
Effects of Treatment Application Rates (FYM and Gypsum) and Pore Volume Leaching Water on Exchangeable Sodium and Saturated Hydraulic Conductivity of Saline Sodic Soils of Babile District, Eastern Lowlands of Ethiopia

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Abstract: Incubation and laboratory experiments were conducted to evaluate the effect of FYM, gypsum and pore volume (PV) of water on ESP and Ksat of saline sodic soils. Factorial combination of three rates of FYM (0, 20 and 30 ton ha⁻¹), four rates of gypsum (0, 50, 75, 100 and 125% GR) and three PV of water (1.0, 2.0, 3.0 and 4.0) were applied into the soil in complete randomized design with three replications. The soils were incubated using a plastic pot for a week followed by leaching with various PV of water. The data obtained subjected to analysis of variance. Results indicated that sole application of gypsum at different rates and their combination with FYM significantly decreased the ESP of the soil compared to FYM and the control. However, larger exchangeable Na released and then decreased the soil ESP with the use of combined FYM and gypsum treatments than sole application of gypsum for every increment in applied PV of leaching water. Similarly, the Ksat of soils was higher in combined than sole application of FYM and gypsum for all applied fixed PV of leaching water. On the other hand, increasing sole application of FYM and gypsum increased the Ksat of soil and the numerical values were significantly ($P < 0.05$) higher than the control but lower than the different combinations. Though, the Ksat of soil increased with increasing rates of applied FYM and gypsum; these values showed decreasing trend as PV of leaching water increased. In general, the interaction effects of different levels of FYM, gypsum and PV of water were significant ($P < 0.05$) in improving the ESP and Ksat of the saline sodic soils of Bisidimo. In conclusion, among the various treatments considered, combinations of 20 tons FYM ha⁻¹ with gypsum (50, 75 and 100% GR) rates and leaching up to three PV of water are adequate to reclaim saline sodic soil to permissible limit and then these combinations are recommended for resource poor farmers. The experiment was laid down in a completely randomized design with two replicates.

Keywords: Saline Sodic Soil, Exchangeable Sodium, Saturated Hydraulic Conductivity

1. Introduction

Soil physical and chemical properties such as soil structure, porosity and hydraulic conductivity may be altered due to accumulation of salts (Rengasamy *et al.*, 2002; Quirk and Schofield, 2005). The decrease in soil permeability and available water capacity might be due to high exchangeable Na decreased infiltration rates through swelling and dispersion of soils as well as slaking of soil aggregates (Rengasamy, 1999; Qadir and Schubert, 2006; Raue, 2008). Salinity sodicity and water logging are the most serious

problems affecting the irrigated agriculture and limit crop productivity in arid and semi arid regions of Ethiopia (Kidane *et al.*, 2006).

Suitable land areas for food production in Ethiopia, particularly in the highland regions are decreasing due to extensive farming practices for a long period of time. As a result of land shortage, farmers started to utilize salt affected soils of the arid and semiarid regions regardless their very low yields (Alexander *et al.*, 2006). In the arid regions, high evaporation tends to accumulate salts in the upper soil profile, especially when it is associated with an insufficient leaching

or where soluble salts move upward in the soil profile from a water table instead of downward movement (Heluf, 1987; Kidane *et al.*, 2006).

Studies on the reclamation of salt affected soils have been carried out in different parts of the world using different techniques (Heluf, 1995; Sahin *et al.*, 2002; Hanay *et al.*, 2004; Sharma and Minhas, 2004). That was achieved by using good quality water, proper choice and/or combination of soil ameliorants, good drainage and appropriate cultural practices which resulted in better physical and chemical properties of saline sodic soils (Raza, 2001; Grattan and Oster, 2003).

The development of the most suitable reclamation technology or a combination of technologies may be critical to improve the physical and chemical properties of saline sodic soils. However, few studies, if any, have assessed such techniques in Ethiopia. Although several reclamation techniques have been investigated, including physical, biological and chemical treatment, limited literature is available on the application of combined use of gypsum and FYM treatments on the reclamation of a saline sodic soil in Ethiopia. Hence, the objective of this experiment was to evaluate the potential of gypsum, FYM and their combination in improving the Ksat of soil, moreover, the research used to determine the quantity of water needed for dissolving and leaching Na⁺ in soil reclaimed with these treatments.

2. Materials and Methods

2.1. General Description of the Study Area

This study was conducted in Bisidimo peasant Association (PA) of Babile District in the Oromia Regional State, Eastern Ethiopia. The District lies between 08^o 21' and 09^o 11' N latitude and 42^o 15'-42^o 55' E longitude with an altitude of 900-2000 meters above sea level (masl). It covers a total area of 3,022.2 km² and constitutes for about 13.36% of the total area of the East Hararghe Zone of Oromia Region. According to the Ethiopian agro climatic zonation (MOA, 1998), the study area falls in the lowland region.

Ten years (2002-2012) climatic data of the study area showed an average annual rainfall of 650 mm which is characterized by bimodal rainfall pattern. The annual mean maximum and minimum temperatures for the same period were 30.9 and 23.5 °C, respectively. Bisidimo PA is situated at about 30 and 90 km, respectively, from Harar and Jijiga towns and 22 km away from the District town. It covers approximately an area of 280 ha and is characterized by hot semi arid agro-ecological zone.

According to FAO (1998) 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 area 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.

2.2. Soil Sample Collection and Laboratory Analysis

The salinity and sodicity status and other properties of soil under study before incubation experiment is given in Table 1.1. The incubation experiments were conducted in a green house using composite surface (0-30 cm) saline sodic soils collected from the study area. The FYM, gypsum and soil were air dried ground and passed through a 2 mm sieve. The gypsum requirement (GR) of the soil was calculated using standard formula.

Table 1.1. Selected Properties of the untreated composite saline sodic soil.

Parameter	Value
Texture	Cay loam
Clay (%)	39.0
Silt (%)	36.0
Sand (%)	27.0
Bulk density (g cm ⁻³)	1.21
Gypsum requirement (tons ha ⁻¹)	20.7
pH	8.5
EC (dS m ⁻¹)	4.3
Exchangeable sodium (cmol ₍₊₎ kg ⁻¹)	8.9
Exchangeable sodium percentage	22.5
cation exchange capacity (cmol ₍₊₎ kg ⁻¹)	39.8
Sodium adsorption ratio (cmol l ⁻¹) ^{1/2}	16.7

A factorial combination of three rates of FYM (0, 20 and 30 ton ha⁻¹), four rate of gypsum (0, 50, 75, 100 and 125% GR) and three pore volume (PV) of water (1.0, 2.0, 3.0 and 4.0) were used in complete randomized design (CRD) with three replications.

The columns were made from the poly vinyl chloride cylinder of 40 cm long and 10 cm internal diameter. The bottom (lower end) of each column was covered with clean porous garment and tightly bandaged with thread and rubber band and then placed on iron stand to prevent loss of soil materials during handling and measurements. In each column, 0.5 kg soil mixed with respective treatments was added. The soil columns were tapped several times after each 10 cm soil addition.

To determine the pore volume of water, the columns were saturated with water from the bottom of the column until indicated by water appearing on the top of the columns and determined by weight difference (Heluf, 1995). Then the columns were kept saturated for a week with irrigation water

to facilitate exchange reaction. After a week, the saturated columns were leached by applying the predetermined amounts of pore volume of water which varies depending on the treatment combinations. While leaching the soil, the required volume of water was applied to the column by maintaining a constant hydraulic head i.e. by filling water in inverted up down round bottom flask using cork and plastic tubes connected to the upper end of the column. The out let of water in the plastic tube was controlled by clamp so as to drain out water into the column to maintain constant head. Storage bottles were placed below the columns to collect the effluent coming from the bottom of each column. Saturated hydraulic conductivity of the soil was calculated using Darcy's experimental equation within every half volume of pore volume of water passed through the columns.

$$K_{sat} = \frac{QL}{A(h+L)T}$$

where, Q = effluent volume (cm^3), A = cross sectional area of flow (cm^2), L = length of soil column (cm), h = water head (cm) and T = time (hr)

The concentration of Na^+ in the leachates of each treatment was determined using flame photo meter. The Na^+ displaced due to the application of treatments were obtained by subtracting the amount of Na^+ measured in the eluent of the control from the eluent treated with different rates of amendments. Similarly the Na^+ remained un exchanged in the exchange site after reclamation were determined by subtracting the exchangeable Na displaced due to the applied respective treatment rate and volume of leaching water from the exchangeable Na measured in the original soil sampling during initial characterization.

2.3. Statistical Analysis

The data were statistically analyzed by a two way analyses of variance using SAS software (SAS, 2002). Means were compared using least significant difference (LSD) test.

3. Results and Discussion

3.1. Interaction Effect of Treatments (FYM and Gypsum) and PV of Leaching Water on Soil Exchangeable Na Content and ESP

The data on interaction effects of treatments in saline sodic soils followed by one week incubation and leaching by different PV of water is shown in Table 1.2. The data showed that the efficiency of all treatments and their interaction increased significantly with increasing treatment rates and applied PV of water. However, the release of exchangeable

Na with the use of gypsum was always higher than the FYM treated soils for every PV of water applied for leaching. Results also indicated that combined application of FYM and gypsum significantly ($p < 0.05$) improved the ESP of the soil compared to the control. The possible reason might be the improvement in porosity and hydraulic conductivity due to FYM, which resulted in enhancing the leaching of salts. Addition of gypsum and/or FYM enhanced the chemical reaction and exchanged the Na^+ with Ca^{2+} in the soil exchange complex. Then, the Na^+ in soluble form leached down due to improved soil physical and chemical conditions. A similar finding was reported by Ahmed *et al.* (2001) who reported that applied FYM into saline sodic soil improved the physical and chemical conditions of saline sodic soil.

The amounts of exchangeable Na leached from FYM treated soil columns were larger than the control (Table 1.2). The Table further indicated that the efficiency of sole application of FYM increased with increasing PV of water. For example, when 20 and 30 tons FYM ha^{-1} were applied in the soil and leached with 0.5 PV of water, the quantity of exchangeable Na displaced from the exchange site were 0.13 and 0.17 $cmol_{(+)} kg^{-1}$, respectively. These resulted in a reduction of 0.33 and 0.43% ESP, respectively, over the control (Figure 1.1).

Whereas, when the amount of water increased to 1.0 PV, the soil treated with the same rate of FYM (20 and 30 tons FYM ha^{-1}), released 0.22 and 0.25 $cmol_{(+)} kg^{-1}$ Na^+ from the soil exchange site and these resulted in a reduction of ESP of the soil over the control. Similar reports were released by Tajada (2006) and Izhar-ul-Haq *et al.*, (2007) who reported that applied FYM into saline sodic soil resulted significant improvements on soil physical properties.

The diminishing trend of the exchangeable Na with increasing FYM levels might be due to the conversion of insoluble Ca and Mg salts in to insoluble compounds with increased pH of the soil solution due to the applied FYM and replaced the exchangeable Na from the soil exchange site. In the control, there was still small decrease in exchangeable Na which could be due to cation exchange between Ca^{2+} in the leaching water and Na^+ in the soil complex (Heluf, 1995).

On the other hand, every increment in the level of gypsum by 25% GR showed significant ($p < 0.05$) change in ESP of soil (Figure 1.1). For example, when the soil treated with gypsum at 50, 75, 100 and 125 %GR rates leached with 0.5 PV of water, 0.21, 0.2, 0.43 and 0.62 $cmol_{(+)} kg^{-1}$ of exchangeable Na were released from the exchange site, respectively. Heluf (1995) and Zaka *et al.* (2005) also indicated that the rate of decrease in soil exchangeable Na resulted from increased rates of gypsum application followed by leaching.

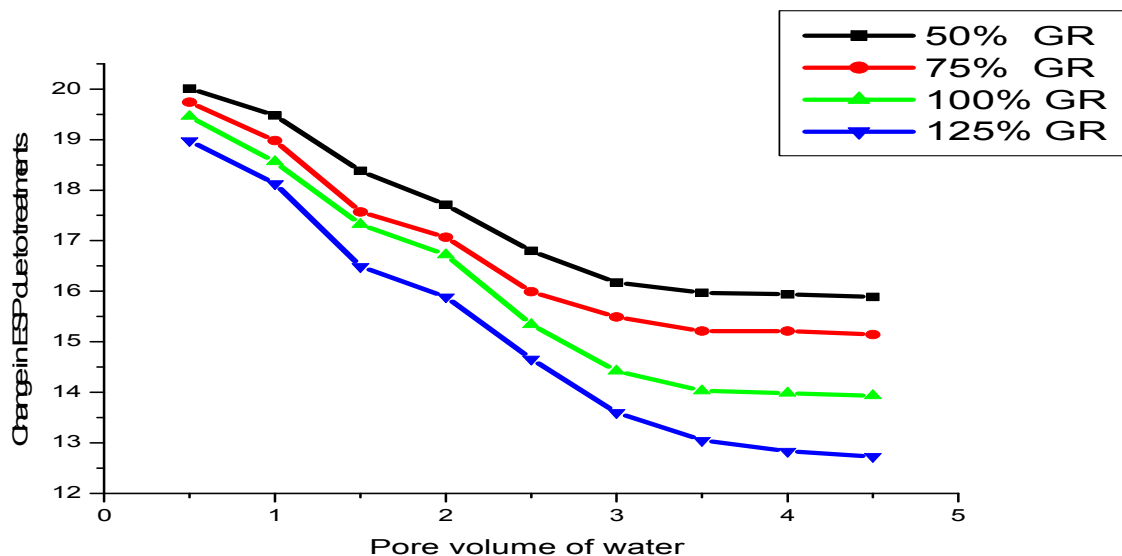


Figure 1.1. Interaction effect of gypsum and PV of on the ESP soil.

On the other hand, combined application of gypsum and FYM decreased the ESP (released larger concentrations of exchangeable Na) of soil more than sole application of gypsum treatments for every increment in the rate of FYM and PV of water applied for leaching (Figure 1.2). For

example, the soil treated with 20 tons FYM ha⁻¹ plus 50% GR and 30 tons FYM ha⁻¹ plus 50% GR gypsum rates, respectively, released higher exchangeable Na than soils treated by sole application of gypsum (50% GR) when the soil leached with increasing PV of water (Table 1.2).

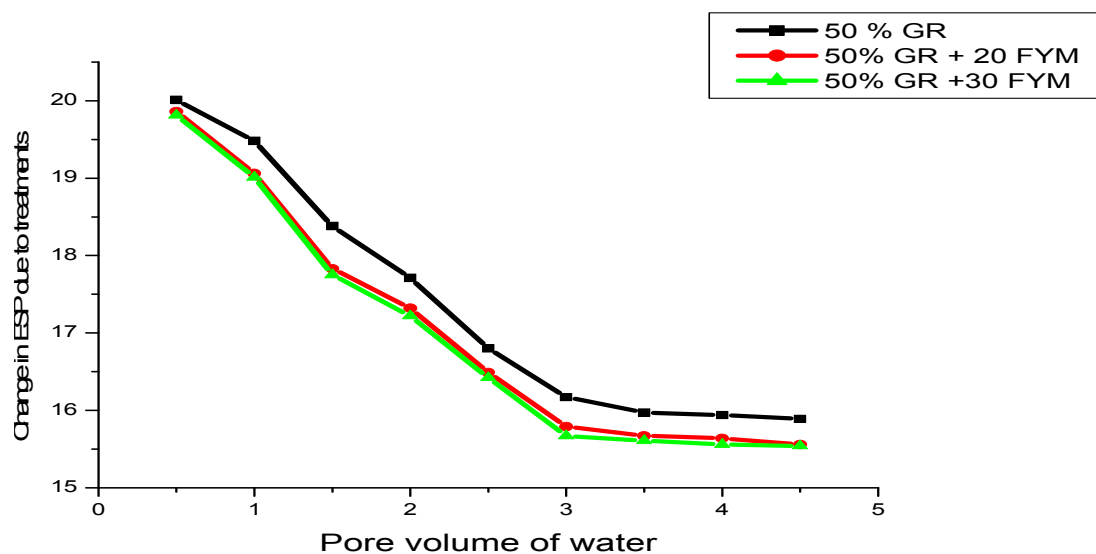


Figure 1.2. Interactions effect of gypsum, FYM and pore volume of leaching water on the the ESP of soil.

Similar pattern of increment in exchangeable Na was observed for other combinations (20 and 30 tons FYM ha⁻¹) and (75, 100, and 125% GR) (Table 1.2). The result of the study then indicated that, irrespective of the applied PV leaching water, the reductions in ESP due to combined application of treatments (FYM and gypsum) were relatively higher than sole application of gypsum and/or FYM treatments. Similarly, sole application of gypsum at 125% GR and its combination with 20 and 30 ton FYM ha⁻¹ closely followed the same pattern as explained above.

Therefore, it could be concluded that significantly ($p < 0.05$) better reductions in ESP of soils were recorded due to the application of the combined treatments (FYM and

gypsum) relative to either one alone. This finding was also supported by Ahemed *et al.* (2001) who concluded that applied combined treatments (FYM and gypsum) decreased soil pH which might have been used in enhancing the solubilization process. Tajada (2006) and Izhar *et al.* (2009) also suggested that combined application of organic and inorganic ameliorants is superior in reducing exchangeable Na from saline sodic soil.

As it can be seen from Table 1.2, all applied levels of gypsum continued to displace additional exchangeable Na from the soil exchange sites until the maximum pore volume of water (4.5) passed through the columns. For example, when the soil treated with gypsum at 50, 75, 100 and 125%

GR rates leached in this order with 0.5 PV of water, 0.21, 0.32, 0.43 and 0.62 $\text{cmol}_{(+)}\text{kg}^{-1}$ exchangeable Na displaced from the soil exchange site. However, when the amount of leaching water increased from to 1.0 PV, the soil treated with the same treatments released 0.59, 0.68, 0.85 and 0.96 $\text{cmol}_{(+)}\text{kg}^{-1}$ exchangeable Na. Moreover, when the amount of leaching water increased to maximum (4.5) PV of water, the soil treated with the same rates of gypsum (50 to 125% GR) released 1.85 to 3.07 $\text{cmol}_{(+)}\text{kg}^{-1}$ exchangeable Na from the soil exchange site (Table 1.2). Therefore, it can be concluded that the efficiency of all treatments (either sole or combined) in releasing exchangeable Na from the soil exchange site increased significantly with increasing applied PV of water from 0.5 to 4.5 (Table 1.2).

This finding was also supported by Heluf, (1995) who notified that the efficiency of gypsum in removing exchangeable Na from the soil exchange site increased significantly with increasing PV of leaching water.

Nevertheless, gypsum alone application, while being successful in restoring some chemical properties of the soil, it may fail to restore the biological properties of the soil unless it is applied with organic treatments (Sahin *et al.*, 2002).

Among the possible reasons could be the improvement in porosity and Ksat due to FYM, which resulted in enhancing the leaching of Na^+ (Kalute, 1986; Husen *et al.*, 2006). It could also be inferred that FYM enhanced the efficiency of gypsum to release Ca^{2+} to be maximally consumed in Na-Ca exchange. The ongoing microbial activity causes reduction of soil pH due to production of organic acids (Wichern *et al.*, 2006; Yuan *et al.*, 2007). Furthermore, the microbial activity increases the carbon dioxide partial pressure and cause development of reducing conditions (Raue, 2008). The lowered pH increases the solubility of gypsum or other naturally occurring Ca^{2+} thus removed some of the exchangeable Na from the soil exchange site (Wahid *et al.*, 1998; Raue, 2008).

Table 1.2. Effect of FYM, gypsum, pore volume of water and their interaction on displaced exchangeable Na ($\text{cmol}_{(+)}\text{kg}^{-1}$).

Applied treatments		Applied pore volume of water									
FYM (tons ha^{-1})	Gypsum (%GR)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	mean
0	0	0.04j	0.06j	0.08k	0.12k	0.14h	0.17e	0.19m	0.21m	0.22n	0.14
	50	0.21h	0.42h	0.86	1.12i	1.49g	1.74d	1.82j	1.83	1.85k	1.26
	75	0.32g	0.62f	1.18g	1.38g	1.81def	2.01c	2.12h	2.12	2.15i	1.52
	100	0.43df	0.79e	1.28e	1.52d	2.07cd	2.43	2.59e	2.61e	2.63f	1.82
	125	0.62b	0.96c	1.61c	1.85c	2.34bc	2.76a	2.98c	3.07c	3.11c	2.14
	mean	0.32	0.57	1.01	1.20	1.57	1.82	1.94	1.97	1.99	
20	0	0.13i	0.22i	0.26j	0.28j	0.29h	0.31e	0.35i	0.37i	0.42m	0.29
	50	0.27g	0.59g	1.08h	1.28h	1.61fg	1.89cd	1.94i	1.95i	1.98j	1.4
	75	0.35fg	0.68f	1.22g	1.42fg	1.87de	2.26b	2.35g	2.36g	2.38h	1.65
	100	0.48cd	0.85d	1.53d	1.72d	2.07cd	2.68a	2.85d	2.95d	2.97e	2.03
	125	0.68ab	1.12b	1.66b	1.97b	2.53ab	2.81a	3.05b	3.12b	3.17b	2.23
	mean	0.49	0.70	1.15	1.33	1.67	2.00	2.11	2.15	2.18	
30	0	0.17hi	0.25i	0.28j	0.32j	0.35h	0.38e	0.42k	0.46k	0.49l	0.35
	50	0.29g	0.61g	1.11h	1.32h	1.64efg	1.94cd	1.96i	1.98i	2.01j	1.43
	75	0.39ef	0.75e	1.25ef	1.45f	1.89de	2.31b	2.42f	2.45f	2.54g	1.72
	100	0.54cb	0.92c	1.58c	1.75d	2.25c	2.72a	2.95c	2.98d	3.08d	2.09
	125	0.72a	1.18a	1.77a	2.02a	2.65a	2.85a	3.11a	3.18a	3.23a	2.30
	mean	0.42	0.74	1.20	1.37	1.76	2.04	2.17	2.21	2.27	
Over all mean		0.48i	0.82h	1.34g	1.53f	1.97e	2.29d	2.44cb	2.48b	2.55a	

Means in the column sharing similar letter(s) do not differ statistically at $p < 0.05$; Interaction between treatments and PV of water was significant at $P < 0.001$ levels and $\text{SD}_{0.001} = 0.0319$ for row and 0.024 for column values

The data in Table 1.2 shows that all treatments (sole and combined) released very small amounts of exchangeable Na at the initial stage and continued to release more Na^+ when the PV of added water increased from 1 to 4.5. Moreover, higher exchangeable Na was released from the combined treatments compared to either gypsum or FYM alone. The critical limit between sodic and non-sodic soil is established at an ESP value of 15% (U.S Salinity Laboratory Staff, 1954). Compared with control, applied gypsum from 50 to 125% GR rates reduced the ESP values below the proposed limits and their combination with FYM further reduced the values to below the permissible limits. In general, the present results show that combined treatments were significant to either one alone in reducing the ESP of the soil.

3.2. Interaction Effect of Treatments (FYM and Gypsum) and PV of Water on Soil Saturated Hydraulic Conductivity (Ksat)

The data on the effect of different rates of FYM, gypsum, PV of water and their interaction on Ksat is presented in Table 1.3. The result revealed that the Ksat increased as the rates of applied treatments increased. However, FYM treated soils increased the Ksat lower than the gypsum treated soils. For example, when the rate of FYM increased from 20 to 30 tons FYM ha^{-1} and leached with 0.5 PV of water, the Ksat increased from 1.83 to 1.85% over the control. While, increasing the levels of applied gypsum from 50 to 125% GR and leached with the same (0.5) PV of water increased the

Ksat form 2.61 to 4.88 mm ha⁻¹.

Regarding sole application of gypsum treatments into saline sodic soil, the data in Table 1.3 demonstrated that minimum improvement in Ksat was observed in the soil treated with gypsum at 50% GR rate while, maximum increment was recorded in the soil columns receiving gypsum at 125% GR rate. Figure 1.2 also demonstrated that every increment in the rate of FYM and gypsum increased the Ksat of the soil under study. This was in agreement with the work of Qadir *et al.* (2005) who concluded that improvements were observed in the physical properties of sodic soils during the reclamation process by gypsum have been attributed to an increase in Ca²⁺ levels, both in the soil solution and on the exchange complex. Such an increase in Ca²⁺ enhances soil aggregation and reduces crusting, thereby improving the soil's hydraulic properties.

On the other hand, interaction of FYM with gypsum improved the Ksat of the saline sodic soil and had shown statically higher value than the soil treated with sole application of treatments and the control (Table 1.3). The increases in soil Ksat were greater with increasing rates of combined treatments (gypsum + FYM) than the increase observed with sole application of gypsum. For example, combined application of gypsum at 50% GR rate with 20 tons FYM ha⁻¹ and leached with 0.5 PV of water increased the Ksat by 98 as compared to the control, whereas, 86% increase was observed when sole application of gypsum at 50% GR rate was applied and leached with the same PV of water

(Table 1.3).

Similarly, combining 30 tons FYM ha⁻¹ and gypsum at 125% GR rate decreased the Ksat by 242% relative to control when leached with 0.5 PV of water; however, 223% increment was recorded when gypsum alone (125% GR) was applied and leached with the same PV of water. Similar pattern of change in soil Ksat was observed for other treatments (sole or combined), too. The result then showed that combined treatments had better effect on the rate of water movement through the soil columns than sole application of treatments (Table 1.3).

The effects of PV of water in decreasing the Ksat of soil were significant at (P<0.05) when the soils were treated with all kinds of treatments. However, applications of combined treatments into saline sodic soil were more effective than sole application of treatments (Table 1.3). On the other hand, increasing the PV of water decreased the Ksat of the soil for each rates of treatments. For instance, increasing the amount of leaching water from 0.5 to 4.5 PV decreased the mean Ksat of soil from 3.44 to 0.83 mm hr⁻¹ (Table 1.3). This finding was also supported by the finding of Izhar-ul-Haq *et al.* (2007) who suggested that the favorable effect of combined treatments in increasing Ksat may be attributed to the improvement in soil structure due to FYM which might have resulted enhanced water movement. Moreover, the interaction between various levels of sole application of treatments and PV of water was significantly different at P < 0.05 levels.

Table 1.3. Effects of various levels of amendments and pore volume of leaching water on Ksat (mm/hr).

Treatment levels		Pore volume of water									
FYM (tons ha ⁻¹)	Gypsum (% GR)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	mean
0	0	1.44	0.65	0.55	0.35	0.27	0.25	0.2	0.18	0.18	0.46e
	50	2.68	2.21	1.91	1.15	0.84	0.74	0.65	0.56	0.52	1.25d
	75	3.62	3.22	2.31	1.85	1.65	1.25	0.95	0.85	0.83	1.84c
	100	4.58	4.18	3.15	2.65	2.35	2.06	1.85	1.45	1.15	2.60b
	125	4.65	4.25	3.25	2.75	2.55	2.31	2.13	1.75	1.25	2.77a
	mean	3.39a	2.90b	2.23c	1.75d	1.53e	1.32e	1.16f	0.96g	0.79h	
20	0	1.63	0.74	0.64	0.42	0.31	0.31	0.23	0.22	0.18	0.52e
	50	2.91	2.44	2.14	1.28	1.02	0.79	0.72	0.61	0.56	1.39d
	75	3.88	3.47	2.51	2.08	1.94	1.55	1.32	0.98	0.95	2.08c
	100	4.67	4.27	3.32	2.82	2.65	2.15	1.98	1.54	1.18	2.73b
	125	4.82	4.31	3.43	2.83	2.62	2.35	2.18	1.78	1.35	2.85
	mean	3.58a	3.05b	2.41c	1.89d	1.71d	1.43e	1.29f	1.03g	0.84h	
30	0	1.85	0.95	0.85	0.45	0.33	0.32	0.22	0.22	0.18	0.60e
	50	2.91	2.44	2.14	1.28	1.02	0.79	0.72	0.61	0.56	1.39d
	75	3.88	3.47	2.51	2.08	1.94	1.55	1.32	0.98	0.95	2.08c
	100	4.77	4.31	3.35	2.95	2.75	2.34	2.01	1.65	1.21	2.82b
	125	4.93	4.43	3.45	2.95	2.75	2.37	2.23	1.84	1.38	2.93a
	mean	3.67a	3.12b	2.46b	1.94cd	1.76d	1.47e	1.30f	1.06g	0.86h	
Over all mean		3.54a	3.02b	2.36c	1.86d	1.66e	1.40f	1.24g	1.01h	0.83i	

Means within a column and row, followed by the same letters are not significantly different at p < 0.05 levels
LSD_{0.001} = 0.027 for rows and 0.046 for column values

Table 1.3 indicated that the soils treated with FYM reached steady state Ksat after leaching with 2.5 PV of water. However, soils treated with sole application of gypsum at 50% GR rate and its combination with 20 tons FYM ha⁻¹ reached

steady state Ksat at about leaching the soil with 3.5 pore volume of water. This implied that the Ksat of soil could not be reduced further with more leaching. These results were also supported by the finding of Heluf (1995) who concluded

that after reached steady state Ksat, no more exchangeable Na can be achieved with further leaching since the electrolyte solution of the soil solution is equilibrated with the electrolyte of the water used for leaching. For the other treatments, steady state Ksat were not attained until the maximum pore volume of water passed through the columns; then the Ksat of soil will decrease further if additional volume of water is used for leaching.

Generally, sole application of gypsum at various rates to the saline sodic soil showed significantly higher Ksat than the FYM treated soils and the control but lower than their various combinations (gypsum + FYM + PV of water). The Ksat of soil increased significantly with increasing rates of applied treatments, however, this value showed a decreasing trend as the PV of leaching water increased (Table 1.3). The rate of decrease in Ksat with increasing of water was higher in combined than sole application of treatments. Among the possible reasons could be due to FYM enhanced the efficiency of gypsum to release Ca^{2+} to be maximally consumed in Na-Ca exchange (Raza *et al.*, 2001; Husen *et al.*, 2006). According to Heluf (1995), the increase in Ksat with increasing level of treatments could be due to the removal of exchangeable Na, whereas, the decrease in Ksat with increasing PV of water is due to the effect of electrolyte concentration of the soil solution than the effect of exchangeable Na.

4. Conclusion

Applied different levels of treatments (FYM and gypsum across all added PV of water released very small amounts of exchangeable Na at the initial stage and continued to release more Na^+ when the PV of water increased. Moreover, significantly higher exchangeable Na was released from the combined treatments compared to either of sole application of treatments. Compared to the control and FYM, applied gypsum from 50 to 125% GR rates reduced the ESP below the proposed limits and their combination with FYM further reduced the values to below the permissible limit. On the other hand, the efficiency of treatments in releasing exchangeable Na increased significantly with increasing applied pore volume of water.

The increase in Ksat of the soils treated with all rates of treatments and leached with all PV of leaching water was statistically significant. However, each rate of applied gypsum treatments showed significant increment of Ksat than the control and FYM treatments. Despite the fact that the leachate volume and then Ksat gradually decreased with time as the of leaching water increased, steady state Ksat of the soil was not attained at the time of experiment when the soil was treated with some of the treatments. In general, the present results show that combined treatments were relatively superior to either one alone in reducing the ESP of the soil and increasing Ksat significantly. On the other hand, increasing the PV of water decreased the Ksat of the soil for each rates of applied treatments.

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