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Effect of gypsum placement on the physical chemical properties of a saline sandy loam soil

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Abstract

Reclamation of salt affected soils using gypsum ($Ca_2SO_4.2H_2O$) as a low cost material is one of the means to reverse a degraded land while improving its fertility for agricultural use and generate income to the farmers living in such lands. A study was therefore undertaken outside the glasshouse of the International Centre for Eremology, University of Ghent, at the end of July 1994. The main objective was to evaluate the effect of gypsum and placement methods on the physical chemical properties of a saline soil during reclamation process by leaching under natural rainfall. Soil samples were collected from a provisionally stored dredged material in a big well near the Peak-shaving plant of Distrigaz in the southern part of inner harbour of Zeebrugge located at 51º18′18″N and 3º14′47″E. The experiment involved six treatments with four replications in a randomised complete block design. Results showed that incorporating gypsum full depth (20 cm) without weekly mixing was superior compared with the other placement methods for the improvement of most of the studied parameters. Furthermore, these results also showed that Na_{exch}, EC_e, SAR, ESP and AWC were significantly ($P≤0.05$) improved. Although gypsum application caused gradual decline in Ks, it however did not reverse it completely, probably due to heavy storm leading to compaction, and/or inequilibrium between Ca^{2+} and Mg^{2+} ions in the soil material.

Keywords: Gypsum, placement, reclamation, saline, exchangeable Na, SAR, Available Water, Electrical conductivity, saturated paste

Abbreviations: AWC_Available water capacity; CEC_Cation exchange capacity; EC_e_Electrical conductivity of the saturated paste; ESP_Exchangeable sodium percentage; GR_Gypsum requirements; Ks_Hydraulic conductivity; MC_Moisture content in percent; Na_{exch}_Exchangeable sodium; Na_Sodium; PWP_Permanent wilting point; SAR_Sodium absorption ratio.

Introduction

Saline soils are characterised as those containing high levels of soluble salts, mainly sodium chloride (NaCl) and sodium sulphate (Na_2SO_4) and is one of the world's most serious environmental problems. Estimates on global salinisation in land and water resources have shown that, about 7% of the world's total land area is affected by salt (Ghassemi et al., 1995; Munns et al., 2002). Most of the current and potential agricultural soils where crops are grown are located in low relief landscapes characterised by dense populations, intensive agricultural activities, higher temperatures and evapotranspiration often associated with insufficient leaching leading to greater salt accumulation (Rhoades et al., 1992; De Pascale and Barbieri, 1997). Accumulation of salts in such agricultural soils alters its physico-chemical properties, including pH (Al-Busaidi and Cooksen, 2003), exchangeable sodium (Na_{exch}), electrical conductivity of the saturated paste (EC_e), sodium absorption ratio (SAR), exchangeable sodium percentage (ESP), saturated hydraulic conductivity (K_s) and soil available water capacity (AWC). Consequently, mineral elements and water availability for plant growth and yield of most crops is affected (Tanji 1990). It has been reported that excessive exchangeable sodium and high pH decrease the soil permeability and infiltration capacity through swelling and dispersion of clays as well as slaking of aggregates (Läuchli and Epstein, 1990). These modifications may further compromise the yield of salinised crops, thus, jeopardising the income of most farmers. Some studies have shown that the use of gypsum on saline-sodic and sodic soils improves most of the properties including the infiltration rate and helps in leaching the salts into the lower layers (Qureshi and Barrett-Lennard, 1998). For example, it has been shown that maximum improvement in hydraulic conductivity (Ks) was only possible with simulated sub-soiling and gypsum-saturated solution (Shahid, 1993). Although abundant literature on the effect of gypsum on sodic and saline-sodic is available (Qadir et al., 2001; Sahin et al., 2003; Makoi and Ndakidemi, 2007), only few studies have reported the effects of gypsum and placement methods on saline soils (Rains and Goyal, 2003). So, understanding the effect of gypsum and placement methods on these properties may be of critical importance in order to optimise farm management strategies by farmers practicing agricultural activities in such soils. The objective of this study was to therefore assess the effect of gypsum and placement methods on Na_{exch}, EC_e, SAR, ESP, Ks and AW in a saline loamy sand soil.

Table 1. Chemical and physical characteristics of the soils studied

Characteristic	Units	Measurements
Soil		
pH (water)	-	7.92
pH (1M KCl)	-	7.85
$CaCO_3$	%	7.75
OM	%	4.24
SP	%	48.50
MC	%	3.10
CEC	me 100 g soil^{-1}	11.33
Saturated extract		
pH	-	7.91
ECe	dS.m^{-1}	8.90
Na^+	mg.L^{-1}	1443.00
Ca^{2+}	mg.L^{-1}	629.00
Mg^{2+}	mg.L^{-1}	225.00
K^+	mg.L^{-1}	109.60
Total Na^+	mg.kg^{-1}	821.00
Soluble Na^+	mg.kg^{-1}	669.40
Na_{exch}	mg.kg^{-1}	122.35

Materials and methods

Site description, soil sample preparation and moisture content determination

The experiment was carried out at the end of July 1994 outside the glass house of the International Centre for Eremology (ICE), University of Ghent, Belgium. Soil material was collected from a provisionally stored dredged material near the Peak-shaving plant of Distrigaz in the southern part of inner harbour of Zeebrugge located at 51º18′18″N and 3º14′47″E. The soil texture was classified as sand loam (SL) with 640 g.kg^{-1} sand, 230 g.kg^{-1} silt and 130 g.kg^{-1} clay. Bulk soil samples were allowed to air dry in a green house at a temperature between 25ºC and 30ºC and were then ground to pass a 2-mm mesh sieve for laboratory analysis. Soil moisture content was determined by oven drying the soil at 105ºC for 24hrs. Moisture content (%) was calculated as:

$$MC(\%) = \left(\frac{M_w - M_t}{M_d - M_t} \right) - 1 * 100$$

Where: MC = moisture content in percent, M_w = weight of wet soil, M_d = weight of dry soil, M_t = weight of container

Experimental layout

Six blocks were laid outside greenhouse in randomised block design, representing six treatments. The sizes of the blocks were 0.93 m x 1.08 m. The soil was uniformly packed over 20 cm soil depth at a bulk density of 1,200 kg.m^{-3} to make a volume of 0.2 m^3 and a weight of 241.1 kg soil per block under direct rainfall outside the glasshouse. The electrical conductivity (EC) of the rainwater was 0.11 dS.m^{-1} and pH was 7.18. Gypsum requirement sufficient for 100% exchangeable sodium percentage replacement was applied at a rate of 110.9 g $CaSO_4.2H_2O$ per block (1.1 t $CaSO_4.2H_2O$ ha^{-1}). Application of gypsum in each treatment was as follows:

Treatment I: Gypsum applied on the soil surface.
Treatment II: Gypsum incorporated 5 cm of soil depth.
Treatment III: Gypsum incorporated 20 cm of soil depth.
Treatment IV: Gypsum incorporated 5 cm of soil depth + weekly ploughing.
Treatment V: Gypsum incorporated 20 cm of soil depth + weekly ploughing.
Treatment VI: Control, no gypsum was applied.
Leaching was achieved by using natural rainfall to simulate farmers' field conditions.

Sampling and laboratory determinations

Soil sampling

Soil samples were collected before, weekly and at the end of the experiment. Soil physical-chemical characteristics of the collected soil samples were analysed at the International Centre for Eremology (ICE), Department of Soil Physics and Soil Care, Ghent University, Belgium (Table 1). The determined soil physical characteristics include field capacity (FC), soil moisture characteristic curves (pF), hydraulic conductivity (Ks), while the chemical characteristics include pH, electrical conductivity of the saturated paste (EC_e), organic matter (OM), calcium carbonate ($CaCO_3$), Na, K, Ca and Mg. These chemical characteristics were determined from the saturation paste as well as the ammonium acetate during CEC determination and percolation tests. In order to mimic what farmers do before planting other crops, the end of experiment soil sampling was conducted after thoroughly mixing the soil.

Laboratory determinations

Soil pH (in H_2O and 1M KCl) was measured in a 1:2.5 soil: water/1M KCl (Chapman and Pratt, 1961). Removal of carbonates, OM and soluble salts were determined as reported in Makoi (1995). Soil OM was determined as in Walkley and Black (1934) and carbonates by volumetric calcimeter according to Allison and Moodie (1965). Electrical conductivity of the saturated paste, soluble cations, and soluble anions were measured in the saturated extracts at 1:1 extracts (USDA-NRCS, 1996). Saturation % was calculated following the procedures given by Rhoades (1982). Determination of Ca and Mg was done by atomic absorption spectrophotometry and K and Na by flame emission spectrophotometry. Cation exchange capacity was determined after Bower et al. (1952). Exchangeable Na and K were extracted with a buffered neutral 1M NH_4OAc solution, and Ca and Mg by 1N NaOAc solution (pH 8.2). Total Na was extracted by 1M NH_4OAc solution followed by flame emission spectrophotometry. Exchangeable Na percentage was estimated by direct determination of exchangeable Na and CEC and calculated as in Richards (1954) as follows:

$$ESP = \frac{Na_{exch}}{CEC} \times 100$$

Where: ESP = Exchangeable sodium percentage; Na = Sodium; CEC = Cation exchange capacity.

Table 2. Percent change in exchangeable sodium during 13 weeks of leaching a saline soil under different placement techniques after gypsum application.

Treatment	Initial sodium	Final sodium	Sodium reduced	Sodium reduced over initial	Time for 100% Na reduction
		mg.kg^{-1}		%	weeks
I		70.30d	52.05c	42.54c	30.56d
II		70.93c	51.43d	42.03d	30.93c
III	122.35	65.85f	56.50a	46.18a	28.15f
IV		75.33b	47.03e	38.43e	33.82b
V		67.08e	55.28b	45.18b	28.78e
VI		94.05a	28.30f	23.13f	56.21a
One – Way ANOVA (F-Statistics)					
		28602**	28602**	28602**	13841.1**
CV (%)		0.17	0.25	0.25	0.52

Values followed by dissimilar letters in the same column are significant at $P \leq 0.05$ according to Fischer LSD. (** = $P \leq 0.01$. I = Surface treatment; II = gypsum incorporated 5 cm soil depth; III = gypsum incorporated 20 cm soil depth; IV = gypsum incorporated 5 cm soil depth and weekly ploughing; V = gypsum incorporated 20 cm soil depth and weekly ploughing; VI = Control for which no gypsum was added).

Sodium absorption ration (SAR) was calculated as in Sposito and Mattigod (1977) as follows:

$$SAR = \frac{Na}{\frac{\sqrt{Ca + Mg}}{2}}$$

Where: SAR = Sodium absorption ratio

In order to determine the particle size analysis (< 2 mm), samples were dispersed in sodium hexametaphosphate solution and shaken horizontally in a reciprocating shaker for 12 h using hydrometer method (Day, 1965). Saturated hydraulic conductivity was determined as follows:

$$Ks = \frac{Q\Delta z}{At\Delta \psi_m}$$

Where: Ks = Saturated hydraulic conductivity; Q = Volume of water collected (cm^3); A = Cross sectional area (cm^2); t = time (hr); z = gravitational constant (cm); ψ_m = Matric potential (cm)

The permanent wilting point (PWP) was measured by passing 350 g of soil sample through a 2 mm sieve. The samples were then saturated for 24 hours, after which they were equilibrated on a pressure-plate apparatus at 1500 KPa for 72 to 96 hours. The available water capacity (AWC) was calculated as in Özdemir et al. (2000) and Arin and Kiyak (2003) as:

$$AWC = FC - PWP$$

Where AWC = available water capacity, FC = field capacity and PWP = permanent wilting point.

Estimation of gypsum requirements

Estimation of the required gypsum was made considering the cation exchange complex of the soil, exchange efficiency and the initial and final ESP using the gypsum requirement (GR) as described in USSL Staff (1954) and Makoi (1995) as follows:

$$GR = Na_{exch} \times \frac{Eqwt\ Gypsum}{Eqwt\ Na} \times mg\ Na\ mmol^{-1}\ kg^{-1}\ soil$$

Where: GR = Gypsum requirements (g.kg^{-1}); Na_{exch} = Exchangeable Na (mmol.kg^{-1} soil); Eqwt = Equivalent weight.

Statistical Analysis

Data collected were analysed statistically using one-way ANOVA statistics. The analysis was performed using the software of STATISTICA program 2007 (StatSoft Inc., Tulsa, OK, USA). Where f-value was significant, Fisher's least significant difference was used to compare treatment means at $P \leq 0.05$ (Steel and Torrie, 1980).

Results and Discussion

Globally, salt stress as manifested in saline soils is an important limitation to agricultural productivity for it reduces water potential and causes ion imbalance or disturbance in ion homeostasis and toxicity. To undo such limitations to agricultural productivity, it is important to understand the effect and placement methods of cheap and readily available amendments. Gypsum ($Ca_2SO_4.2H_2O$), which has been used as ameliorant in saline-sodic and sodic soils for example, has been shown to overcome most of this stress by reducing dispersion and pH. So, use of $Ca_2SO_4.2H_2O$ in the amelioration of saline soils is one way of improving global agricultural productivity due to salt stress. While there is abundant literature on the effect of $Ca_2SO_4.2H_2O$ on salt affected soils, very limited literature is available on the effect of $Ca_2SO_4.2H_2O$ on saline soils and its placement method in the soil. As a result, the effect of $Ca_2SO_4.2H_2O$ on saline soils and its placement method in the soil needs to be explored for the benefit of small scale farmers. In this study, effect of $Ca_2SO_4.2H_2O$ in a saline soil was assessed using six different placement methods.

Results from this study have shown that there was significant ($P \leq 0.05$) difference on the exchangeable Na^+ when soil was leached after gypsum application across all treatments compared with control (Table 2). For example, decreased exchangeable Na^+ ranged from 34.6 - 56.5 mg.kg^{-1} soil (i.e. 28.3% to 46.2%), indicating that leaching after gypsum application may lower the exchangeable Na^+ in the soil profile. The results also showed that effectiveness of gypsum placements was in the order of III>V>I>II>IV>VI, just as the time required for total replacement of exchangeable Na^+. The data suggest that incorporating gypsum 20 cm depth without

Table 3. Percent change in ECe during 13 weeks of leaching a saline soil under different placement techniques after gypsum application.

Treatment	Initial ECe	Final ECe	Reduced ECe	Reduced ECe relative to initial ECe	Time for 100% ECe reduction
		$dS.m^{-1}$		%	Weeks
I		5.69b	3.22c	36.12c	36.11b
II		5.76b	3.14c	35.28c	36.85b
III	8.9	5.02c	3.88b	43.62b	29.80c
IV		5.75b	3.15c	35.37c	36.76b
V		4.23d	4.67a	52.47a	24.78d
VI		8.37a	0.53d	5.96d	218.34a
One – Way ANOVA (F-Statistics)					
		1040.4**	1040.36**	1040.36**	7790.38**
CV (%)		1.49	2.79	2.79	2.70

Values followed by dissimilar letters in the same column are significant at $P\leq0.05$ according to Fischer LSD. (** = $P\leq$ 0.01. I = Surface treatment; II = gypsum incorporated 5 cm soil depth; III = gypsum incorporated 20 cm soil depth; IV = gypsum incorporated 5 cm soil depth and weekly ploughing; V = gypsum incorporated 20 cm soil depth and weekly ploughing; VI = Control for which no gypsum was added; ECe = Electrical conductivity of the saturated paste).

Table 4. Percent change in SAR during 13 weeks of leaching a saline soil under different placement techniques after gypsum application.

Treatment	Initial SAR	Final SAR	Reduced SAR	Reduced SAR relative to initial	Time for 100% SAR reduction
				%	Weeks
I		5.18c	7.37d	58.73d	22.14bc
II		4.25e	8.30b	66.14b	19.66c
III	12.55	2.67f	9.88a	78.73a	16.51d
IV		5.93b	6.62e	52.75e	24.65b
V		4.53d	8.02c	63.90c	20.34c
VI		11.39a	1.16f	9.24f	140.76a
One – Way ANOVA (F-Statistics)					
		40807.2**	40807.2**	40807.2**	2730.4**
CV (%)		14.06	11.57	11.57	6.35

Values followed by dissimilar letters in the same column are significant at $P\leq0.05$ according to Fischer LSD. (** = $P\leq$ 0.01. I = Surface treatment; II = gypsum incorporated 5 cm soil depth; III = gypsum incorporated 20 cm soil depth; IV = gypsum incorporated 5 cm soil depth and weekly ploughing; V = gypsum incorporated 20 cm soil depth and weekly ploughing; VI = Control for which no gypsum was added; SAR = Sodium absorption ratio).

weekly mixing was superior in reducing exchangeable Na^+ with relatively shorter duration compared with the other placement methods as shown by Rasmussen et al. (1972) and Frankel et al. (1989). These results suggest that less water for leaching, higher hydraulic conductivity (less time for reclamation) and greater effective gypsum solubility may be obtained when gypsum is mixed within the entire soil depth to be reclaimed. Although initially the objective was to reduce the exchangeable Na^+ by 100%, the current results however, indicate an achievement of less than 100% after 13 weeks of leaching, also depending on the placement method (Table 2). As a result, more time was required for 100% exchangeable Na^+ replacement. For example when gypsum was incorporated 20 cm soil depth, time required for 100% replacement of exchangeable Na^+ was 32.5 weeks. Comparatively, incorporating gypsum 20 cm depth without weekly mixing can be cost effective in the amelioration process since this was achieved naturally by rainfall, a condition practiced by most farmers in the arid and semi arid regions.

Electrical conductivity of the saturated paste showed significant ($P\leq0.05$) decrease between treatments after leaching compared with control (Table 3). For example, reduction of EC_e after leaching ranged from 35.2% to 52.5% across the treatments (Table 3). Surface application of gypsum decreased EC_e by 37.2% (i.e. from 8.90 $dS.m^{-1}$ to 5.59 $dS.m^{-1}$). Gypsum incorporated 5 cm soil depths without mixing was similar to gypsum incorporated 5 cm soil depth and weekly mixing, for EC_e was reduced by 35.2% (i.e. from 8.90 $dS.m^{-1}$ to 5.76 $dS.m^{-1}$). Incorporating gypsum 20 cm depth, EC_e was lowered by 43.6% (8.90 $dS.m^{-1}$ to 5.02 $dS.m^{-1}$). However, gypsum incorporated 20 cm soil depth and weekly ploughing (V) reduced EC_e by 52.5% (i.e. from 8.90 $dS.m^{-1}$ to 4.23 $dS.m^{-1}$). Differences in reducing EC_e levels suggest that reduction of EC_e in saline soils will depend on where and how the gypsum was placed in the soil profile. Similar to the findings of Frenkel et al. (1989) and Mishra et al. (2003), our result showed that gypsum incorporated 20 cm soil depth and weekly ploughing (V), was superior to other placement methods suggesting that if applied, could reduce EC_e in saline soils, a result of effectively higher gypsum solubility.

Results of sodium absorption ratio (SAR) showed significant ($P\leq0.05$) reduction in all treatments compared with control (Table 4). For example, initial sodium absorption ratio (SAR_i) decreased from an initial value of 12.55 to values ranging from 2.66 (III) to 5.93 (IV). Results also indicates that treatment III was superior in changing SAR compared with other treatments

Table 5. Percent change in ESP during 13 weeks of leaching a saline soil under different placement techniques after gypsum application.

Treatment	Initial ESP	Final ESP	Reduced ESP	Reduced ESP relative to initial	Time for 100% ESP reduction
			%		Weeks
I		3.25b	1.44c	30.70c	42.35b
II		3.24b	1.45c	30.92c	42.07b
III	4.69	2.95c	1.74b	37.10b	35.05c
IV		3.29b	1.40c	29.85c	43.58b
V		2.55d	2.14a	45.63a	28.50d
VI		3.61a	1.08d	23.03d	56.49a
One – Way ANOVA (F-Statistics)					
		389.6**	389.6**	389.6**	314.7***
CV (%)		1.16	2.37	2.37	2.56

Values followed by dissimilar letters in the same column are significant at $P\leq0.05$ according to Fischer LSD. (** = $P \leq 0.01$; *** = $P \leq 0.001$; I = Surface treatment; II = gypsum incorporated 5 cm soil depth; III = gypsum incorporated 20 cm soil depth; IV = gypsum incorporated 5 cm soil depth and weekly ploughing; V = gypsum incorporated 20 cm soil depth and weekly ploughing; VI = Control for which no gypsum was added; ESP = Exchangeable sodium percentage).

Table 6. Percent change in AWC at -70 cm H_2O during 13 weeks of leaching a saline soil under different placement techniques after gypsum application.

Treatment	Initial AWC	Final AWC	Increase in AWC	Increase in AWC relative to initial AWC
		mm m^{-1}		%
I		28.46b	7.66b	36.83b
II		28.47b	7.67b	36.88b
III	20.8	26.34c	5.54c	26.63c
IV		28.44b	7.64b	36.73b
V		29.37a	8.57a	41.20a
VI		25.00d	4.20d	20.19d
One – Way ANOVA (F-Statistics)				
		481.6**	481.6**	481.6**
CV (%)		0.54	2.19	2.19

Values followed by dissimilar letters in the same column are significant at $P\leq0.05$ according to Fischer LSD. (** = $P\leq 0.01$; I = Surface treatment; II = gypsum incorporated 5 cm soil depth; III = gypsum incorporated 20 cm soil depth; IV = gypsum incorporated 5 cm soil depth and weekly ploughing; V = gypsum incorporated 20 cm soil depth and weekly ploughing; VI = Control for which no gypsum was added; AWC = Available water capacity).

(Table 4) suggesting that incorporating gypsum 20 cm soil depth could significantly reduce SAR in saline soils. Furthermore, the result suggests that the rate of natural amelioration of saline soil by rainfall leaching is faster enough to have practical benefits when gypsum is incorporated. This reduction could be due to replacement of Na as monovalent on the exchange complex by Ca^{2+} from the soil solution (Amstrong and Tanton, 1992; Zara et al., 2001; Gharaibeh et al., 2009).

Exchangeable sodium percentage (ESP) was significantly ($P\leq0.01$) lowered from 4.7% (initial) to values ranging from 2.5% to 3.6% (Table 5). The data indicated that incorporating gypsum full depth (20 cm) and weekly mixing reduced the ESP by 45.6% and was rated as superior to other placement methods suggesting that this method could reduce time required for desalinization of a saline soil. The decreased ESP could be ascribed to desalinisation resulting from increased exchange-able efficiency of Ca^{2+} on the exchange complex (Amstrong and Tanton, 1992; Mamoun et al., 2009). Similar to the views by Frenkel et al. (1989); Koo et al. (1990) and Qadir et al. (2003), reduced ESP in our study could also imply greater effective solubility of gypsum since the cation exchange in the thoroughly mixed treatment acted as sink, thus, encouraging further dissolution to the satisfaction of their solubility product. Our results suggest that gypsum was more efficient in replacing Na_{exch} when incorporated in full soil depth (20 cm) and mixed weekly (Table 5). However, incorporating gypsum 20 cm without weekly mixing was second best, and may probably be better choice to farmers since it is more practical considering farmer's economic conditions and the reclamation costs.

There was significant ($P\leq0.01$) effect of gypsum placement on the available water capacity (AWC) in all treatments compared with control (Table 6). At field capacity (-70 cm H_2O), applying gypsum 20 cm soil and weekly mixing was different ($P\leq0.01$) compared with other placement methods. These results suggests that weekly mixing of gypsum at 20 cm is the best in the improvement of AWC whereas mixing gypsum 5 cm is the second best in the tested saline soil. These findings are parallel to reports by Bridge and Kleing (1968) and Arie and Magaritz (1986) which indicated that higher values of moisture in the upper part of the profile was due to improved water holding capacity caused by cultivation. Improved AWC is ascribed to reduced osmotic forces around the salt affected

Table 7. Percent change in saturated hydraulic conductivity (Ks) during 13 weeks of leaching a saline soil under different placement techniques after gypsum application.

Treatment	Initial Ks	Final Ks	Reduced Ks	Reduced Ks relative to initial	Time for 100% Ks reduction
		cm hr^{-1}		%	Weeks
I		0.46a	3.04e	86.79e	14.98a
II		0.31d	3.20b	91.29b	14.24d
III	3.5	0.35c	3.15c	90.00c	14.44c
IV		0.40b	3.10d	88.57d	14.68b
V		0.30d	3.20b	91.36b	14.23d
VI		0.19e	3.31a	94.57a	13.75d
One – Way ANOVA (F-Statistics)					
		155.3***	155.0***	155.0***	159.0***
CV (%)		2.59	0.84	4.51	1.77

Values followed by dissimilar letters in the same column are significant at $P \leq 0.05$ according to Fischer LSD. (*** = $P \leq$ 0.001. I = Surface treatment; II = gypsum incorporated 5 cm soil depth; III = gypsum incorporated 20 cm soil depth; IV = gypsum incorporated 5 cm soil depth and weekly ploughing; V = gypsum incorporated 20 cm soil depth and weekly ploughing; VI = Control for which no gypsum was added; Ks = hydraulic conductivity).

soil particles, thus, reducing plant stress hence plant growth (Bauder and Brock, 2001; USDA-NRCS, 2002). Furthermore, maintaining higher moisture content in the upper horizons of agricultural soils as suggested by Loveday (1976) was the reason for improved seedling emergence in gypsum treated soils suggesting that gypsum application decreased surface crusting. Results from this study clearly underscore the importance of thorough mixing of gypsum in agricultural soils during desalinisation of a saline soil to bring about improvement in available water capacity for optimum plant growth.

Results from this study have also showed significant ($P \leq 0.01$) difference in saturated hydraulic conductivity (Ks) in all treatments compared with control (Table 7). For instance, Ks decreased from 3.5 cm.hr^{-1} (initial) to values between 0.19 to 0.46 cm.hr^{-1}. Compared with control where Ks decreased sharply, other treatments had a relatively gradual decrease in Ks (Table 7). Although Frenkel et al. (1989), Mace and Amrhein (2001) and Gharaibeh et al. (2009) reported that soil hydraulic conductivity was much higher in the mixed gypsum column than in the gypsum applied on the surface; our results showed that gypsum application on the surface was best in preventing sharp drop in Ks indicating that gypsum placement plays a vital role in gradual decrease of Ks in saline soils. Similar results was also reported by Loveday (1976) that mixing gypsum in salt affected soils provided a higher electrolyte concentration, which was more effective in displacing sodium than the surface gypsum application, a result of the higher effective gypsum solubility. Furthermore, the reduced Ks imply slaking of aggregates or dispersion which consequently blocks the conducting pores, thus, slowing water movement. Similar results have also been reported by Kazman et al. (1983) who reported that gypsum prevented the sharp drop of Ks at all levels of ESP. Similar to the views by Pupisky and Shainberg (1979) and Shainberg et al. (1981), reduced Ks may be due to low rate of mineral dissolution during leaching or insufficient maintenance of flocculated conditions as a result of low electrolyte front after rainfall. Improvement of Ks will consequently improve the ability of the soil to retain and conduct water (soil hydraulic properties) in saline affected soils, thus, increasing crop yields.

In conclusion, our study has shown that incorporating gypsum in a saline soil improves their physical chemical characteristics. However, the improvement depends on the placement of gypsum in the soil profile, which also determines the time required for total reclamation. In this regard, incorporating gypsum full depth (20 cm) and weekly mixing of the soil improved most of the parameters studied and was considered as probably the best method. Incorporating gypsum full depth (20 cm) without weekly mixing of the soil was considered as the second best placement method. But considering management, reclamation costs and economical difficulties to farmers on a large scale, and since the two methods were not significantly different, method III was suggested as the best option in the reclamation process of a saline soil. It is also suggested that, since surface application prevented sharp decline in Ks, farmers can combine both surface application (I) and incorporating gypsum full depth (20 cm) without weekly mixing (III).

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