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EFFICIENCY OF Ca^{2+} APPLICATION FOR THE RECLAMATION OF SALINE-SODIC SOILS WITH DIFFERENT SOIL TEXTURES

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A lysimeter experiment was conducted to evaluate the effectiveness of different Ca^{2+} concentrations in canal water for the reclamation of saline-sodic soils with a range of textures. Calcium Sulphate ($CaSO_4.2H_2O$) was added to canal water at Ca^{2+} concentrations of 4 (Ca_4), 8 (Ca_8) and 12 (Ca_{12}) $mmol_c$ L^{-1}. Four pore volumes (PV) of irrigation were applied in four equal splits. During each leaching cycle, leachates were collected and analyzed for EC and soluble ions (Na^+, K^+ and Ca^{2+}). The maximum volume of leachates was obtained in the fourth leaching cycle at the highest Ca concentration (Ca_{12}). The leaching volume was affected significantly by soil texture and was the highest for the sandy clay loam (SCL) followed by sandy loam (SL) and clay loam (CL). The treatments had an insignificant effect on the removal of salts (EC) but the SAR of leachates was significantly affected by the treatments. The results clearly showed that increasing Ca^{2+} concentration in leaching solution decreased EC_e of the soil but there were no differences among Ca^{2+} treatments for removal of Na^+ and it was significantly higher in first leachate and gradually decreased in subsequent. The concentration of Ca^{2+} in leachates followed the order of Ca_{12}> Ca_8> Ca_4> Ca_0 and was also affected by soil texture in the order of SCL> SL> CL. The saturated hydraulic conductivity (K_{sat}) increased linearly with increasing rate of Ca applied in the leaching water and maximum K_{sat} was observed for SCL soil followed by SL and CL.
Keywords: Salt, SAR, leachate, Calcium, EC_e

INTRODUCTION

Salinity is the accumulation of dissolved salts in soil and is a major limiting factor for crop yield in poorly drained soils (Patel *et al*., 2002). Low precipitation and high evapotranspiration are responsible for inadequate leaching and the accumulation of salts in the root zone which hinders plant growth. The problem is especially critical in semi-arid and arid regions like Pakistan, where the hot climate combined with intensive irrigation using poor quality ground water is negatively affecting one third of cultivated land.

Most of the salt-affected soils in Pakistan have lower CEC (6-12 $cmol_c kg^{-1}$) because of the dominance of illite type clay minerals, low organic matter owing to arid and semi-arid climate condition and high oxidation of organic matter. As a result, Na-Ca exchange takes place at a slow rate (Bear, 1964). Hence, high amounts of soluble Ca^{2+} addition may not cause a proportional increase in the Na-Ca exchange in the native saline-sodic soils during their reclamation and the unreacted Ca^{2+} could be leached below the treatment target zone (Ghafoor, 1999; Mutraza *et al*., 2006). Experiments were undertaken to assess the optimum concentration of Ca^{2+} to be added in amendment solution in order to affect Na-Ca exchange more efficiently and economically for different textured saline-sodic soils (Qadir *et al*., 2001b; Mutraza *et al*., 2006). This knowledge will determine suitable application rates of Ca-amendments for removal of Na^+ from the root-zone of saline-sodic soils to achieve better plant growth.

MATERIALS AND METHODS

Bulk soil samples of three different textured saline-sodic soils (clay loam, sandy loam, and sandy clay loam) were collected from Faisalabad District of Punjab province. The representative soil samples of each soil were analyzed for physical and chemical characteristics (Table 1).

Polyvinyl chloride (PVC) lysimeters (60 cm heigh×30 cm wide) were used and were filled with 40 kg of soil. The bottom of the lysimeters had a one cm thick layer of glass wool was placed on gauze covering the bottom of the lysimeter. On top of the glass wool was a 1.5 cm layer of sand. The bottom of the core was covered until the commencement of the leaching experiment where it was removed and plastic bottles were placed below the lysimeters to receive leachates. For determination of saturated hydraulic conductivity, five undisturbed soil samples were vertically excavated with 250 cm^{-3} cylinders.

Table 1. Physical and chemical characteristics of soils

Characteristic	Unit	Clay Loam	Sandy Loam	Sandy Clay Loam
pH_s		10.22	11.32	8.87
EC_e	dS m^{-1}	30.30	30.50	10.37
Exch. Na^+	$cmol_c$ kg^{-1}	5.66	3.71	2.45
Soluble Na^+	$mmol_c$ L^{-1}	368.54	395.00	133.52
Exch. K^+	$cmol_c$ kg^{-1}	0.71	0.54	0.64
SAR	$(mmol\ L^{-1})^{1/2}$	388.70	232.90	79.90
CEC	$cmol_c$ kg^{-1}	7.31	5.53	4.41
ESP	%	77.42	67.08	55.56
Organic matter	%	0.37	0.54	0.43
Bulk density	Mg m^{-3}	1.54	1.52	1.64
Pore volume	L pot^{-1}	11.41	8.90	8.47

The cylinders were carefully saturated with water, by placing the cylinders on a layer of rough wire netting in a tub and then slowly raising the water level to the top of the cylinders. The amount of water percolating through the profile was measured and the saturated hydraulic conductivity (K_{sat}) was calculated by falling water head method (Jury *et al*., 1991). After soaking, undisturbed soil cores were drawn to calculate the pore volume (PV) according to the method of Jury *et al*. (1991).

Four treatments (canal water alone (Ca_0) and with 4 (Ca_4), 8 (Ca_8) and 10 (Ca_{12}) $mmol_c$ L^{-1} of Ca^{2+}) were applied to three soils (clay loam (CL), sandy loam (SL) and sandy clay loam (SCL). Leaching solutions were prepared by dissolving $CaSO_4.2H_2O$ in canal water and were applied as four PVs in four equal splits to each treatment. Leachate was collected when 1st PV of water leached through the soil. After collecting the first leachate solution of 1st PV (L_1), 1st PV was again added three times (L_2, L_3, L_4). In this way four leachates were collected and analyzed for EC and soluble ions (Na^+, K^+, and Ca^{2+}). At the termination of the experiment, soil columns were sampled and analysed for EC_e and soluble ions (Na^+ K^+ and Ca^{2+}). The SAR of soil was calculated by the formula given by US Salinity Lab. Staff (1954). The analytical methods for leachate, soil and canal water measurements followed methods of Page *et al*. (1982). The data obtained were analyzed statistically using Analysis of Variance technique with a completely randomized design (CRD) and the LSD test was applied to test the significant difference between treatments (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Volume of Leachates: The volume of leachate (Table 2) was the highest for Ca_{12} while it was the lowest for control (Ca_o), which revealed that increasing Ca^{2+} concentration caused increased infiltration of water through soil columns. The low concentration of electrolyte in Ca_o treatment slowed down the leaching rate of saline-sodic soils by deflocculating soil particles (Sharma, 1971). There was a significantly higher leachate volume in the 4th leaching fraction than the 4th, 2nd and 1st fractions respectively. Leachate volume was significantly greater for the sandy clay loam (SCL) followed by sandy loam (SL) and clay loam (CL) indicating that clay content decreased infiltration of applied water due to increased dispersion (Ghafoor *et al*., 2001). The highest volume of leachate was observed with L_4Ca_{12} combination while the lowest volume was recorded with L_1Ca_0

Table 2. Volume of leachates (mL L^{-1}) for different soil textures as affected by Ca^{2+} concentration in leaching solutions

Treatment	Leachate-1			Leachate-2			Leachate-3			Leachate-4			Mean
	CL	SL	SCL	CL	SL	SCL	CL	SL	SCL	CL	SL	SCL	
Ca_0	261.5	494.4	464.4	350.5	383.8	617.8	584.3	662.9	688.7	511.2	501.7	645.4	513.9
Ca_4	390	588.4	552.9	414.8	395.1	657.8	593.1	632.9	708.4	560.9	666.5	712.3	572.8
Ca_8	350.5	449.4	519.5	388.5	411.9	704.6	555.1	614.2	712.3	423.6	486.8	846.1	538.6
Ca_{12}	407.5	509.3	562.7	446.9	426.9	664.8	563.8	726.5	794.9	531.6	734.1	952.4	610.2
L x S	352.4	510.4	524.9	400.2	404.5	661.3	574.1	659.2	726.1	506.9	597.3	789.1	
Leachate		462.6			488.7			653.1			631.1		

Std Error: Treatments (T) = 13.31**, Soil (S) = 11.52**, Leachate (L) = 13.31**, L×S = 23.04**, S×T = 23.04**, L×T = 126.61NS, S×T×L=46.10NS : CL = sandy loam, SL = sandy loam, SCL = sandy clay loam.

combination. This suggested that external application of gypsum or some other source of Ca^{2+} is essential to sustain the electrolyte concentration in soil solution and reclamation process, otherwise defloculation in response to decreased electrolyte concentration in soil solution could impair the leaching effectiveness during amelioration of saline-sodic soils. This is in conformity with the findings of Ghafoor and Salam (1993). They reported more volume of leachates for gypsum than that from the control treatment, even when highly brackish water (EC, SAR and RSC) was applied. In general, volume of leachates gradually increased with time (L_1 to L_4) with all the treatments for all the three soils, although increase was more for coarse textured soil and high rate of Ca_{iw}.

***Calcium concentration in leachates*:** The highest amount of Ca^{2+} leached with the Ca_{12} treatment (Table 3) while the lowest amount of Ca^{2+} leached with canal water alone (Ca_0). This indicates that the Ca^{2+} added at the rate of Ca_{12} was higher than the requirement of the Na^+-Ca^{2+} exchange and caused un-reacted Ca^{2+} leached. Significantly more Ca^{2+} was removed in L_4 and least in L_1 for all the soils. This may be due to the fact that Ca^{2+} applied in irrigation water during L_1 was mostly consumed in Na^+ Ca^{2+} exchange and in L2-L4 further Ca^{2+} was not required for amendment (Ghaffor *et al.*, 2000). Significantly more un-reacted Ca^{2+} passed through the SCL than through the SL and CL soils due to low CEC and an initially lower SAR of SCL soil.

***Sodium removed in Leachate*:** The results suggested that Ca^{2+} treatments had no significant impact on removal of Na^+ in the leachate (Table 4), however, removal of Na^+ was significantly higher in L_1 followed by L_2, L_3 and L_4. The insignificant differences among treatments show that high Ca^{2+} concentration failed to replace a proportional amount of adsorbed Na^+ because the rate-limiting factor for replacing Na^+ was the low soil CEC (Rashidi and Seilsepour, 2008). High Na^+ removal in L_1 could be due to the initially high Na^+ in solution of these saline-sodic soils which leached creating better probability for Na^+– Ca^{2+} exchange and thus a lower concentration of Na^+ in the subsequent leachates (Ghafoor and Salam, 1993). Murtaza *et al*. (2006) also reported that removal of Na^+ in leachates was more in the first than that in the following leachates. The soil texture differed significantly and more Na^+ was removed from SL than that from CL and SCL soils.

***Soil Improvement*:** The results clearly showed that increasing Ca^{2+} concentration in leaching solution decreased in soil salt concentration (EC_e). The post experiment soil EC_e showed a marked decreased (Table 5) with significant differences among different levels of Ca^{2+} treatments. The decrease in EC was higher in treatment with high calcium (Ca_{12}) but it did not differ considerably with calcium treatment Ca_4 except to some extant in CL soils. After infiltration of 4 PV of leaching solution through SCL soil, EC_e decreased to less than 4 dS m^{-1} which is considered as a critical line between normal and saline soil (US Salinity Lab. Staff, 1954), whereas the EC_e of CL and SL soils remained 16.15 and 12.62 dS m^{-1} respectively. The decrease in EC_e of SL soil was more compared to that of CL soil because of its coarse texture, which facilitates high hydraulic conductivity and K_{sat} for better leaching of salts.

The soil sodicity status (SAR) decreased after the experiment (Table 6) and its rate was affected by calcium contents in treatments but the effect was dependent on soil texture and type of salinity as reported earlier (Qadir and Oster. 2004; Murtaza *et al*., 2006). The SAR decrease was the maximum in SL soil texture followed by SCL and CL, however, the highest rate of Ca^{2+} addition in Ca_{12} affected non-significantly or even sometimes increased SAR values in SCL due to low initial SAR values or low sodicity. This decrease in SAR observed without Ca^{2+} addition in Ca_0 might be due to the "valence dilution" (Reeve and Bower, 1960) for reclaiming sodic soil. On the basis of decrease in SAR, treatment Ca_8 and Ca_4 were better than Ca_{12}. A substantial decrease in SAR of SL and SCL soils with all the treatments is likely due to their coarse texture, low clay content and low CEC.

Similarly, the highest K_{sat} was recorded for Ca_{12} during leaching (Table 7) of 1st and 4th PV of applied water, while minimum for the control (Ca_o). The SCL had a higher K_{sat} than the SL and CL which may be due to its coarse texture. Increasing Ca^{2+} concentration did not have a significant effect on hydraulic conductivity.

Table 3. The Ca^{2+} ($mmol_c$ L^{-1}) concentration of leachate after passing through saline-sodic soil column

Treatment	Leachate-1			Leachate-2			Leachate-3			Leachate-4			Mean
	CL	SL	SCL	CL	SL	SCL	CL	SL	SCL	CL	SL	SCL	
Ca_0	1.26	0.23	7.60	1.83	0.30	10.13	0.60	0.15	0.76	0.75	0.70	0.65	2.04
Ca_4	1.33	0.40	5.00	2.23	0.30	1.63	1.60	0.17	2.00	2.06	0.27	1.73	1.57
Ca_8	1.53	0.40	4.20	4.76	0.35	1.07	4.2	0.40	0.77	4.36	0.54	1.92	2.04
Ca_{12}	1.80	0.26	5.30	3.83	0.53	2.50	4.43	0.70	3.98	6.63	0.74	3.66	2.86
L x S	1.48	0.32	5.52	3.17	0.37	3.83	2.70	0.36	1.88	3.45	0.46	2.04	
Leachate		2.44			2.45			1.65			1.98		

Std Error: Treatments (T) = 0.19*, Soil (S) = 0.17*, Leachate volume (L) = 0.19*, L×S = 0.34*, S×T = 0.34*, L×T = 0.39*, S×T×L = 0.68*: CL = sandy loam, SL = sandy loam, SCL = sandy clay loam.

Table 4. The Na^+ ($mmol_c$ L^{-1}) in leachates as affected by Ca^{2+} concentration in leaching solutions

Treatment	Leachate-1			Leachate-2			Leachate-3			Leachate-4			Mean
	CL	SL	SCL	CL	SL	SCL	CL	SL	SCL	CL	SL	SCL	
Ca_0	122.0	173.2	157.3	105.1	131.4	226.6	66.9	96.2	32.8	45.2	76.3	39.4	106.1
Ca_4	119.2	187.1	203.4	106.3	119.3	164.4	68.2	107.4	36.0	42.7	84.0	43.5	106.8
Ca_8	153.0	105.4	235.8	86.63	104.9	118.8	55.7	93.2	35.9	44.2	79.4	42.5	96.3
Ca_{12}	158.4	192.5	209.1	87.1	136.5	113.2	64.0	136.4	31.2	34.8	84.1	47.5	107.9
L x S	138.2	164.6	201.4	96.2	123.1	155.8	63.7	108.3	34.0	41.7	81.0	43.2	
Leachate		168.1			125.0			68.69			55.3		

Std Error**:** Treatment (T) = 5.12 ^{NS}, Soil (S) = 4.43* Leachate volume (L) = 5.12*, L×S = 8.87*, S×T =8.87 ^{NS}, L×T = 10.24*, S×T×L =17.74*; CL = sandy loam, SL = sandy loam, SCL = sandy clay loam.

Table 5. Post-experiment EC_e (dS m^{-1}) of soils as affected by Ca^{2+} concentration in leaching solution

Treatment	Depth (0-15) cm			Depth (15-30) cm			Mean
	CL	SL	SCL	CL	SL	SCL	
Ca_0	20.53	18.8	4.20	23.50	14.70	4.83	10.76
Ca_4	17.70	16.1	3.70	16.00	12.43	4.06	10.66
Ca_8	17.13	12.9	2.03	13.80	11.16	3.17	10.36
Ca_{12}	13.80	11.3	2.46	11.73	09.56	3.23	9.52
D×S mean	16.06	12.78	2.10	16.25	12.46	2.32	
Depth mean		10.31			10.35		
Soil mean	16.15	12.62	2.213				

Std Error: Treatment (T) = 0.24 *, Soil (S) = 0.29*, Depth (D) = 0.24 ^{NS}, D×S =0.48 ^{NS}, S×T =0.59 ^{NS}, D×T=0.58 ^{NS}, S×T×D =0.84 ^{NS}; CL = sandy loam, SL = sandy loam, SCL = sandy clay loam.

Table 6. Post-experiment SAR (mmol L^{-1}) $^{1/2}$ of soils as affected by Ca^{2+} concentration in leaching solutions

Treatment	Depth (0-15) cm			Depth (15-30) cm			Mean
	CL	SL	SCL	CL	SL	SCL	
Ca_0	154.31	122.99	12.40	156.34	116.31	17.08	91.97
Ca_4	151.86	110.64	9.93	140.00	108.13	10.53	86.68
Ca_8	146.30	95.88	9.77	139.52	100.99	10.23	83.76
Ca_{12}	118.49	91.61	11.65	125.98	87.02	14.39	74.99
D×S mean	147.81	98.03	10.44	140.40	95.62	13.06	
Depth mean		85.43			83.03		
Soil mean	144.10	96.82	11.75				

Std Error. Treatment (T) =4.64*, Soil (S) =4.02*, Depth (D) =3.28 ^{NS}, D×S =5.69 ^{NS}, S×T = 8.04 ^{NS}, D×T= 6.57^{NS}, S×T×D =11.38^{NS} ; CL = sandy loam, SL = sandy loam, SCL = sandy clay loam.

Table 7. Saturated hydraulic conductivity (cm h^{-1}) of soils as affected by Ca^{2+} concentration in leaching solutions

Treatment	Soil depth (D)						Mean
	(0-15 cm)			(15-30 cm)			
	CL	SL	SCL	CL	SL	SCL	
Ca_0	0.27	0.34	0.48	0.67	0.76	0.90	0.57
Ca_4	0.35	0.45	0.60	0.85	0.88	0.98	0.68
Ca_8	0.49	0.54	0.68	0.96	0.98	0.99	0.77
Ca_{12}	0.40	0.60	0.75	0.89	1.03	1.03	0.80
D x S Mean	0.40	0.48	0.63	0.84	0.91	0.97	
Depth Mean		0.50			0.91		

Std Error: Treatment = 0.015*, Soil (S) = 0.013**, D×S = 0.028; CL = sandy loam, SL = sandy loam, SCL = sandy clay loam.

CONCLUSION

The results indicated that application of Ca in water decreased EC_e and SAR values of all the soils with a Ca^{2+} addition of 12 $mmol_c$ L^{-1} being most effective. Ca^{2+} application in saline sodic soils countered deleterious effects of higher Na contents by its removal which was highest in first leachate then decreased gradually and more Na^+ was removed from sandy loam than that from clay loam or sandy clay loam soils. However, there was no proportional relationship between removal of adsorbed Na^+ and Ca^{2+} application rates that showed rate-limiting factor for replacing Na^+ is low soil CEC. Leaching volume was higher in sandy clay loam followed by sandy loam and clay loam soils indicating that clay content decreased infiltration of applied water. This also suggested that external application of gypsum or some other source of Ca^{2+} is essential to sustain the electrolyte concentration in soil solution and reclamation process, otherwise defloculation in response to decreased electrolyte concentration in soil solution could impair the leaching effectiveness during amelioration of saline-sodic soils.

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