soil samples was 16, 14.22, 15.35 and 15.85 %, respectively (Figure 10).

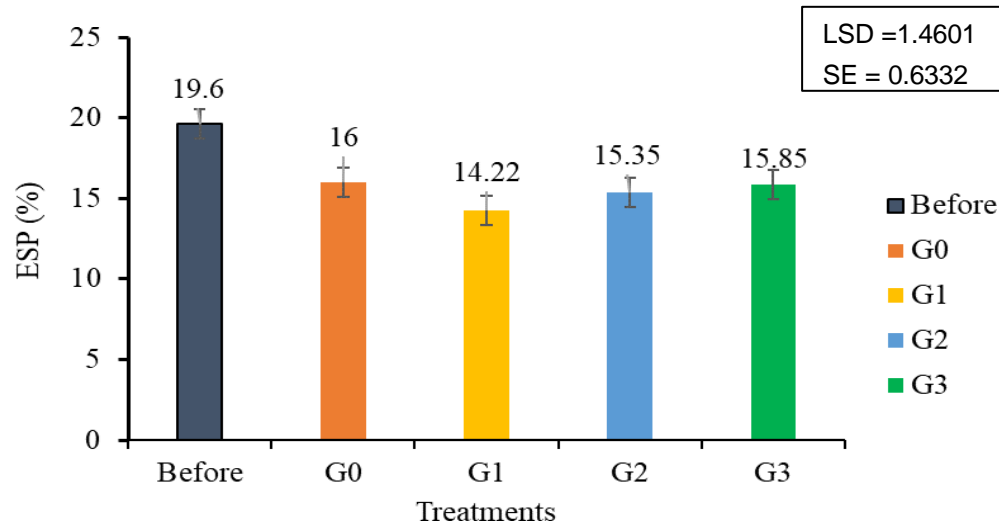


Figure 10. Effect of gypsum amendment on soil ESP

The study found that using gypsum is better to decrease soil sodicity, enhance soil chemical properties, and promote water infiltration. The gypsum amendment treatments comprised control and four combinations of gypsum effects on soil attributes.

However, the overall cost of gypsum in G1 gypsum requirement per hectare is Rs. 312,000 which is the maximum compared with other treatments shown in Table 4.

Table 4. Most economical doses of gypsum amendment

Treatments	Quantity of gypsum g/pot	Cost of gypsum g/pot	Quantity of gypsum kg/ha	Cost of gypsum kg/ha
G0 (control)	0	Rs. 0	0	Rs. 0
G1 (1/2 GR)	449.28	Rs. 23	6240	Rs. 312,000
G2 (1/3 GR)	299.51	Rs. 15	4160	Rs. 208,000
G3 (1/4 GR)	224.64	Rs. 11	3120	Rs. 156,000

DISCUSSION

Effect of gypsum amendment on soil physical properties

Several physical properties of the soil studied in this research are discussed here, such as soil bulk density, dry density, porosity, and water holding capacity. According to the results, soil bulk density frequently decreased after gypsum amendments applied and leaching compared to the G0 (control treatment) without gypsum. However, the average soil bulk density of the soil was significant differences among the treatments (Figure 3). These results are corresponding with the study of Prapagar et al. (2012). Their findings showed that the soil bulk density of control soil was 1.35 g/cm³ and that soil bulk density after using the gypsum amendment was noted at 1.30 to 1.20 g/cm³. According to the previous reported by Hanay et al. (2004), determining the effects of gypsum on sodic soil, the soil bulk density was tested to be between 1.35 and 1.26 g/cm³.

The effect of gypsum application with or without gypsum on dry density of soil is shown in Figure 4. Among the treatments, gypsum combination was decreased significantly when it was treated. The dry density of the soil as matched to control soil without the combination of gypsum. The dry density of soil samples was recorded as 1.86, 1.42, 1.63, and 1.68 (g/m³) after leaching with water in different treatments G1, G2 and G3, respectively. These findings are in line with past research where it was found that Singh et al. (2016) study's had substantial variances in dry density, the results of dry density decreased from 2.65 to 2.61 g/m³ after using the amendment of gypsum into soil.

The Figure 5 revealed that soil porosity was considerably impacted by the different treatments. However, the values of soil porosity increased due to gypsum amendment. The result of soil porosity was determined as 53.86 % in control soil, however, 56.22, 54.33, and 53.2% under gypsum requirement treatments G1 = 1/2 gypsum requirement,

G2 = 1/3 gypsum requirement, and G3 = 1/4 gypsum requirement, respectively. Therefore, these results are near to the report of El-Shazely (2021), they found that the soil porosity of untreated soil was obtained at 39 % and that soil porosity of treated soil with gypsum amendment was found at 43 %. Bekele et al. (2021), studied that the result of soil porosity was 45 to 49 %. Tejada et al. (2006) stated that organic amendments are proven to enhance the flocculation of clay minerals, which maintain soil structure, enhance soil porosity, and lower the bulk density of saline-sodic soil.

Our results show that the soil water holding capacity compared to before the adoption of modifications and leaching with the control treatment (without gypsum) and gypsum requirements used in G1 = 1/2 gypsum requirement, G2 = 1/3 gypsum requirement, and G3 = 1/4 gypsum requirement, the important variations were among themselves (Figure 6). Possible explanations for the reduced WHC include an improvement in water holding capacity and a reduction in gypsum amendment. The WHC of the soil dropped as the gypsum content rose. According to Singh et al. (2016), who found that combining gypsum with soils lowers water holding capacity.

Effect of gypsum amendment on soil chemical properties

The different chemical characteristics of the soil investigated in this study are reviewed, including soil pH, soil EC, soil SAR, and soil ESP. The pH of the control soil was 8.66, and after the combination of gypsum, the pH of the soil samples in different treatments G0, G1, G2 and G3 was reduced to 7.88, 8.27, and 8.35, respectively after leaching with water (Figure 7). It could be that water encourages gypsum dissolving, speeds up reclamation processes, and improves soil Matosic et al. (2018). In compared to the control soil, organic amendments alone treatments resulted in a small reduction in pH, with needs for 1/2 gypsum in treatment (G1) and without gypsum (G0) falling between 7.88 and 8.66. That may be because organic acids released during the breakdown of organic additions have an acidifying impact. These findings are quite similar to the reports of Prapagar et al. (2012). The pH of the soil decreased from 7.61 to 7.12 after the addition of several types of amendments, according to their findings of Guidi and Hall (1984), also concluded that the treatment of diverse organic materials lowers pH levels due to the formation of organic and inorganic acids when organic matter decomposes.

Figure 8 depicts the impact of gypsum treatment on EC, in comparison to control soil (without gypsum). Gypsum combination among the treatments was more successful in lowering the EC of the soil than control soil without the addition of gypsum. The EC of soil was slightly decreased from 12 to 3.21, 4.5, and 5.85 (dS/m) after leaching with water. According to Hanay et al. (2004), the results of electrical conductivity decreased from 12.35 to 1.98 (dS/m) after using the amendment of gypsum into soil. According to Udayasoorian et al. (2009), combining organic and inorganic ameliorants is more effective in lowering soil EC. Ghafoor et al. (2021) found that gypsum treatment resulted in a reduction in EC. The drop in EC could be attributed to the inclusion of organic fertilizers after salt extraction produced organic acids throughout the breakdown and caused salt leaching. With the inclusion of various organic amendments, Zaheer et al. (2024) was able to significantly lower the EC of saline-sodic soils. Organic matter release of excess ions by enhanced soil physical characteristics resulted in a reduction in EC.

The results of various treatments on the sodium adsorption ratio (SAR) of the soil after reclamation are shown in Figure 9. The SAR decreased significantly when it was treated. The treated soils showed a substantial drop in SAR. The SAR value of 16.25 % was obtained in control soil (without gypsum) and the SAR value of 14.12, 15.08, and 15.86 % was determined under the gypsum requirement under different treatments representing, G1 = 1/2 gypsum requirement, G2 = 1/3 gypsum requirement, and G3 = 1/4 gypsum requirement. With leaching, the SAR values of the treated soil significantly dropped. These results are corresponding to the reports of Gharaibeh et al., (2009), who found that the SAR value was decreased from 40 to 14 % after leaching. Gypsum has a lower solubility and takes longer to completely reclaim sodic soil. The elimination of exchangeable sodium from the soil was primarily responsible for the fall in SAR. Many analytical and experimental investigations have shown that using too much gypsum to reclaim sodic and saline-sodic soils result in a rapid loss of soluble salt and a reduction in soil SAR (Osman and Osman, 2021).

The soil exchangeable sodium percentage (ESP %) often reduced with the use of amendments and leaching compared to the control treatment (without gypsum) and gypsum requirement used under different treatments G1 = 1/2 gypsum requirement, G2 = 1/3 gypsum requirement, and G3 = 1/4 gypsum requirement found that the average ESP of the soil samples was 16, 14.22, 15.35 and 15.85 %, respectively (Figure 10). In comparison to the applied treatments, the soils with a combined effect of gypsum for all soil columns had the lowest ESP values, while the control sample had the maximum ESP value. This research confirmed the findings of Swarp, (2004) and Abdel-Fattah, (2012), who found that combining gypsum with soils lowers ESP compared to not amending the soil.

Most economical doses of gypsum amendment

The results show that the most economical doses of gypsum amendment are comparable to the control treatment. The treatment G1 = 1/2 gypsum requirement had a positive effect on reducing soil bulk density, dry density, water holding capacity, pH, EC, SAR, and ESP. The G1=1/2 is the most effective dose of gypsum among the several treatments, which lowers the soil's general characteristics. Implementation of G1=1/2 of the soil's recommended gypsum dose appears to be the most cost-effective and effective way to recover saline-sodic soil. The proper management of gypsum application is necessary for better soil resource quality. Many scientists believe that adding gypsum to saline-sodic soils considerably enhanced their physiochemical characteristics by lowering the EC and pH and increasing crop production, which produced satisfying results. Therefore, according to Shruthi et al. (2024), the modifications comprised applications for gypsum at 50% of gypsum applications, which changed the properties of the soil and improved the yield of the crop. Bello et al., (2021) study found that the use of gypsum is better to decrease soil sodicity, enhance soil chemical properties, and promote water infiltration. The gypsum amendment treatments comprised a control and four combinations of gypsum effects on soil attributes.

CONCLUSION

According to this study, gypsum may be added to salt-affected soils to ameliorate unfavorable physical and chemical conditions. The findings of our investigation have demonstrated that applying gypsum will be able to restore the saline-sodic soils. However, the soil's physical and chemical characteristics were recovered after gypsum treatment. The best performance was found for treatment G1 = 1/2 gypsum requirement. The G1=1/2 gypsum application to the soil appears to be the most cost-effective and effective way to recover salty soil. The improved quality of soil resources is dependent on gypsum application management.

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Not applicable.

AUTHOR CONTRIBUTIONS

All authors contributed equally to this research.

COMPETING OF INTEREST

There are no known conflicts of interest or personal relationships that could have appeared to influence the results of this study.

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