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Research Article

Effects of treatment application rates (fym and gypsum) on selected chemical properties of saline sodic soils under water limited condition in eastern lowlands Ethiopia

Abstract

A laboratory incubation experiment was carried out on saline sodic soils collected from Babile, Eastern Ethiopia to evaluate and compare the potentials of gypsum and farm yard manure (FYM) treatments for the reclamation of saline sodic soils. The treatment tested consisted of combination of six rates of gypsum (0, 25, 50, 75, 100 and 125% gypsum requirement) and four rates of farmyard manure (0, 10, 20 and 30 tons FYM ha^{-1}) in a completely randomized design (CRD) replicated three times. Results revealed that sole and combined application of treatments significantly ($P<0.001$) improved soil pH, electrical conductivity saturated paste (ECe) and ESP over the control. Maximum reduction in soil pH (14.14%), ECe (48.99%) and ESP (16.20) recorded in soils treated with combined 30 tons FYM ha^{-1} and gypsum (125% GR) treatments. Furthermore, soils treated with sole application of gypsum at higher rates (50, 75,100 and 125% GR) achieved significantly higher reduction in soil pH, ECe and ESP than sole application of FYM. However, combined applications of FYM and gypsum were relatively more efficient than either one alone in removing exchangeable Na under condition of water limitation for dissolution. Hence, it may be concluded that all combinations of 20 and 30 tons FYM ha^{-1} with gypsum (50, 75,100 and 125% GR) rates reduced the soil pH, EC and ESP to agricultural permissible level.

Keywords: gypsum, FYM, exchangeable Na, ESP, Exchangeable sodium percentage, GR, gypsum at higher rates

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Abbreviations: FYM, gypsum and farm yard manure; CRD, completely randomized design; ECe, electrical conductivity saturated paste; C, carbon, N, nitrogen; P, phosphorus; S, sulfur; CRD, complete randomized design; SAS, statistical analysis system

Introduction

Salt affected (particularly saline and saline sodic) soils are known to occur in vast areas of the arid and semi-arid regions of Ethiopia. This together with the potentially saline and saline sodic soils occurring in the climatically arid low lands of the country will undoubtedly constrain and challenge the country's plan of massive expansion of irrigated agriculture which is currently entering in to the beginning of the plan period. As a result, saline sodic soil is becoming a serious threat to crop production in the irrigated lands of the arid and semi-arid regions of Ethiopia.

Sodic and saline sodic soils exhibit unique structural problems as a result of certain physical processes (slaking, swelling and dispersion of clay, surface crusting and hard setting,[1,2] These affect water and air movement, plant available water holding capacity, root penetration, seedling emergence, runoff and erosion, as well as tillage and sowing operations.[3] In addition, changes in the proportions of soil solution and exchangeable ions lead to osmotic and ion specific effects together with imbalances in plant nutrition, which may range from deficiencies of several nutrients to high levels of Na$^+$.[4,5]

Over the past 100 years, several different approaches involving chemical amendments, tillage operations, crop assisted interventions, water related approaches, and electrical currents have been used to reclaim sodic and saline sodic soils. Of these, chemical amendments have been used most extensively.[3]

Reclamation of saline sodic soils requires the removal of part or most of the exchangeable Na and its replacement by Ca/Mg ion and removal of the displaced Na ion below the root zone by leaching. Gypsum is the most commonly used chemical amendment due to its availability at low cost. The amelioration of saline sodic soils, thus, requires both leaching and application of gypsum.[6] However, it is slightly soluble in water and requires more high quality water to dissolve, react with the exchange site and leach the displaced Na ion from the root zone.[7] In addition, the quantity of gypsum required in reclaiming saline sodic soils, the labor it needs to mix with soil, and the amount of water needed to leach the displaced Na from the root zone as well its cost for farmers make the reclamation of saline sodic soils very much water intensive and time and energy consuming. Moreover, this approach fails to improve biological properties of the already degraded soil.[5]

Application of organic amendments such as FYM or compost to soils can improve the physical and biological properties including water stable aggregates, water holding capacity, cation exchange capacity and plant nutrition elements (Walker and Bernal, 2008). Meanwhile, these treatments use to improve microbial biomass linked to soil carbon (C), nitrogen (N), phosphorus (P) and sulfur (S) cycles.[4,5] However, these amendments have very little effect on improving soil salinity and sodicity when they are applied alone.[8] On the other hand, combined application of these treatments preferably FYM and gypsum helped in maximizing and sustaining yields and in improving soil health and input use efficiency.[5,8,9]

A clear understanding of various methods of reclaiming saline sodic soils using sole and combined application of FYM and gypsum in the arid and semi-arid regions of Ethiopia in general and the study area in particular is crucial for sustainable soil management. However, only limited numbers of researches were conducted on the distribution of salt affected soils.[7] With this general background, the study was conducted to evaluate the efficiency of FYM and gypsum and their combination to displace exchangeable Na from the soil exchange site under the condition of water limitation in Babile District, Eastern low lands of Ethiopia.

Materials and methods

General description of the study area

The study was conducted in Bisidimo peasant association of Babile District in the Oromia Regional State, Eastern Ethiopia (Figure 1). The District lies between $08^0 21'$ and $09^0 11'$ N latitude and 42^0 $15'$-$42^0 55'$ E longitude with an altitude of 900-2000 meters above sea level (masl). The study site is situated at about 30 and 90km, respectively, from Harar and Jijiga towns. According to the Ethiopian agro climatic zone,[10] the study area falls in the lowland region. The ten years (2002-2012) climatic data of Bisidimo area indicated an average annual rainfall of 650mm which is characterized by bimodal rainfall pattern. The annual mean maximum and minimum temperatures for the same period were 30.9 and 23.5^0C, respectively.

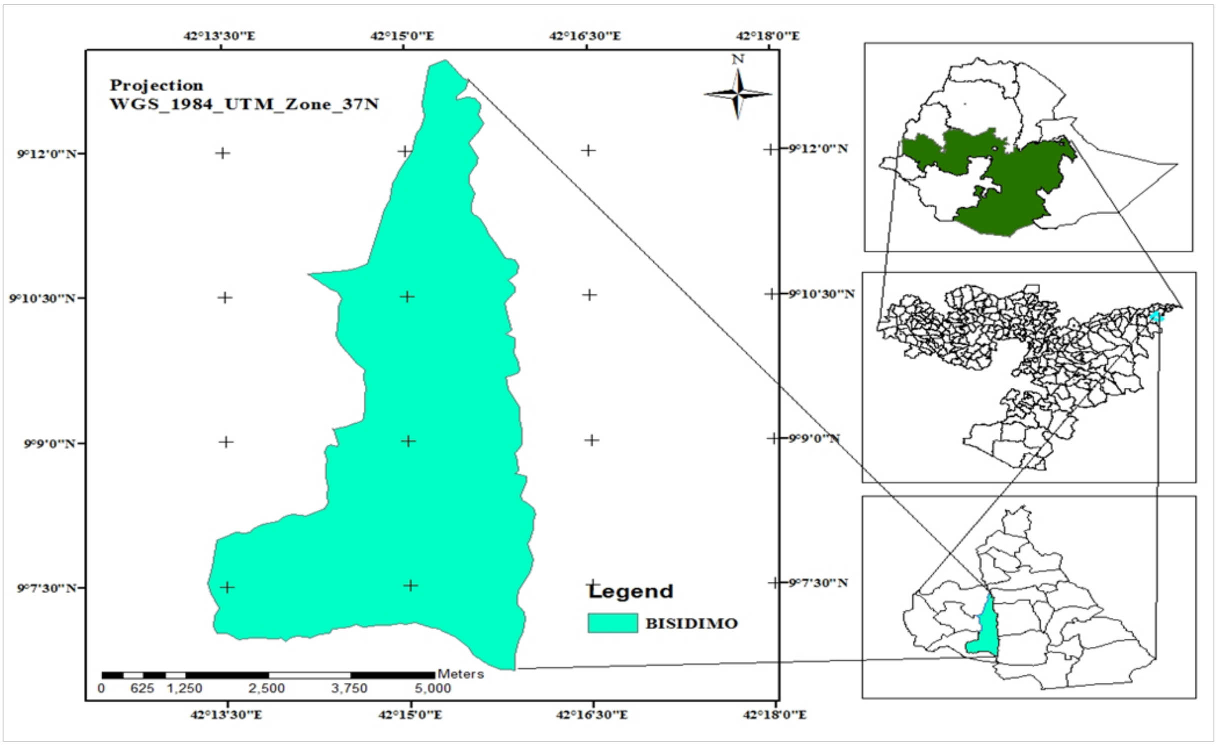

Figure 1 Map of Babile District and location of the study area (Bisidimo area).

According to FAO,[11] classification, the major soil types found in the District are Regosols and Arenosols association, Leptisols, Luvisols and its association, and Fluvisols and its association. The soils of the study area are dominantly sandy loam; however, some pocket areas of the District are dominated by clay and clay loam textures. The major crops grown include maize (*Zea mays* L.), sorghum (*Sorghum bicolor*) and groundnut (*Arachis hypogae*) and haricot beans. Sorghum, maize and haricot bean are cultivated for food consumption; whereas, groundnuts and chat are grown as cash crops. Crop production is based on rain fed agriculture and harvested usually once in a year. However, farmers in Bisidimo peasant association practiced irrigated agriculture using the Errer River and ground water sources.

Agricultural production in the District is constrained by small land holdings, high price of inputs and inadequate credit service along with shortage of rain/water and increased level of soil salinity/sodicity problems. The livestock raised includes cattle, camel, goats and donkeys. The major vegetation groups found in the study area include woodland, acacias, bushes and shrubs.

Site selection, soil sampling and sample preparation

The soil sampling sites were selected using the topographic map of the Babile District in East Hararge Zone of the Oromia National Regional State. Nine representative composite soil samples with three replications were collected from the surface layer (0-30cm) for further laboratory analysis during the 2011 period. The samples were bagged, labeled and transported to the laboratory for preparation. Sufficient amount of composite soil samples were air dried and ground to pass through a 2mm sieve.

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Fifty grams (50g) soil samples were mixed with treatments in plastic pots. The treatments consisted of combination of six levels of gypsum (0, 25, 50, 75, 100 and 125% calculated gypsum requirement) and four levels of FYM (0, 10, 20 and 30 tons FYM ha^{-1}). The experiments were laid out in complete randomized design (CRD) with three replications. Distilled water was added to the treated soils to maintain soils moisture at field capacity. All pots were incubated in a greenhouse for a week and rewetted regularly with distilled water to maintain field capacity.

Laboratory analysis

At the end of the incubation period, the soil samples were air dried before analyses. Then, 1:1 soils to water suspensions were prepared for each treatment with distilled water. The suspensions were stirred occasionally and allowed to stand for 24hours and were centrifuged at 3600 revolution per minute for 2minutes and then filtered through a watt man filter paper. Then, the solutions were saved for the analysis of pH and ECe as well as the Na$^+$ displaced due to the application of the treatments.

The concentrations of Na$^+$ in the extracts were determined using flame photometer. The concentration of Na$^+$ in the control represents the soluble Na$^+$ in the soil whereas the concentration of Na$^+$ in the other suspensions represents both the soluble Na$^+$ in the soil and the exchangeable Na displaced due to the application of the treatments.

Therefore, exchangeable Na displaced due to the application of treatments were obtained by subtracting the soluble Na$^+$ determined in the control from that determined on the extracts treated with the treatments. The exchangeable Na displaced was then subtracted from the exchangeable Na of the determined prior to the reclamation to obtain the amount that remained in the soil after reclamation. The ESP after reclaiming treatments was calculated as percentage of exchangeable Na remained in the exchange complex to the CEC determined in the original sample.

Statistical analysis

Pearson's simple correlation coefficient was executed using Statistical Analysis System (SAS) version 9.00 (SAS Institute, 2004) to reveal the magnitudes and directions of relationship between the different soil properties due to treatments.

Results and discussion

Effects of treatments on soil ph and electrical conductivity of Soil (EC)

Assessment of soil physicochemical properties was done before the start of the incubation experiment and the results of physiochemical analysis of soils are shown in (Table 1). Analysis of the data showed that some selected soil chemical properties exceed maximum values for a normal arable soil (PH of 8.56, EC of>4 dS m^{-1}, exchangeable Na of 8.97 cmol$_{(+)}$ kg^{-1} and SAR of 13 (cmol L^{-1})$^{1/2}$). According to Ghafoor et al.[12] the soil of the study area can be classified into the saline sodic category.

In the following sections, changes in soil pH due to treatments (sole and combined) were compared against the control and presented in the (Table 2). The analysis of variance indicated that sole and combined application of FYM and gypsum on saline sodic soil significant ($P<0.05$) influenced soil pH over the control. Sole Application of 10, 20 and 30 tons FYM ha^{-1} to the soil reduced the pH compared to control by 1.3, 2.8 and 4.4%, respectively.

Table 1 Selected physicochemical properties of soil before incubation experiment

Parameter	value
Texture	Cay loam
Clay (%)	39
Silt (%)	36
Sand (%)	27
Bulk density (g cm^{-3})	1.21
Gypsum requirement (tons ha^{-1})	20.71
pH	8.56
EC (d Sm^{-1})	4.68
Exchangeable sodium (cmol(+) kg^{-1}	8.97
Exchangeable sodium percentage (%)	22.54
cation exchange capacity (cmol(+) kg^{-1})	39.80
Sodium adsorption ratio (cmol l^{-1})$^{1/2}$	16.67

ECe, electrical conductivity of saturated pest

Table 2 Effect of FYM, gypsum and their interaction on pH of saline sodic soils

Gypsum (% GR)	Farm yard manure in tons ha^{-1}			
	0	10	20	30
0	8.49	8.44	8.38	8.33
25	8.45	8.32	8.25	8.21
50	8.38	8.23	8.15	8.09
75	8.25	8.12	7.96	7.86
100	8.1	7.85	7.67	7.54
125	7.88	7.72	7.42	7.35
Mean	8.26	8.11	7.97	7.9

GR, Gypsum requirement; FYM, farm yard manure; ECe, electrical conductivity of saturated pest extract

Furthermore, the graph in (Figure 2) revealed that the value of soil pH showed a decreasing trend as the rate of sole application of FYM increased from 10 to 30 tons ha^{-1}. This was in line with the explanation given by Eduardo et al. who reported that decomposition of FYM can release H$^+$, thereby creating a more acidic environment.[4,13] also reported that the decrease in soil pH could be the acidifying effect occurred due to organic acids produced during the course of decomposition of FYM treatments.

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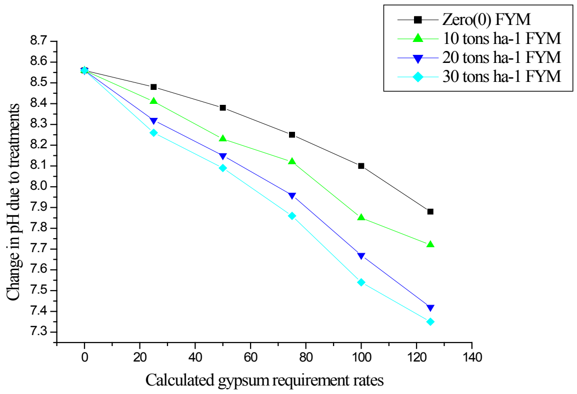

Figure 2 Effect of treatments on the soil pH in saline sodic soils

Similarly, there was also significant ($P<0.05$) difference in soil pH among the sole application of various gypsum treatments by which the highest and the lowest decrease observed in soils treated with gypsum at 125 and 25% GR rates, respectively (Table 2). Increment of sole application of gypsum by 25% GR increased their efficiency in reducing soil pH by 0.4, 1.3, 2.8, 4.6 and 7.2%, respectively, over the control (Table 2). The decreasing trend of soil pH due to increased application of gypsum could be due to the increased rate of exchange reaction took place between Ca^{2+} and Na^{+} as the concentration of Ca^{2+} increased due to gypsum dissolution.

On the other hand, combination of 10 tons FYM ha^{-1} with all rates of gypsum (25, 50, 75, 100 and 125% GR) reduced the soil pH by 2.1, 3.1, 4.4, 7.5 and 9.1% over the control. Similarly, combined application of 20 tons FYM ha^{-1} with all gypsum rates also reduced the soil pH by 2.8, 4.1, 6.3, 9.7, and 12.6%, over the control, respectively.

However, higher reductions of soil pH bellow the permissible limits recorded when 30 tons FYM ha^{-1} combined with all rates of gypsum (Table 2). The finding was supported by Abdurrahman et al. who noted that the decrease in soil pH was more remarkable in combined application of FYM and gypsum treatments than sole applications. According to him, both are good contributors to the cause i.e. gypsum provides Ca^{2+} to replace Na^{+} and FYM further boosts the process by providing organic acids to dissolve native calcium carbonate ($CaCO_3$) to release more Ca^{2+} for replacement. Therefore, from the result of the study it can be concluded that combined application of treatments (gypsum+FYM) minimized the pH of saline sodic soils than either one alone.

Similarly, the significant reduction of ECe with increasing gypsum levels is likely associated to the replacing ability of the applied gypsum. For example, increasing the applied level of gypsum treatments 25, 50, 75, 100 and 125% GR, in this order, reduced the ECe of saline sodic soil by 2.6, 6.8, 11.4, 12.2 and 17.1%, respectively, over the control. This is in line with the explanation by Sharma et al. who revealed that gypsum application supplies Ca^{2+} and replaced Na^{+} from the soil exchange site. Similarly, ECe is observed to be affected significantly ($P<0.05$) by increasing FYM rates. The graph in (Figure 3) also indicated that there is a decreasing trend in ECe when the amount of FYM increased from 0 to 30 tons FYM ha^{-1}.

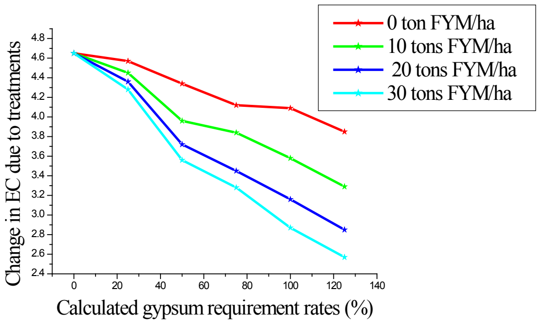

Figure 3 Effect of treatments on EC (dS m^{-1}) of saline sodic soil.

Interaction effects of FYM with gypsum significantly ($P<0.05$) reduced the ECe of the saline sodic soil over the control (Table 3). Among the treatments, combination of 30 tons FYM ha^{-1} with gypsum at 125% GR rate was more effective in reducing the ECe of the soil by 33% compared to sole application of gypsum rates or other treatment combinations. Similarly, the combination of gypsum at 75% GR rate with 20 tons FYM ha^{-1} reduced the ECe of the soil by 17.34% over the control.

Table 3 Effect of FYM, gypsum and their interaction on ECe (dSm^{-1}) of saline sodic soils

Gypsum (% GR)	tons FYM ha^{-1}				
	0	10	20	30	Mean
0	4.68	4.65	4.61	4.45	4.60a
25	4.56	4.48	3.85	3.68	4.15b
50	4.36	3.99	3.66	3.48	3.85c
75	4.15	3.77	3.43	3.31	3.67d
100	4.11	3.51	3.19	2.78	3.40e
125	3.85	3.42	3.01	2.67	3.24f
Mean	4.29a	3.97b	3.63c	3.39d	

GR, gypsum requirement; FYM, farm yard manure; ECe , electrical conductivity of saturated pest extract. Means within a row and column followed by the same letters are not significantly different at 0.05 levels

The significant decrease in ECe with increasing FYM levels could be due to the raises of pH of the soil solution thus dissolves gypsum and other salts to replace Na^{+} in the soil exchange site. This was in agreement with the work of Udayasoorian et al. who reported that combined application of organic and inorganic ameliorants were superior to sole application of treatments in reducing ECe of soil.

On the other hand, the decrease in ECe could be due to the result of FYM triggered leaching of excessive ions by improving the physical properties of soil Izhar-ul-Haq et al.[14], Alawi et al.[15] also reported a decrease in EC due to combined application of gypsum with FYM at different rates improved the soil porosity and hydraulic conductivity which resulted in enhancing the leaching of salts.

Effects of amendments on soil exchangeable Na and ESP

The amounts of exchangeable Na displaced as a result of reclaiming the saline sodic soil using varying levels of treatments (FYM and gypsum) is presented in (Table 4). The result of the data revealed that gypsum was far better than FYM in displacing exchangeable Na from the soil exchange site. For example, increasing sole application of FYM ha^{-} from 10 to 30tons^{1} reduced exchangeable Na from the soil exchange site from 4.0 to 6.6%, respectively, over the control and this resulted in decreasing the ESP of the soil by 0.91 to 1.3%.

Table 4 Effect of FYM, gypsum and their interaction on Exchangeable Na (cmol$_{(+)}$kg^{-1}))

Gypsum (% GR)	FYM (ton ha^{-1})				Mean
	0	10	20	30	
0	0.00	0.36	0.45	0.52	0.44f
25	1.28	1.86	2.45	3.05	2.16e
50	2.00	3.33	4.56	5.53	3.86d
75	3.34	4.01	5.32	5.92	4.65c
100	4.18	5.13	6.14	6.33	5.45b
125	4.43	5.32	6.18	6.40	5.58a
Mean	2.54d	3.34c	4.18b	4.63a	

GR, Gypsum requirement; FYM, farm yard manure; ECe, electrical conductivity of saturated pest extract

Mean within a row and column followed by the same letters is not significantly different at 0.05 levels

LSD$_{0.05}$=0.033 and 0.040 for rows and columns, respectively

Whereas, sole application of gypsum at 25, 50, 75, 100 and 125% GR rates reduced exchangeable Na by 14.3, 22.3, 37.2, 46.6 and 49.4%, respectively, and the ESP by 3.2, 5.0, 8.5, 10.5 and 11.1% over the control. The graph in (Figure 4) also demonstrated that the rate of release of exchangeable Na increased as the rate of gypsum increased from 25 to 125% GR. It could be inferred that the concentration of Ca^{2+} increased with increasing the rate of applied gypsum so as to maximally consume in Na-Ca exchange better than gypsum application at the lower rates.

On the other hand, significantly ($p<0.05$) higher releases of exchangeable Na recorded with combined than sole application of treatments (Table 4), (Figure 3). For example, combined application of 10 tons FYM ha^{-1} with gypsum at 25 and 50% GR rates released 20.73 and 37.11% exchangeable Na, respectively, over the control.

Relatively maximum (71.14%) release of exchangeable Na was observed by combined application of 30 tons FYM ha^{-1} with gypsum at 125% GR rate followed by 30 tons FYM ha^{-} with gypsum at100% GR rate. However, it is evident from the graph that combining gypsum at 100% GR rate with 10, 20 and 30 tons FYM ha^{-1} appeared nearly as efficient as combining gypsum at 125% GR rate with the same rates of FYM at 10, 20 and 30 tons FYM ha^{-1} (Figure 4). Joachim et al.[13] attributed the beneficial effect of combined use of FYM and gypsum on the reclamation of sodic soils (Table 5).

All combined application of gypsum, except gypsum at 25% GR rate with 10 tons FYM ha^{-1}, decreased the ESP of the soil to values less than the permissible limit (ESP<15 %). For example, combined application of 30 tons FYM ha^{-1} with gypsum at 125% GR rate reduced the ESP by 16.20%, while 4.67% reduction was observed when 30 tons FYM ha^{-1} combined with gypsum at 25% GR rate. Similarly, combined gypsum at 50 and 75% GR rates with 20 and 30 tons FYM ha^{-1} were also effective in reducing ESP of the soil to permissible level (Table 6).

Table 5 Effect of amendments on selected soil chemical properties

Treatments	Change in pH	Change in ECe (dS/m)	Displaced Na due to amendments (cmol$_{(+)}$kg^{-1})	Change in Exch. Na from the control (cmol$_{(+)}$kg^{-1})	ESP (%) values of the displaced Na	Change in ESP (%) from the control due to amendments
T1=(control)	8.49	4.65	0	0.00		0.00
T2=(FYM 10 ton ha^{-1})	8.45	4.62	0.36	8.61	0.91	21.63
T3=(FYM 20 ton ha^{-1})	8.32	4.58	0.45	8.52	1.13	21.41
T4=(FYM 30 ton ha^{-1})	8.18	4.42	0.52	8.45	1.31	21.23
T5=(gypsum 25% GR)	8.50	4.57	1.28	7.69	3.22	19.32
T6=(gypsum 50% GR)	8.45	4.34	2	6.97	5.03	17.51
T7=(gypsum 75% GR)	8.39	4.12	3.34	5.63	8.39	14.15

Table continued

Treatments	Change in pH	Change in ECe (dS/m)	Displaced Na due to amendments (cmol$_{(+)}$kg^{-1})	Change in Exch. Na from the control (cmol$_{(+)}$kg^{-1})	ESP (%) values of the displaced Na	Change in ESP (%) from the control due to amendments
T8=(gypsum 100% GR)	8.10	4.09	4.18	4.79	10.50	12.04
T9=(gypsum 125%)	7.88	3.85	4.43	4.54	11.13	11.41
T10=T2+ T5	8.40	4.45	1.86	7.11	4.67	17.86
T11=T2+ T6	8.03	3.96	3.33	5.64	8.37	14.17
T12=T2+ T7	7.83	3.74	4.01	4.96	10.08	12.46
T13=T2+ T8	7.66	3.48	5.13	3.84	12.89	9.65
T14=T2+T9	7.55	3.39	5.32	3.65	13.37	9.17
T15=T3+ T5	8.32	3.82	2.45	6.52	6.16	16.38
T16=T3+ T6	7.87	3.63	4.56	4.41	11.46	11.08
T17=T3+ T7	7.50	3.45	5.32	3.65	13.37	9.17
T18=T3+ T8	7.34	3.16	6.14	2.83	15.43	7.11
T19=T3+T9	7.23	3.02	6.18	2.79	15.53	7.01
T20=T4 + T5	8.01	3.65	3.05	5.92	7.66	14.87
T21=T4+T6	7.48	3.46	5.53	3.44	13.90	8.64
T22=T4+T7	7.42	3.28	5.92	3.05	14.87	7.66
T23=T4+T8	7.32	2.75	6.33	2.64	15.91	6.63
T24=T4+T9	7.11	2.57	6.40	2.57	16.08	6.46

Table 6 Mean square estimates of ECe and Na

Soil properties	FYM			gypsum			FYM* gypsum			CV (%)	RMSE	R-square
	MS	F -Value	P -value	MS	F -value	P -value	MS	F -value	P -value			
ECe	6.10*	1371.23	<0.001	0.41*	92.32	<0.001	0.28*	63.5	<0.001	1.75	0.07	0.99
Exch Na	84.54*	35390.3	<0.001	5.26*	2200.92	<0.001	2.07*	844.19	<0.001	1.33	0.05	0.99

MS, mean square; CV, coefficient of variation of treatments; * significant at P≤0.001; RMSE, root mean square error; Exc Na, exchangeable sodium

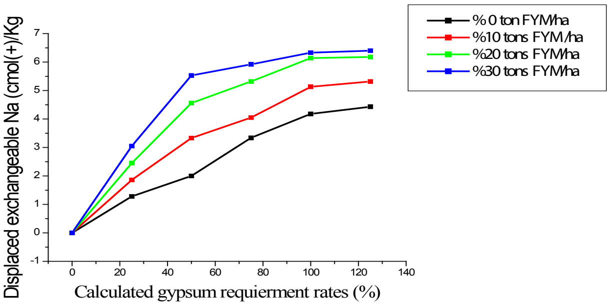

Figure 4 Exchangeable Na (cmol$_{(+)}$ kg^{-1}) displaced d to treatments.

In general, the study indicated that significant (P<0.05) quantity of exchangeable Na was released as a result of chemical replacement took place between the cations present in the treatments and the Na$^+$ present in the soil exchange site. The reason could be due to the fact that gypsum directly supplies soluble Ca^{2+} for the replacement of exchangeable Na, on the other hand, FYM through chemical and biological action make the relatively insoluble carbonates of Ca and Mg commonly found in soils available for replacement of Na$^+$.[16]

Conclusion

The result of the study revealed that application of sole and combined treatments (gypsum and FYM) acted as ameliorant to salinesodic soils; significantly decreased the pH of the soil, decreased the exchangeable Na and then decreased ESP. Sole application of gypsum at 50, 75, 100 and 125% GR rates in saline sodic soils and incubated for a week decreased average exchangeable Na by 22.30, 37.20, 46.60 and 49.40%, pH by 5.02, 8.53, 10.51 and 11.78% and ECe by 6.80, 11.40, 12.20 and 17.1% over the control, respectively. These also resulted in reduction of ESP by about 3.20, 5.0, 8.50, 10.50 ann11.40%, in that order.[17–20]

Among the combining treatments, combining gypsum at 75, 100 and 125% GR rates with 20 and 30 tons FYM ha^{-1} had a remarkable effect in reducing soil salinity/sodicity to permissible level. Generally, under water limited conditions for dissolution, sole application of gypsum performed better in decreasing soil chemical properties compared to sole application of FYM treatments. However, significantly better improvement in soil pH, ECe and ESP observed by the combined application of treatments than either one alone. Therefore, further knowledge on the extent to which level treatments combined to reclaim saline sodic soil is needed so as to plan and implement soil management systems.

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Conflicts of interest

Authors declare that there is no conflict of interest.

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