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Amelioration of a Calcareous Saline-Sodic Soil by Gypsum Application and Different Crop Rotations

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ABSTRACT

A lysimeter study was conducted to assess the impact of some crop rotations and gypsum on amelioration of a calcareous saline-sodic soil (pH_s = 8.4, EC_e = 8.6 dS m^{-1}, SAR = 37.7, $CaCO_3$ = 81.1 g kg^{-1}) irrigated with marginal-quality water (EC = 1.0 dS m^{-1}, SAR = 4.2, RSC = 3.1 $mmol_c$ L^{-1}). There were five treatments: (1) control (no crop or chemical amendment), (2) cropping with wheat (*Triticum aestivm* L.) and rice (*Oryza sativa* L.) without gypsum application (WR), (3) cropping with wheat and rice with soil application of gypsum (GWR), (4) cultivation of berseem (*Trifolium alaxandrinum* L.) and Kallar grass {*Leptochloa fusca* (L.) Kunth} without gypsum application (BK), and (5) cultivation of alfalfa (*Medicago sativa* L.) and sesbania (*Sesbania aculeata* L.) without gypsum application (AS). It has been observed that the GWR treatment removed greater amounts of sodium (Na^+) from the root zone leaving behind minimum level of sodium adsorption ratio (SAR) and the greatest EC_e: SAR ratio in post-amelioration soil. Cropping treatments alone had little effect on calcite dissolution and removed less Na^+ during one year period. This evidence suggests that application of a chemical amendment like gypsum could only be advantageous while irrigating saline-sodic soils with marginal-quality waters during reclamation.

Key Words: Calcite; Sandy clay loam; Marginal-quality water; Leachate; EC_e; SAR ratio

INTRODUCTION

Soil salinity and sodicity are among the serious concerns to irrigated agriculture in arid and semi-arid regions of the world (Ayers & Tanji, 1999). Low rainfall, use of un-managed water resources and high evaporation in these regions are among the causes of soil salination and sodication. Among these problem soils, sodic nature show structural problems (Qadir & Schubert, 2002) causing decrease in water up-take by plants, seedling emergence and root penetration. In addition, osmotic and specific ion effects together with imbalance plant nutrient supply in such soils affect plant growth.

Saline-sodic and sodic soils need a source of soluble calcium (Ca^{2+}) to replace excess Na^+ from cation exchange sites. Chemical amendments have a long history of usage for soil amelioration (Gupta & Abrol, 1990; Ghafoor *et al*., 1991; Qadir *et al*., 2001). Gypsum is the commonly used chemical amendment. It improves soil physical properties through Na^+ - Ca^{2+} exchange, increasing ionic strength around the soil particles and making ionic complexes with SO_4^{2-} during gypsum dissolution (Renjasamy & Olsson, 1991). Calcium contents in soil solution above 8 $mmol_c$ L^{-1} have been considered the most efficient for reclamation of calcareous saline sodic soils of Pakistan (Ghafoor & Salam, 1993). Research done in recent decades also suggests the possible role of salt tolerant crop species like Kallar grass, sesbania and alfalfa in reducing salinity/sodicity of such soils (Robbins, 1986; Qadir *et al*., 1996; Batra *et al*., 1997). These crops increase the level of CO_2 during roots and microbial respiration in the rhizosphere, which upon dissolution in water acts as a weak acid and helps in dissolution of soil calcite (Qadir & Oster, 2002). Moreover, these salt-tolerant crop species also absorb ions like Na^+ and Cl^- to maintain turgor (Ahmad *et al*., 1990; Qadir *et al*., 2003), which are removed from soil during foliage removal. Hence appropriate crop rotations could be helpful for achieving continued improvements in saline-sodic soils.

The EC_e: SAR ratio of soil although not well established yet is very important while considering the reclamation process. Studies show that soil dispersion occurs at a very low SAR if EC_e: SAR ratio is also low (McNeal & Coleman, 1966a; Shainberg *et al*., 1981). According to McNeal and Coleman (1966b), saline-sodic/sodic soils dominated by montmorillonite type clay minerals start dispersing at EC_e: SAR ratio < 0.24, when SAR was greater than 20 and pronounced decrease occurs at SAR > 25.

Increased competition for fresh-water, among industrial, domestic and agricultural sectors has led to the shortage of good-quality irrigation water for crop production even on non-saline non-sodic soils (Pimental *et al*., 1999). Consequently, ground-water of different qualities is being used to make-up the shortage of good-quality waters for crop production. Previous studies on phytoremediation of saline-sodic soils have been carried out with good-quality waters having no residual sodium carbonates (Robbins, 1986; Qadir *et al*., 1996; Ilyas *et al*., 1997). Since the use of marginal-quality waters has become inevitable, we conducted a lysimeter experiment to evaluate the role of chemical and biological amendments in the amelioration of a calcareous saline-sodic soil, while irrigating with marginal quality water.

MATERIALS AND METHODS

Preparation of soil columns. Concrete made lysimeters (60 cm long & 30 cm internal diameter) connected with plastic receivers at the bottom through a narrow out-let were used in the experiment. These lysimeters were lined with polyethylene sheet in order to prevent lateral losses of water. Approximately 1 cm thick layer of glass wool and 2 cm layer of sand were spread on the out-let in order to facilitate leaching with-out any suspended material. Then 45 kg calcareous saline-sodic soil (Table I) passed through 2 mm sieve was poured in each lysimeter gently. These lysimeters were watered with marginal-quality water (EC = 1.0 dS m^{-1}, RSC = 3.1 $mmol_c\ L^{-1}$, SAR = 4.2) at the rate of 50% of soil saturation in order to have uniform soil packing. In this way, 35 cm long soil columns were prepared. The same water was subsequently used for irrigating the crops.

Treatments. Four cropped and one non-cropped treatments were arranged in a completely randomised design with three replications. The treatments used were:
(1) Control: No crop or gypsum application
(2) WR: Wheat - Rice (without gypsum application)
(3) GWR: Wheat - Rice with gypsum application at 50% soil gypsum requirement before sowing of wheat
(3) BK: Berseem - Kallar grass (without gypsum application)
(4) AS: Alfalfa - Sesbania (without gypsum application).

Wheat cultivar SARC-1 was sown (10 seeds per pot), while 30-days old rice seedlings of variety KS - 282 (5 per pot) were transplanted. These crops were harvested at maturity. Berseem and alfalfa were grown but they could not produce good biomass. Stumps of Kallar grass were used for cultivation at the rate of five stumps per pot. Sesbania was sown at 10 seeds per pot. These crops were harvested thrice during whole of the summer season as fodder. Water was applied according to each crop water requirement along with an additional amount of water on each irrigation of wheat and rice such that 20% of 75 mm irrigation (1080 mL) was passed through the soil columns. All the crops were grown for the same duration as those of wheat and rice in their respective seasons.

Leachate collection and soil sampling. Water was allowed to infiltrate through each lysimeter until 1080 mL was collected in the receivers. A representative sample was collected from the leachate of each lysimeter. Leachates were collected five times during winter and eleven times during summer crops. At termination of the experiment soil columns were allowed to dry up to workable water contents. Then each lysimeter was sampled with the help of core sampler. These samples were ground, mixed thoroughly and produced for chemical analyses.

Analytical procedure. Important physical and chemical parameters of soil before and after experiment were determined. Soil and leachate samples were analysed chemically following the methods described by the US Salinity Lab. Staff (Richards, 1954). Particle size analysis was conducted using hydrometer (Bouyoucos, 1962), while gypsum requirement was determined following Schoonovers' method. Cumulative salt/ionic removal at a leachate (Q_j) was calculated by the following equation:

$$Q_j = \sum_{i=1}^{i=j} C_i V_i \qquad (1)$$

where, C_i is salt/ionic concentration in individual leachate and V_i is volume of that leachate. The evapotranspiration, E was calculated with the help of water budget method (Krishnan, 1992) using the following equation

$$E = Iw - Dw \qquad (2)$$

Where, Iw and Dw are irrigation and drainage waters respectively, all expressed in L $crop^{-1}$.

RESULTS AND DISCUSSION

Crop biomass and evapotranspiration. In winter crops, only wheat yielded good biomass in both the WR and GWR treatments. Its yield in gypsum treatment was 169 g $lysimeter^{-1}$ and in non-gypsum treatment was 164 g $lysimeter^{-1}$. Berseem and alfalfa did not grow well and produced less biomass (Table II). During summer season, rice did not grow well and produced only 28 g $lysimeter^{-1}$ biomass in WR and 17 g $lysimeter^{-1}$ in GWR treatment. Sesbania and Kallar grass produced better biomass.

Evapotranspiration was found to depend upon crop vigour during winter as well as in summer season (Table II). Maximum water was evapotranspired by wheat followed by alfalfa and berseem during winter. It was the highest for sesbania followed by Kallar grass and rice during summer season.

Salts and cations removal from soil during reclamation. Soil treatment, leachate number and their interactions affected removal of salts and cations (Ca^{2+}, Mg^{2+} & Na^+) through leachates (Fig. 1 & 2). Control treatment leached more salts, $Ca^{2+} + Mg^{2+}$ and Na^+ in early stage of study than those of the other treatments. Removal of salts and cations decreased gradually in the later leachates. It was due to the natural action of water that dissolved and carried salts while passing through soils and effective infiltration of water in control compared to other treatments. This reflects that decrease in soluble salts is rapid action even without crop and amendments.

Overall, GWR was found the leading treatment in leaching of salts and cations, leachate L_5 of GWR carried

Table I. Physical and chemical characteristics of soils at the start of experiment

Characteristic	Value
Textural class	Sandy clay loam
Saturation, %	31.56
pH_s	8.36
EC_e, dS m^{-1}	8.62
Soluble CO_3^{2-} (mmol$_c$ L^{-1})	0.60
″ HCO_3^- (mmol$_c$ L^{-1})	3.30
SAR (mmol $L^{-1})^{1/2}$	37.69
CEC (cmol$_c$ kg^{-1})	5.70
GR (g kg^{-1})	3.21
$CaCO_3$ (g kg^{-1})	81.10
OM (g kg^{-1})	5.80

Table II. Biomass produced by crops and water evapotranspired

Treatment	Crop	*Biomass (g lysimeter^{-1})	Evapotranspiration (L Crop^{-1})
Control	Winter	--	18.3
	Summer	--	31.5
WR	Wheat	164	40.0
	Rice	28	31.8
GWR	Wheat	169	41.3
	Rice	17	33.3
BK	Berseem	141	21.1
	Kallar grass	311	36.4
AS	Alfalfa	156	23.2
	Sesbania	547	73.5

*Biomass of wheat and rice is sum total of grain and straw whereas for other crops is only straw on fresh weight basis.

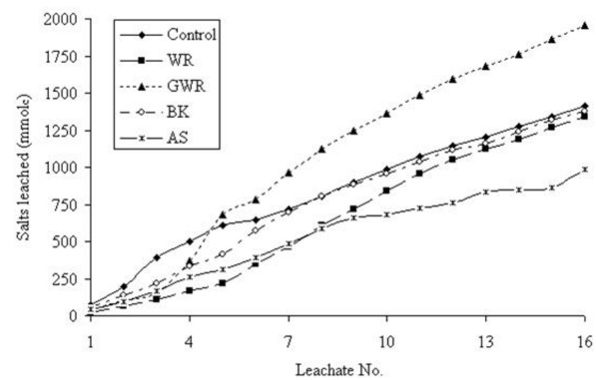
the maximum salts and Na^+ (Fig. 1 & 2). Similarly, L_5 of this treatment gained significantly the highest load of Ca^{2+} + Mg^{2+} and almost all the leachates from GWR carried double the quantity than respective leachates from other treatments. The Ca^{2+} + Mg^{2+} in soil solution above 8 mmol$_c$ L^{-1}, as in GWR of present study (Fig. 2) has been considered the most efficient for Na^+—Ca^{2+} exchange of native soils (Ghafoor & Salam, 1993). Moreover, it leached more salts and Na^+ with the same amount of water as compared to other treatments. It was due to the fact that gypsum improves soil flocculation through enhancing ionic strength effect and ionic complexes with SO_4^{2-} envisaged by gypsum dissolution (Rengasamy & Olsson, 1991). Moreover, higher leaching of Ca^{2+} + Mg^{2+} with this treatment helped flocculate soil underneath the gypsum receiving layer, which is important for soil permeability. All this helped efficient removal of Na^+ through expediting Na^+—Ca^{2+} exchange and leaching of salts. This decreased the SAR of post-amelioration soil to the maximum (54.1%). However, the post-amelioration soil EC_e remained a little more with GWR than WR and BK (Table III). It was due to presence of residual gypsum that dissolved to sustain high electrolyte concentration (soluble Ca^{2+} + Mg^{2+} = + 7.89%) and continued replacement of Na^+ from exchange sites into the soil solution. It can be observed from data that gypsum application at 50% soil gypsum requirement leached Ca^{2+} + Mg^{2+} through 35 cm soil columns in excess of that required for Na^+—Ca^{2+} exchange. This process would ultimately contribute to the ground-water brackish-ness. Hence, soil gypsum application can be reduced further in order to decrease salt load of leaching solution and cost of reclamation for such soils. However, this aspect needs further investigations.

Table III. Soil characteristics after termination of the experiment

Characteristic	Control	WR	GWR	BK	AS	CV, %
pH_s	8.65 a	8.68 a	8.21 b	8.71 a	8.68 a	0.78*
	(+3.47)	(+3.83)	(-1.79)	(+4.19)	(+3.83)	
EC_e	3.95 b	4.87 b	5.07 b	4.45 b	6.86 a	14.57*
(dS m^{-1})	(-54.18)	(-43.50)	(-41.18)	(-48.38)	(-20.42)	
HCO_3^-	5.50 a	5.50 a	3.50 b	5.67 a	5.33 a	14.98*
(mmol$_c$ L^{-1})	(+41.03)	(+41.03)	(-10.26)	(+45.38)	(+36.67)	
Ca^{2+} + Mg^{2+}	3.87 bc	4.33 bc	12.30 a	3.60 c	5.87 b	18.20*
(mmol$_c$ L^{-1})	(-66.05)	(-62.02)	(+7.89)	(-68.42)	(-48.51)	
Na^+	35.07 b	44.19 b	42.79 b	40.15 b	66.28 a	15.06*
(mmol$_c$ L^{-1})	(-61.03)	(-50.90)	(-52.46)	(-55.39)	(-26.36)	
SAR	24.90 c	30.15 b	17.29 d	29.91 bc	36.20 a	9.96*
(mmol $L^{-1})^{1/2}$	(-33.93)	(-20.01)	(-54.13)	(-20.64)	(-3.95)	
$CaCO_3$	80.70	85.50	83.30	83.00	83.20	5.25^{NS}
(g kg^{-1})	(-0.49)	(+5.43)	(+2.71)	(+2.34)	(+2.59)	

Figures sharing the same letter(s) in common are similar at P = 5 %
Figures in parenthesis are % increase (+) or decrease (-) over the initial values.

Fig. 1. Cumulative removal of salts in leachates of different treatments



All the non-gypsum cropped treatments except AS were statistically similar in their response to salts and Na^+ removal in leachates (Fig. 1 & 2); AS leached less salts and Na^+. Hence the SAR of AS remained the highest followed by WR, BK and control. Overall, decrease in SAR with these treatments was from 3.9 to 33.9%. A small increase in $CaCO_3$ has been observed with all the cropped treatments but in control it decreased.

Sesbania caused the highest evapotranspiration from AS (Table II). Moreover, better sesbania crop is indicative of more root growth. This compacted the soil adjacent to roots (Bauder & Brock, 1992) making solute movement across the channel walls slow while plants were growing. These factors allowed only a fraction of water to pass through the soil columns carrying salts and Na^+ into the leachates. Hence, only a small decrease in EC_e and SAR was observed with AS (Table III). Apart from this decrease in EC_e and SAR, a small change could be due to ion up-take by plants (Ahmad *et al*., 1990; Qadir *et al*., 2003) and precipitation of desorbed Ca^{2+} as $CaCO_3$. Hence, this treatment would need excessive amount of water to decrease EC_e and SAR to the safe level as compared to gypsum treatment. Other non-gypsum treatments decreased EC_e and SAR more than that of AS although remained higher than control perhaps due to better leaching and less ET over AS

Fig. 2. Cumulative Ca^{2+}+Mg^{2+} and Na^{+} leached with each treatment

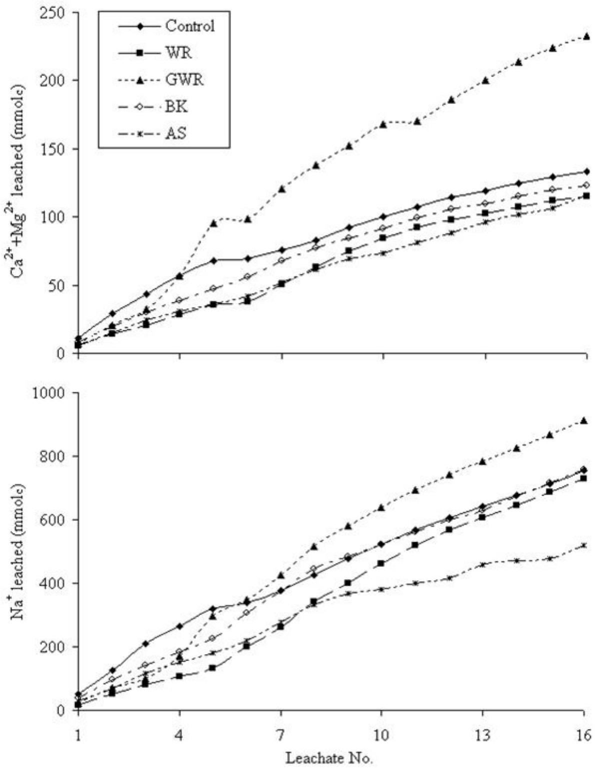
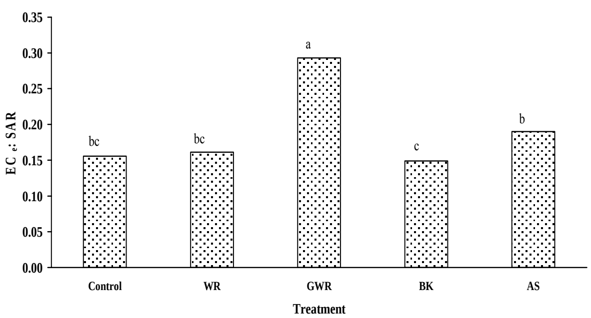


Fig. 3. EC_e: SAR ratio of post-amelioration soil



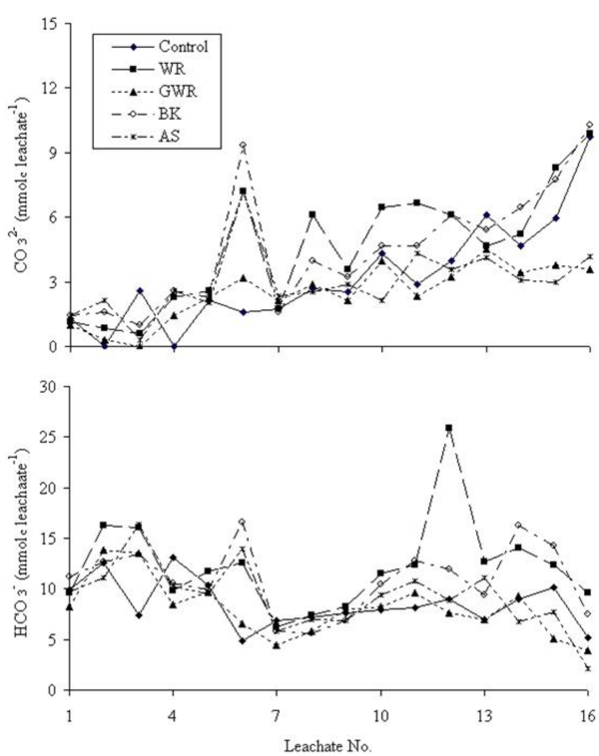
treatment.

Effect of salts removal on EC_e: SAR ratio of post-amelioration soil. In the present study gypsum treated post-amelioration soil (GWR) showed considerably higher EC_e: SAR ratio (Fig. 3). In non-gypsum treatments, decrease in EC_e over the initial soil level was more (up to 54.2%) as compared to SAR (up to 34%) resulting in EC_e: SAR ratio less than 0.2. Hence cropping alone for a year could not decrease SAR below 25. Here plants appeared to have negative effect on solubility of calcite present in the soil as $CaCO_3$ contents increased a little over the initial soil level showing a net precipitation (Table III). It indicates that crops under present study could not help maintain sufficient salts to keep the soil flocculated during reclamation process. This process can make the soil as sodic, which is more difficult to reclaim than any other soil. Ahmad *et al.* (2003) also observed a decrease in EC_e: SAR ratio and an increase in soil dispersion as judged from gleying in one-year sesbania-rice-wheat study. The overall response of different treatments to EC_e: SAR ratio of post-melioration soils remained in the order of GWR > AS > WR ≈ control > BK (Fig. 3).

Previous studies also show that soil dispersion occurs at a very low SAR if EC_e: SAR ratio is low (McNeal & Coleman, 1966a; Shainberg *et al*., 1981). According to McNeal and Coleman (1966b), saline-sodic soils dominated by montmorillonite type clay minerals, like the soil under present study (Anonymous, 1986), start dispersing at EC_e: SAR ratio < 0.24, when SAR exceeds 20 and pronounced decrease occurs at SAR > 25, which is not suitable for most of the agronomic crops and soil amelioration. Hence it is only the gypsum treatment that maintained high electrolyte concentration and decreased SAR of post-amelioration soil to maintain EC_e: SAR ratio above threshold value of 0.24.

Carbonates chemistry of leachates and post-amelioration soil pH_s. Overall, the amount of CO_3^{2-} in leachates increased during winter and summer crops, while those of HCO_3^- varied inconsistently or decreased with time (Fig. 4). This phenomenon depicts that pH of soil solution tends to increase. Significantly higher CO_3^{2-} and HCO_3^- were removed in the leachates from WR and BK compared

Fig. 4. Treatments affect CO_3^{2-} and HCO_3^- removal through leachates



to other treatments (Fig. 4). In leachates from GWR and AS, these ions remained lower compared to others even though, CO_3^{2-} increased and HCO_3^{2-} decreased with time. Overall, treatment order for CO_3^{2-} removal in leachates was WR > BK > control > AS > GWR and that of HCO_3^- was WR > BK > AS > control > GWR. With non-gypsum treatments, pH of post-amelioration soil saturation extract (pH_s) was not only significantly higher than that of GWR treatment but also increased over the initial soil pH_s (Table I & III), being maximum with BK followed by AS ≈ WR > control.

The pH_s of GWR treatment decreased statistically below 8.5 (Table III). It was because of continued supply of Ca^{2+} through dissolution of gypsum that decreased carbonates to the minimum either through precipitation as $CaCO_3$ or their leaching through piston flow mechanism. Increase in pH_s with non-gypsum treatments, could be due to an increase in CO_3^{2-} over those of the initial soil level. In leachates from these treatments, HCO_3^- as well as CO_3^{2-} leached significantly more than those from GWR (Fig. 4). It shows that increased ET during crop growth (Table II) induced soil solution to concentrate, which along with high RSC of irrigation water (3.1 $mmol_c\ L^{-1}$) precipitated Ca^{2+} as $CaCO_3$ (Eaton, 1950). Introduction of OH^- ions in the system either by plant root activities (Marschner *et el*., 1986) or by hydrolysis of Na^+ affected conversion of HCO_3^- into CO_3^{2-} ions in these treatments (Brady, 1990). Since no additional Ca^+ was used to bind free CO_3^{2-} into $CaCO_3$ or leach down through piston flow mechanism, activity of Na^+ and CO_3^{2-} ions increased to affect an increase in pH_s of non-gypsum treatments.

In case of AS treatment, CO_3^{2-} in leachates increased approximately to that of GWR but HCO_3^- remained a little higher over that of GWR indicating the calcite dissolution (Table III). This could be due leguminous nature of sesbania that released H^+ ions during N-fixation in addition to respiratory CO_2 production. However, this effect was not as pronounced partly because of the use of high RSC water that kept pH of soil solution higher enough (pH > 8.4) to depress calcite dissolution or tended to precipitate it. It indicates that plants could not produce enough H^+ ions to meet the environmental stress like the use of high RSC or high Na^+ water during phytoremediation and this technology could only work in the presence of good-quality water as the previous work indicated (Robbins, 1986; Qadir *et al*., 1996; Ilyas *et al*., 1997).

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