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A Comparative Study of Different Amendments on Amelioration of Saline-Sodic Soils Irrigated with Water Having Different EC: SAR Ratios

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ABSTRACT

Soil degradation affects soil properties such as structure, water retention, porosity, electrical conductivity (EC), sodium adsorption ratio (SAR), and soil flora and fauna. This study was conducted to evaluate the response of contrasting textured soils irrigated with water having different EC:SAR ratios along with amendments: gypsum (G), farm manure (FM), and mulch (M). Water of different qualities viz. EC 0.6 + SAR 6, EC 1.0 + SAR 12, EC 2.0 + SAR 18, and EC 4.0 + SAR 30 was used in different textured soils with G at 100% soil gypsum requirement, FM at 10 Mg ha^{-1}, and M as wheat straw was added on surface soil at 10 Mg ha^{-1}. Results revealed that the applied amendments in soils significantly decreased pH_s and electrical conductivity (EC_e) of saturated paste and SAR. Four pore volumes of applied water with leaching fraction 0.75, 0.77, and 0.78 removed salts 3008, 4965, and 5048 kg ha^{-1} in loamy sand, silty clay loam, and sandy clay loam soils, respectively. First four irrigations with LF of 0.82, 0.79, 0.75, and 0.71, removed 5682, 5000, 3967, and 2941 kg ha^{-1} salts, respectively. The decreasing order for salt removal with amendments was FM > G > M > C with LF = 0.85, 0.84, 0.71, and 0.68, respectively. This study highlights a potential role of soil textures to initiate any mega program for reclamation of saline-sodic soils in the perspective of national development strategies.

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KEYWORDS
Amendments; EC: SAR ratio; leaching; reclamation; saline-sodic soil

Introduction

For the reclamation of saline-sodic and/or sodic soils, removal of adsorbed sodium (Na^+) and a sustainable threshold electrolyte concentration in soil solution is important. Therefore, addition of calcium (Ca^{2+}), to replace adsorbed Na^+ followed by the addition of solutes, is always useful. The maintenance of a sufficient electrolyte concentration is crucial as it increases water-conducting properties of soils, which indirectly could promote their reclamation by increasing leaching (Ghafoor et al. 2012; Hassan, Saqib, and Ghafoor 2011). These requirements are often achieved with the application of gypsum, which has an additional advantage of being cost-effective (Murtaza et al. 2017b). Other amendments that can be used for this purpose include calcium chloride ($CaCl_2$), phosphogypsum ($3H_3PO_4 + 5CaSO_4 \cdot 2H_2O$) (by-product from high-analysis phosphatic fertilizers), and acids or acid formers for calcareous soils (Ghafoor et al. 2001). By-products of agricultural industries, e.g., press mud and molasses meals have been found effective but their use is limited and localized. Addition of organic

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matter (farm manure, slaughterhouse wastes, poultry excreta, green manure, and vegetable/fruit market wastes) is also used to reclaim such soils but their action is very slow.

Soil pH changes with the application of brackish water as irrigation source. Increase in pH_s with high sodium adsorption ratio of irrigation water (SAR_{iw}) and residual sodium carbonate (RSC) was also observed in several field and laboratory studies along with nutritional and infiltration problems (Murtaza, Ghafoor, and Qadir 2006; Parlak and Parlak 2006). Murtaza et al. (2011) concluded that irrigation with saline-sodic water [EC of irrigation water (EC_{iw}) 2.33 dS m^{-1}, SAR_{iw} 9.61 (mmol $L^{-1})^{1/2}$] resulted in an increase in pH from 8.58 to 8.68. In a three-year field study in the Indus Plains of Pakistan, Murtaza, Ghafoor, and Qadir (2006) observed that the application of saline-sodic waters with higher levels of EC_{iw} (3.32 dS m^{-1}), SAR_{iw} (16.29 (mmol $L^{-1})^{1/2}$), and RSC (5.25 $mmol_c$ L^{-1}) resulted in an increase in pH_s at deeper soil layers.

Literature indicates that EC_e increased linearly with EC_{iw} and number of irrigations (Chao-Yin et al. 2011; Parlak and Parlak 2006). According to an estimate, 8 to 90% variability in EC_e of soil is accounted for by the EC_{iw} applied to different crops grown on medium-textured soils (Kahlon 2011). Other factors, like soil texture, drainage conditions, and initial salt level of soil may also affect the EC_e of soil. Al-Rashed and Al-Senafy (2004) reported that there was a sharp increase in EC_e up to a depth of 150 cm during first three years while the irrigation water have EC 3.6 dS m^{-1}, SAR 15.8 (mmol $L^{-1})^{1/2}$, and RSC 6.8 $mmol_c$ L^{-1}, which have linear relationship with EC_{iw} and average change in EC_e of soil was from 1.23 to > 4.0 dS m^{-1}.

Water and soil sodicity are expressed in terms of SAR, with high SAR values having the potential for deterioration of soil structure, low infiltration rate, specific-ion effect, and deficiencies of several micro and macro nutrients (Murtaza, Ghafoor, and Qadir 2006). In an experiment at Mona Reclamation Experimental Project area, Sargodha, Pakistan, Sikandar et al. (2010) and Muyen, Moore, and Wrigley (2011) reported that high SAR_{iw} was more harmful than the total salinity of water. Furthermore, water having SAR_{iw} < 4.0 and total soluble salts up to 2600 mg L^{-1} could not adversely affect soils provided leaching requirements were met for successful crop production on medium-textured soils. Under field conditions, SAR/exchangeable sodium percentage (ESP) increased significantly in direct proportion to SAR_{iw} and was more harmful for soils as well as expected crops when SAR_{iw} increased (Rasouli, Pouya, and Karimian 2013; Shouse et al. 2010). Keeping in view the importance of this issue, the present studies were planned with following objectives: (1) To compare the effectiveness of brackish water with variable EC: SAR for salt removal from different textured saline-sodic soils and (II) evaluate the use of amendments for decreasing soil sodicity with the use of marginal quality brackish water.

Materials and methods

The bulk soil samples were collected from the plough layer (upper 0.12 m) of three different fields located at village Dheroki, District Toba Tek Singh, Pakistan. These fields were selected on the basis of textural differences determined through feel method and ultimately analyzed in the laboratory to establish their textural classes. Bulk soil samples were air-dried, ground to pass through a 2-mm sieve, and mixed thoroughly. Soil samples were analyzed to determine the physical and chemical characteristics of the soils (Table 1). Soil characterization including sand; silt and clay fraction was determined by Hydrometer method (Rowell 2014), organic matter content (Nelson and Sommers 1982), soil gypsum requirement (Schoonover 1952), saturation percentage, lime contents, pH of saturated soil paste (pH_s), electrical conductivity of saturation extract (EC_e), cations (Na^+, K^+, Ca^{2+} $+Mg^{2+}$), anions (CO_3^{2-}, HCO_3^-, SO_4^{2-}, Cl^-), and SAR (Estefan, Sommer, and Ryan 2013). The textures of these soils were loamy sand (S_1), silty clay loam (S_2), and sandy clay loam (S_3). This experiment was conducted in lysimeters using calcareous saline-sodic soils in the wire house, at the Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, during 2008.

Lysimeters were made of polyvinyl chloride (PVC) and had the dimensions of 0.50 m length and 0.11 m diameter. Bulk soil was mixed with the designed amendment as control (without

Table 1. Initial chemical and physical properties of soils.

Soil Parameter	Unit	Value		
		LS (S_1)	SiCL (S_2)	SCL (S_3)
Sand	g kg^{-1}	780	190	560
Silt	g kg^{-1}	80	530	230
Clay	g kg^{-1}	140	280	210
Textural class	—	Loamy sand	Silty clay loam	Sandy clay loam
pH_s		8.88	8.97	9.15
EC_e	dS m^{-1}	8.19	23.86	33.95
$Ca^{2+} + Mg^{2+}$	$mmol_c$ L^{-1}	7.63	14.56	18.23
Na^+	"	84.48	285.67	430.23
K^+	"	5.62	6.82	7.0
SAR	$(mmol\ L^{-1})^{1/2}$	23.32	106.19	133.52
CO_3	$mmol_c$ L^{-1}	1.4	1.0	1.62
HCO_3^-	"	4.83	6.54	9.68
Cl-	"	32.0	58.42	104.89
SO_4^{2-}	"	59.77	250.44	351.82
Organic matter	g kg^{-1}	5.8	6.1	5.3
$CaCO_3$	g kg^{-1}	60	110	75
CEC	$cmol_c$ kg^{-1}	7.25	15.5	11.0
Bulk density	Mg m^{-3}	1.08	1.01	1.03
Gypsum requirement	Mg ha^{-1}	8.2	12.5	10.3
Saturation percentage		26.9	31.4	30.5
Pore volume	mL	944	1097	1067

amendment). Farm manure (FM), means cattle manure, was incorporated into 0–0.12 m soil layer at 10 Mg ha^{-1}; agricultural grade gypsum powder passed through a 30-mesh sieve, having 70% purity was broadcasted uniformly at 100% soil gypsum requirement (SGR) of the 0.12 m upper soil depth {S_1 = loamy sand (8.2 Mg ha^{-1}), S_2 = silty clay loam (12.5 Mg ha^{-1}), and S_3 = sandy clay loam (10.3 Mg ha^{-1})}; mulch (M) as wheat straw was added on surface soil at 10 Mg ha^{-1}. In each soil column, 3.5 kg soil was added in small increments to obtain uniform packing. The bottom of each column was padded with 0.03 m gravel and sand to facilitate leaching. Before the addition of each increment, the surface of the previously packed layer was scratched to avoid local compaction. Soil was packed to a height of 0.27 m, making soil column of 0.24 m. Soil columns were placed vertically on iron stands. Storage bottles were placed underneath the columns to collect leachate. The lysimeters were saturated with tap water (EC_e 0.87 dS m^{-1}, SAR 0.62, and RSC Nil) at 75% of saturation and allowed to equilibrate for three weeks during which leachate, if any, was recycled. Following four treatments were repeated three times in completely randomized design (split) for all the three soils. T_1 = EC 0.6 & SAR 6, leaching with brackish water of EC 0.6 and SAR 6, T_2 = EC 1.0 and SAR 12, leaching with brackish water of EC 1.0 and SAR 12, T_3 = EC 2.0 and SAR 18, leaching with brackish water of EC 2.0 and SAR 18, and T_4 = EC 4.0 and SAR 30, leaching with brackish water of EC 4.0 and SAR 30. Initially additional water equal to soil-saturation percentage was added for soaking the soil in lysimeters. The calculated amount of 1 pore volume (1 PV) water was poured and allowed to infiltrate till dropping of water at the bottom of the lysimeters stopped. Pore volume was calculated with the help of saturation percentage and bulk density by the formula (Kahlon 2011):

$PV\ (cm^3) = \theta_v\ \pi\ r^2\ L$, where
θ_v = Volumetric water contents calculated from saturation percentage,
L = Height of soil column (cm),
r = Radius of soil column (cm), and
π = 3.148.

Leachate was collected in plastic bottles when 1 PV of water infiltrated through the soil. After collecting the first leachate, water equal to 1 PV was again added. In this way, water equal to 4 PV was allowed to infiltrate consecutively and analyzed for soluble cations and anions (Sparks 2003). At the termination of the experiment, soil columns were allowed to dry up to workable water contents in wire house. The graphs of leaching fractions, salt removal, EC_e, pH_s, and SAR against amendments were drawn using Origin Pro 8.5. Completely randomized design with factorial arrangement and three replications was applied for the experiment. The data were tested for normal distribution and homogeneity of variance. Data were tested at a significant level of $p < 0.05$ by using two-way analysis of variance (ANOVA). The soil properties were analyzed statistically and significant treatment differences were evaluated using the least-significant difference (LSD) test (Gardea-Torresdey et al. 2004).

Results and discussion

Leaching fraction

Main and interactive effects were significant for leaching fraction (LF) (Figure 1). The LF remained higher with sandy clay loam (SCL) 0.78 followed by loamy sand (LS) 0.75 and silty clay loam (SiCL) 0.77. For treatments, the highest LF was obtained for T_4 (0.79) whereas, the lowest LF was obtained for T_1 (0.74). The highest LF was obtained (0.82) in first leachate (L_1) and the lowest (0.71) in fourth leachate (L_4). Gypsum application significantly increased LF (0.85) compared to mulch and control. Higher LF was recorded with S_3L_1 (0.84) and lower (0.72) for S_1L_4. Higher LF (0.80) was obtained with S_3T_4 and lower (0.73) with S_2T_1. Among T × L interactions, higher LF was obtained with T_4L_1 (0.85) and lower with T_1L_4 (0.66). Among T × A interactions, LF was the highest with T_4G (0.87) and it was lower for T_1M (0.65).

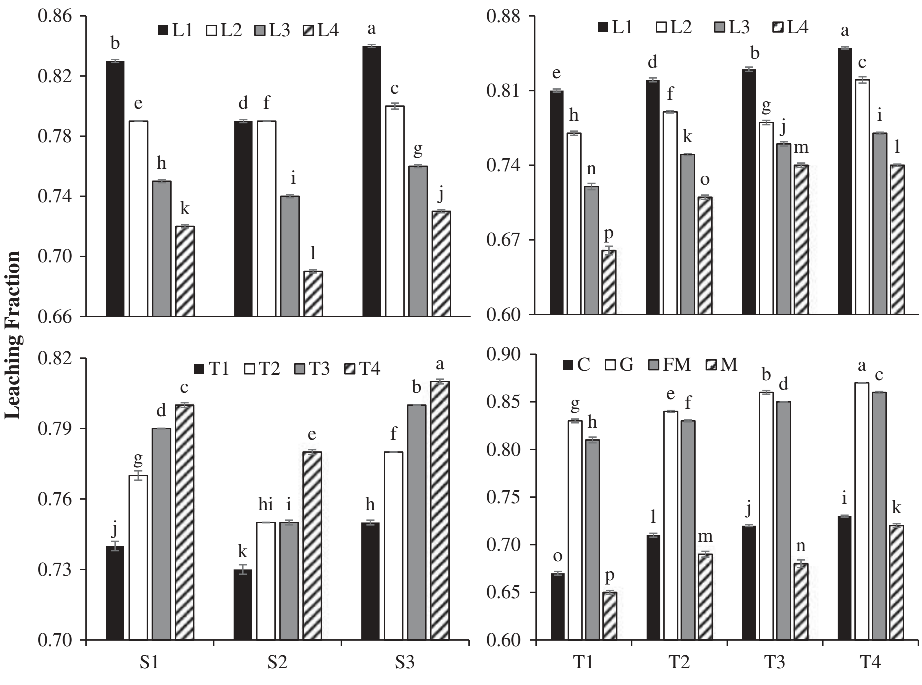

Figure 1. Treatment × amendment effect on leaching fraction in different soils.

Values sharing same letter(s) in rows are statistically similar at $p < 0.05$ and * = Significant at $p < 0.05$.L = leachate, L_1 = First leachate, subscript indicates the leachate number, LS (S_1) = Loamy sand, SiCL (S_2) = Silty clay loam, SCL (S_3) = Sandy clay loam, C = Control, G = Gypsum @ 100% SGR, F = Farm manure @ 10 t ha^{-1}, M = Mulch @ 10 t ha^{-1}.LSD: Soil = 6.02×10^{-4}*, Treatments = 6.96×10^{-4}*, Leachates = 6.96×10^{-4}*, Amendments = 6.96×10^{-4}*, S × T = 1.20×10^{-3}*, A × S = 1.20×10^{-3}*, T × L = 1.39×10^{-3}*, T × A = 1.39×10^{-3}*.

In gypsum- and FM-amended soils receiving brackish water of different EC: SAR ratios, the LF was not statistically different from that obtained from control and mulch. All the treatments increased the LF because high EC_e tends to flocculate soils (Rengasamy 2010). A decrease in exchangeable Na^+ in soil helped to promote the infiltration rate and facilitate the leaching of applied water through soil columns (Ghafoor et al. 2001; Suarez, Wood, and Lesch 2008). Higher amount of water was passed through soil column receiving gypsum at 100% soil gypsum requirement. This seems due to high electrolyte concentration from applied gypsum which leads to addition of soluble Ca^{2+} upon dissolution and thus desorbs Na^+ from exchange site and partially due to induced flocculation of dispersed saline-sodic soils (Ahmad et al. 2006; Qadir et al. 2005). From control- and mulch-amended soils, LF gradually decreased. This might be due to the removal of soluble salts without enough removal of Na^+ that caused dispersion of soils and thus decreased hydraulic conductivity of soil (Dikinya, Hinz, and Aylmore 2008; Hassan, Saqib, and Ghafoor 2011). In all the three soils, application of gypsum and FM performed better than control. This showed that the applied gypsum initially supplied electrolyte and along with the original solute concentration facilitated the water infiltration, which gradually decreased due to decrease in EC (Ghafoor et al. 2001; Oad et al. 2002). In gypsum and FM treatments, LF was the highest with S_3 (SCL) and the lowest with S_2 (SiCL). According to general trend, the micro-porosity is higher for fine-textured soils than the coarse-textured soils (Brady and Weil 2010). This can be clearly observed from the results of this study that the application of gypsum and FM on two relatively coarse-textured sodic/saline-sodic soils has performed better than the finer ones.

Amount of salt removed (kg ha^{-1})

The soil types, treatments, leachates, and their combination differed significantly with regard to total soluble salts removed in leachate (Figure 2). The quantity of salts removed in each leachate increased significantly as the EC:SAR ratios of applied water increased. The quantity of salts removed in initial leachates was high which decreased successively with all the treatments in all the three soils. The highest salt removal was observed in case of S_3 followed by S_2 and S_1. Among treatments, more salt leached with T_4 followed by T_3, T_2, and T_1. Regarding amendments, the greatest concentration of salts was removed (6182 kg ha^{-1}) with gypsum application and the smallest concentration of salts was removed with control (2740 kg ha^{-1}) treatment. More salts were removed in L_1 and lower in L_4. Among S × L interactions, more salts were removed with S_3L_1 and lower with S_1L_4. Salt removal was more with S_2T_4 (7385 kg ha^{-1}) and lower with S_1T_1 (2384 kg ha^{-1}). Among T × L interaction, salt removal was more for T_1L_4 (7236 kg ha^{-1}) and lower with T_4L_4 (3064). Regarding T × A interaction, the highest amount of salt was removed with T_4G (8320) and lower with T_1C (1628).

Assuming that 1 PV = one irrigation, then four pore volumes of water or four irrigations of LF 0.75, 0.77, and 0.78 removed 3008, 4965, and 5048 kg ha^{-1} salts in LS, SiCL, and SCL soil, respectively. In 1st, 2nd, 3rd, and 4th irrigation with LF 0.82, 0.79, 0.75, and 0.71 removed 5682, 5000, 3967, and 2941 kg ha^{-1} salts, respectively. For amendments, the decreasing order for salt removal was G > FM > M > C with LF 0.85, 0.84, 0.71, and 0.68. However, above findings are hypothetical simulations and 1 PV may not remove above-mentioned salts under field conditions, because there is tortuosity factor in soil which never allows applying any simulation hypothesis in natural undisturbed farmer field conditions (Jarvis 2008).

With gypsum application, the removal of salts in the first and second leachates was higher, probably because most of the soluble salts would have dissolved and leached with the leachates. The third leachate contained relatively less salts compared to first and second leachates. It seems that soil columns might have been washed to acquire low amount of salts by the time of the third leachate. Similar results of high removal of salts in initial leachate have been reported by Ahmad et al. 2006. Salt removal with water from soil is dependent on several factors including the amount of salts, time of solute contact with solvent, and volume of water passed through the soil. Therefore, high initial total soluble salts leached out of the studied soils along with low flow rate of water through soils due

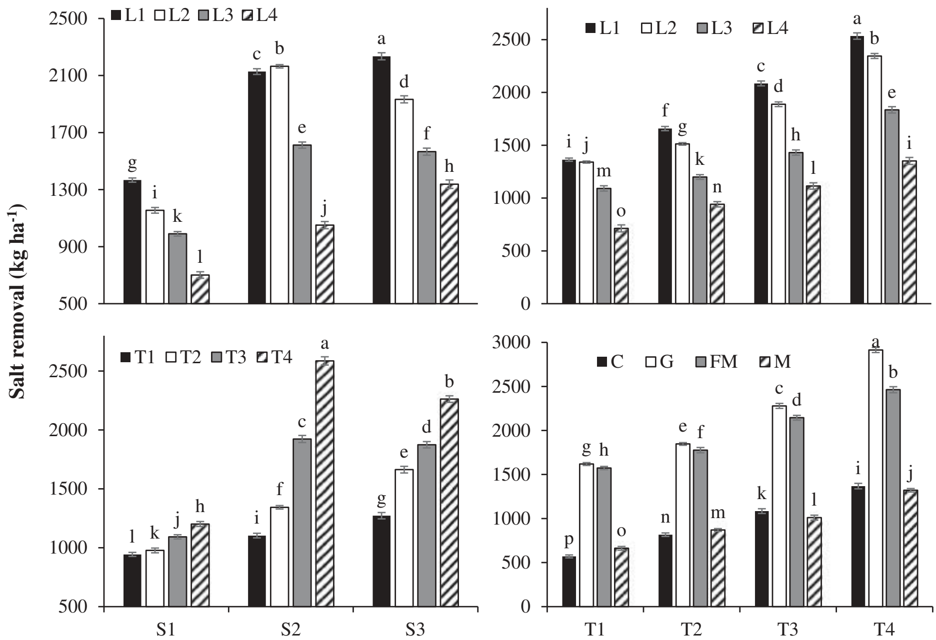

Figure 2. Treatment × amendment effect on salt removal (kg ha^{-1}) in different soils.

Values sharing same letter(s) in rows are statistically similar at $p < 0.05$, and * = Significant at $p < 0.05$.L = leachate, L_1 = First leachate, subscript indicates the leachate number, LS (S_1) = Loamy sand, SiCL (S_2) = Silty clay loam, SCL (S_3) = Sandy clay loam, C = Control, G = Gypsum @ 100% SGR, FM = Farm manure @ 10 t ha^{-1}, M = Mulch @ 10 t ha^{-1}.LSD: Soil = 50.68*, Treatment = 6.10*, Leachate = 6.10*, Amendment = 6.10*, S × L = 10.57*, S × T = 10.57*, T × L = 12.20*, T × A = 12.20*.

to relatively high SAR caused more solute removal in initial leachates, which decreased with time for all the treatments. Similar pattern of salt removal was also reported in earlier studies (Burt and Isbell 2005; Ghafoor et al. 2012; Hassan, Saqib, and Ghafoor 2011). The variable amounts of salts removed from different textured soils indicated that total salt concentration in soil solution per unit mass of a soil depends upon its saturation percentage. More salts leached from sandy clay loam soil during reclamation due to its low CEC compared to LS and SiCL. During Na^+-Ca^{2+} exchange, Na^+ ions along with dissolved gypsum increased electrolyte concentration of the leachates. Increasing rate of gypsum application increased the flocculation of soil (Ghafoor et al. 2008; Qadir et al. 2006) that might increase the infiltration rate and reduce evaporation, thereby causing more salt removal through increase in the volume of leachates. However, in the control treatment of S_3, the leachate volume compared to that of added (fraction of applied) decreased to such an extent that it could not lead salt to leach down compared to control of S_1 and S_2. This effect was different with different textured soils. In loamy sand soil (S_1), less salt removal with application of different EC:SAR water might be due to increased flow velocity of water that decreased the time of contact between water and applied gypsum which lowered gypsum dissolution and thus efficiency of Na^+-Ca^{2+} exchange (Mace and Amrhein 2001).

Soil reaction (pH_s)

The data on pH_s of 0–0.12 m (D_1) and 0.12–0.24 m (D_2) layers of three soils after leaching with 1 PV water are presented in Figure 3. The effects of soil, leachate, treatments, amendments, and their combinations remained significant for soil pH_s. The pH_s of S_2 was the highest followed by S_3 and S_1.

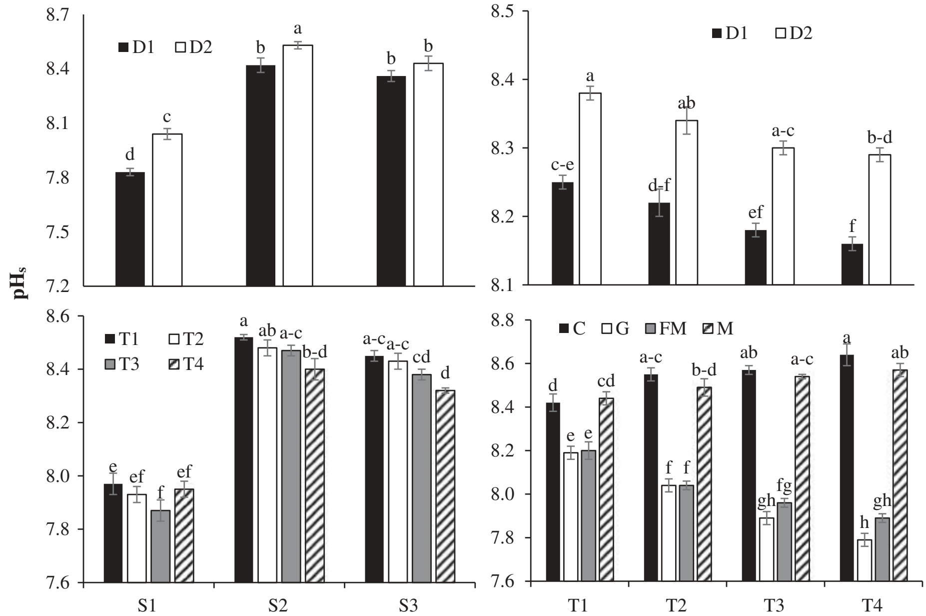

Figure 3. Treatment × amendment effect on pH$_s$ in different soils.

Values sharing same letter (s) in mean columns or rows are statistically similar at $p < 0.05$, and * = Significant at $p < 0.05$.D = Depth, D_1 = first Depth, subscript indicates depth number, LS (S_1) = Loamy sand, SiCL (S_2) = Silty clay loam, SCL (S_3) = Sandy clay loam, C = Control, G = Gypsum @ 100% SGR, FM = Farm manure @ 10 t ha^{-1}, M = Mulch @ 10 t ha^{-1}.LSD: Soils = 0.04, Treatment = 0.08, Amendment = 0.04, Depth = 0.04*, S × D = 0.078, S × T = 0.08, T × D = 0.08, T × A = 0.12.

For the treatments, higher pH$_s$ was recorded with T_1 and lower with T_4. Among amendments, higher pH$_s$ was recorded for mulch and lower for gypsum. The pH$_s$ was statistically higher in D_2 than that of D_1. Interactions between S × D, S × T, T × D, and T × A differed statistically for pH$_s$. For S × D combination, pH$_s$ was higher with S_2D_2 and lower for S_1D_1. For interaction between S × T, pH$_s$ was higher for S_2T_1 and lower for S_1T_3. Higher pH$_s$ for T × D was recorded with T_1D_2 and lower for T_4D_1. The pH$_s$ was the highest for T_4C and lowest for T_4G.

The pH$_s$ measures alkalinity/acidity of soils, which in turn depends upon the dissolution/precipitation of $CaCO_3$ (Ghafoor, Qadir, and Murtaza 2004; Maulood et al. 2012). The equilibrium between lime precipitation and dissolution exists at pH$_s$ 8.4. The pH$_s$ of the system above this point tends to induce precipitation of $CaCO_3$ while below this point help its dissolution. Therefore, a change in pH$_s$ has sometimes been associated with the degree of soil reclamation, especially with a change in soil sodication process (Ahmad et al. 2003; Hammecker et al. 2009). The pH$_s$ is not considered a criteria for saline-sadic or sodic soils since 1977 because it is the result of interactive effect of EC and SAR ratio (Bohn, Myer, and O'Connor 2002).

The increase in pH$_s$ at the end of experiment depicts the precipitation of Ca^{2+} ($CaCO_3$) rather than its dissolution which could be due to the use of high RSC water. This enhanced the Ca^{2+}-Na^+ exchange that resulted in the gradual increase in the sodicity hazard in term of pH$_s$. The increased activity of $CaCO_3$ in the soil system also showed a precipitation tendency of Ca^{2+}. However, only a slight change in pH$_s$ could be due to the precipitation of CO_3^{2-} as $CaCO_3$ that acted as buffer and resisted any remarkable change in soil pH$_s$ in alkaline range (Hamid and Fueleky 2008; Maulood et al. 2012).

Overall, it could be concluded that in all the three soils, pH$_s$ decreased below the critical limit of pH$_s$ (8.5) except the control and mulch treatments. The increase in pH$_s$ with soil depth after termination of experiment could be attributed to the high SAR and RSC of irrigation water as well as leaching of Na^+ from upper to lower layers (Ghafoor et al. 2012; Gupta and Khan 2009; Kahlon 2011; Murtaza et al. 2016).

Soil sodicity (SAR)

The effects of treatments, soil texture, amendments, and their interactions were significant on SAR of soils (Figure 4). SAR being highest for S_2 (SiCL) followed by S_1 (LS) and S_3 (SCL) with values as 16.3, 14.9, and 11.4 $(mmol\ L^{-1})^{1/2}$. The higher SAR of silty clay loam soil may have possibly resulted from high Na^+ concentration in solution owing to higher amount of adsorbed sodium at equilibrium than that in sandy clay loam or loamy sand. The differences in SAR with treatments were significant being higher with T_4+ control (28) and lower with T_1+ Gypsum (5.6). Similarly, SAR was higher at D_2 than that at D_1. Same pattern was recorded for all the three soils. The interactive effect of S × T for SAR was significant, being higher with S_2T_4 (22.0) and lower with S_3T_1 (7.6). The SAR was higher with S_2D_2 and lower with S_3D_1. The highest SAR was recorded with T_4D_2+ control and the lowest with T_1D_1+ gypsum with a significant difference.

The SAR of silty clay loam soil with all the treatments remained more than that of sandy clay loam and loamy sand because of its high clay contents and thus CEC. Decrease in SAR of soil might be due to "valence dilution" as demonstrated by Murtaza et al. (2011) for reclaiming saline-sodic soil. The reverse is true when soil solution is concentrated due to evapo-transpiration. The addition of Ca^{2+} in saline-sodic/sodic soils causes the reduction of SAR and thus the soil is flocculated (Prapagar, Indraratne, and Premanandharajah 2012). The decrease in SAR of loamy sand may be attributed to the coarse texture of the soil, low clay contents, and low CEC value. The Ca^{2+} in the soil

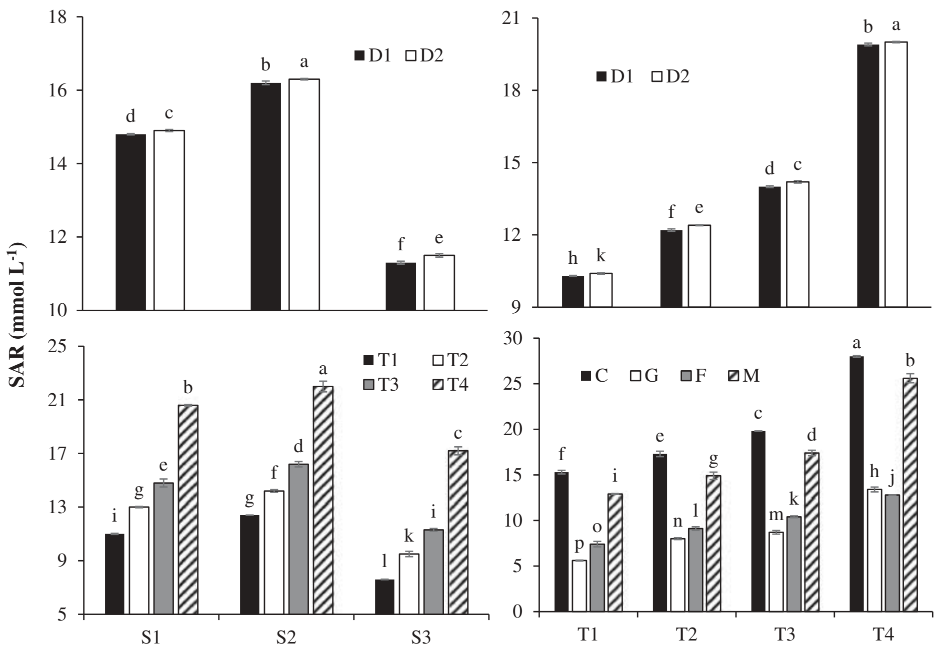

Figure 4. Treatment × amendment effect on SAR $(mmol\ L^{-1})^{1/2}$ in different soils.

Values sharing same letter (s) in mean columns or rows are statistically similar at $p < 0.05$, and * significant at $p < 0.05$.D = Depth, D_1 = first Depth, subscript indicates depth number, LS (S_1) = Loamy sand, SiCL (S_2) = Silty clay loam, SCL (S_3) = Sandy clay loam, C = Control, G = Gypsum @ 100% SGR, FM = Farm manure @ 10 t ha^{-1}, M = Mulch @ 10 t ha^{-1}.LSD: Soils = 0.04, Treatment = 0.08, Amendment = 0.04, Depth = 0.02*, S × D = 0.06*, S × T = 0.08*, T × D = 0.08*, T × A = 0.10* due to lime dissolution or valance dilution contributes to sufficient desorption of Na^+ from the soil and thus decreases the SAR of the soil (Murtaza et al. 2017a).

Higher SAR at D_2 might be due to an increased concentration of Na^+ leached from D_1 along with other anions like CO_3^{2-}, HCO_3^-, SO_4^{2-}, and Cl^- which helped in decreasing $Ca^{2+} + Mg^{2+}$ concentration through precipitation as $CaCO_3$ (Deshmukh 2012). Addition of gypsum in the surface layer made it to attain steady state earlier. Thus, there is need to add amendment in upper soil layers in amounts that could make other ions to transverse along the wetting front without precipitation and occupy exchange sites to keep soil flocculated concurrently.

It is concluded that SAR of all the three soils remained highest with control and mulch treatments receiving water of different EC to SAR ratios. With FM and gypsum application, SAR decreased below the critical limit. The SAR of upper layers decreased more than that at lower depths of all the soils.

Soil salinity (EC_e)

Effect of treatment, soil texture, amendment, and their interactions were statistically significant on EC_e (Figure 5). Higher EC_e was recorded for S_2 (SiCL) followed by S_1 (LS) and S_3 (SCL). It was higher for T_4 and lower with T_1. For amendments, higher EC_e was recorded with C (without amendment) followed by M, FM, and G. Salinity remained statistically similar at both the soil depths. The interactive effect of S × T were significant, being higher with S_2T_4 and lower with S_1T_1. The interactive effect of T × D was also significant being higher with S_1D_2 while it was lower with S_3D_1. Regarding the interaction of treatment and depth, it was recorded that EC_e was higher with T_4D_2 and lower with T_1D_1. The interactive effect of T × A was also significant, being higher with T_3

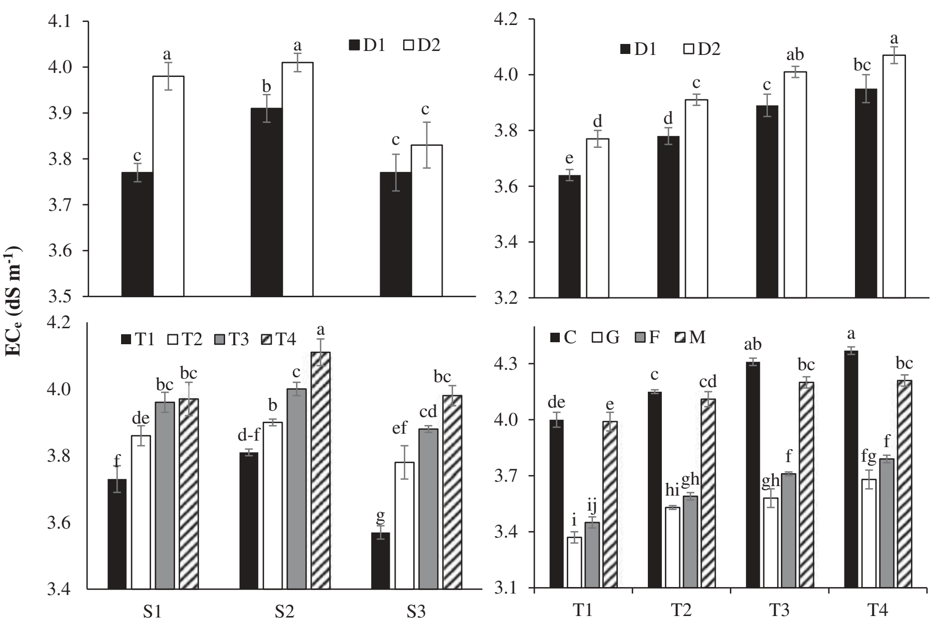

Figure 5. Treatment × amendment effect on EC_e (dS m^{-1}) in different soils.

Values sharing same letter (s) in mean columns or rows are statistically similar at $p < 0.05$, and * significant at $p < 0.05$.D = Depth, D_1 = first Depth, subscript indicates depth number, LS (S_1) = Loamy sand, SiCL (S_2) = Silty clay loam, SCL (S_3) = Sandy clay loam, C = Control, G = Gypsum @ 100% SGR, FM = Farm manure @ 10 t ha^{-1}, M = Mulch @ 10 t ha^{-1}.LSD: Soils = 0.04, Treatment = 0.08, Amendment = 0.04, Depth = 0.02*, S × D = 0.06*, S × T = 0.08*, T × D = 0.08*, T × A = 0.10*.

+ control while it was lower for T_1 + gypsum. Overall, it could be concluded that the application of different EC to SAR ratio water decreased the EC_e but the decrease was less in control compared to that of gypsum or FM application. The order of decrease for EC_e was G > FM > M > C with all the treatments applied on all three soils. Valdez-Aguilar, Grieve, and Poss (2009) reported that EC_e increased linearly with EC_{iw} and number of irrigations. According to an estimate, 86 to 90% variability in EC_e of soil is accounted for by the EC_{iw} applied to different crops grown on medium textured soils. The remaining variability in EC_e may be due to factors like soil texture, drainage conditions of field, and initial salt level of soil profile. Average EC_e of soil profile up to 150 cm was raised from 1.23 to > 4.0 dS m^{-1} during this period.

Conclusions

Application of irrigation water (4 PV) with leaching fraction of 0.75, 0.77, and 0.78 removed 3008, 4965, and 5048 kg ha^{-1} salts from LS, SiCL, and SCL soils, respectively. Moreover, 1^{st}, 2^{nd}, 3^{rd}, and 4^{th} irrigations with leaching fractions of 0.82, 0.79, 0.75, and 0.71 removed 5682, 5000, 3967, and 2941 kg ha^{-1} salts, respectively. The efficiency of various amendments for salt removal was observed in the order of FM > G > M > C with leaching fractions 0.85, 0.84, 0.71, and 0.68, respectively. The farmers must be motivated to improve water use-efficiency (with minimum leaching fractions) during the reclamation of saline-sodic soils for maximum salt removal through increased water contact, thereby decreasing the movement of salts into the groundwater aquifers. Application of amendments in each soil decreased their pH_s, EC_e, and SAR depending upon EC:SAR ratios of irrigation water.

A general trend for soil amelioration was in the order of FM > G > M > C. Results indicated that use of water having different EC:SAR ratios without amendment increased pH_s, EC_e, and SAR in SiCL and SCL but not in LS soils. This observation highlights a potential role of soil texture that must be recognized while initiating any mega project to reclaim saline and/or sodic soils in the perspective of national development strategies.

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