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Chemistry of Leachates Collected During Phytoremediation of Calcareous Saline-sodic Soil with *Sesbania aculeate*

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Abstract: A calcareous saline-sodic soil ($\text{pH}_s = 8.26$, $\text{EC}_e = 9.07 \text{ dS m}^{-1}$, $\text{SAR} = 37.90$, $\text{CaCO}_3 = 8.58 \%$, texture = sandy clay loam) packed in concrete lysimeters was tested for Phytoremediation. The treatments were: No-*Sesbania* (T_1), *Sesbania*-harvested (T_2) and *Sesbania*-incorporated (T_3) before flowering. Rice-wheat crop rotation was followed after *Sesbania*. Each crop was irrigated with high RSC water ($3.1 \text{ mmol}_c \text{ L}^{-1}$) according to its water requirement and 20 % extra water was allowed to infiltrate each time. Three leachate were collected during *Sesbania*, five during rice and four during wheat crop. One leachate was collected at pre-planting irrigation (Rouni) of rice. It was observed that the treatment from where *Sesbania* was harvested (T_2) caused more salts leaching as compared to other treatments. Net salt removal was observed only during rice crop while during rest of the crops there was salt deposition in soil. Net CO_3^{2-} removal increased while that of HCO_3^- decreased throughout the study period showing an increase in pH of soil solution phase. Similarly $\text{Ca}^{2+} + \text{Mg}^{2+}$ removal remained less while that of Na^+ more but similar with all the treatments than that of added through irrigation water indicating ineffectiveness of *Sesbania* either in the form of harvest or incorporate into the soil. It is opined that salts/ionic removal is not sufficient enough to coup with the amelioration of calcareous saline sodic soils.

Key words: High RSC water, *sesbania*, sandy clay loam, leachate, CO_3^{2-} , HCO_3^{2-}

Introduction

Crops can play a significant role in amelioration of salt-affected soils through promoting their hydraulic conductivity upon introducing root channels (Lal *et al.*, 1979; Ahmad *et al.*, 1990) as well as modifying the soil environment when they release CO_2 (Robbins, 1986a) during respiration along with the excretion of exudates (Dormaar, 1988). The CO_2 forms carbonic acid upon dissolution in water, which helps dissolve native soil lime (Amrhein *et al.*, 1985; Qadir and Oster, 2002). This action of crops could provide a low cost amendment to maintain soil health. Deep-rooted crops are preferred over shallow ones in order to promote hydraulic conductivity of soil. Leguminous crops could be more useful as they decrease pH in the rhizosphere through protonation (Jarvis and Robson, 1983; Hinsinger, 1998) in addition to CO_2 and exudate production. *Sesbania* could be preferred in this case. Ahmad *et al.* (1989) reported positive effect of introducing *Sesbania* as the first crop during soil reclamation. Keeping these facts in view a study was conducted to assess the impacts of *Sesbania* on the chemical composition of leachates collected during calcareous saline-sodic soil reclamation.

Materials and Methods

An experiment was conducted in the wire-house, Dept. of Soil Science, University of Agriculture, Faisalabad during April 2000 to April 2001. Calcareous saline-sodic soil ($\text{pH}_s = 8.26$, $\text{EC}_e = 9.07 \text{ dS m}^{-1}$, $\text{SAR} = 37.90$, $\text{CaCO}_3 = 8.58 \%$, texture = sandy clay loam) was collected from 0-15 cm soil layer of the Khurrianwala soil series and packed in concrete lysimeters to prepare 35 cm soil columns. These lysimeters were connected with plastic receivers at the bottom through a narrow outlet. Approximately 2 mm thick layer of glass wool and 2 cm layer of sand were spread on the outlet in order to facilitate leaching and check clay illuviation. Then the lysimeters were watered @ 50 % of the soil saturation such that no water was drained out of the soil columns. The same water ($\text{EC} = 0.96 \text{ dS m}^{-1}$, $\text{CO}_3^{2-} = 0.30 \text{ mmol}_c \text{ L}^{-1}$, $\text{HCO}_3^- = 5.7 \text{ mmol}_c \text{ L}^{-1}$, $\text{RSC} = 3.10 \text{ mmol}_c \text{ L}^{-1}$, $\text{SAR} = 4.16$) was subsequently used for irrigating the crops. The treatments included were: No-*Sesbania* (T_1), *Sesbania*-harvested (T_2) and *Sesbania*-incorporated (T_3) before flowering. *Sesbania* was sown (10 seeds per pot) as first crop on May 18, 2000 and harvested three times up to July 4, 2000 as T_2 and incorporated once on July 4, 2000 as T_3 . Rice-wheat crop

rotation was followed after Sesbania. Thirty days old rice seedlings (5 per pot) of variety KS-282 were transplanted on July 20, 2000 and harvested on November 5, 2000. Wheat cultivar SARC-1 (10 seeds per pot) was sown on November 20, 2000 and harvested on April 20, 2001.

Each crop was irrigated with water according to its water requirements along with 20% extra water (1.08 L) over wheat water requirement that passed to leach down salts each time. Three leachates were collected during Sesbania, five during rice and four during wheat crop. One leachate was collected at pre-planting irrigation of rice. At the incorporation of Sesbania in T₃, pots were irrigated to facilitate its decomposition and 15 days here after rice was transplanted. Rice and wheat were grown up to maturity. Water applied to each crop (Table 1) and biomass produced (Table 2) were recorded. Leachates were analysed chemically following the methods devised by US Salinity Lab. Staff (Richards, 1954).

Net salts/ionic removal through leachates (Q_i) were calculated with the help of formula

$$Q_i = \sum (C_{ij} - C_{is}) V_j$$

Where C_{ij} is salt/ionic concentration in the leachate and C_{is} is that in the leaching solution (applied water) at a given volume V_j. A positive value of Q_i indicates an addition of ion I to the leachate compared with the leaching solution, whereas a negative value indicates its depletion from solution and therefore accumulation in the soil.

Results and Discussion

Salts removal: During the study period significant differences have been observed in salts removal through leachates. On an average, salts removal was low during initial three leachates followed by a sharp increase in salt contents in the leachates from L₄ to L₉ (Fig. 1), i.e. during rice growing period. There was again a decrease in salts removal after L₉ during wheat growing period. This behaviour of salt removal appears because of more water percolations during rice growing period as it is grown under flooded conditions while wheat and Sesbania are grown under aerobic conditions. Moreover, the removal of salts depends upon the reaction time of water within soil and the nature and solubility of salts. In earlier leachates due to high salts in the soil and less dispersion, water passed more quickly through the soil columns without much interaction with salts (Costa *et al.*, 1991), therefore carried less salts. At this time Sesbania was grown. Hence, Sesbania appeared to have a little effect on salts removal through leachates.

When considered net salt removal through leachates, more removal was observed during rice growth in T₁

Table 1: Biomass produced by various crops (g lysimeter⁻¹)

Crop	No Sesbania		Sesbania harvested		Sesbania incorporated	
	Fresh wt.	Dry wt.	Fresh wt.	Dry wt.	Fresh wt.	Dry wt.
Sesbania	--	--	189.4	45.9	188.9	*
Rice**	3.3	1.3	14.7	7.9	6.2	7.8
Wheat**	142.4	124.2	115.2	101.6	123.9	108.5
Total	145.7	125.5	319.3	155.4	319.0	116.3

*Incorporated into the soil at the time of harvest

**Fresh weight of wheat and rice was taken at the time of harvest at maturity

Table 2: Water applied (L lysimeter⁻¹) during each crop

Crop	No Sesbania	Sesbania harvested	Sesbania incorporated
Sesbania	12.0 (73.0)*	23.5 (86.2)	26.2 (87.6)
Rice	35.5 (81.7)	39.1 (83.4)	38.7 (83.3)
Wheat	30.5 (83.8)	35.3 (87.8)	36.2 (88.1)
Total	78.0 (80.2)	97.9 (85.7)	101.1 (86.1)

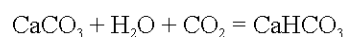
*Figures in parentheses are per cent evapotranspired of added water

followed by T₂ and T₃ (Fig. 2) while Sesbania and wheat crops showed salt deposition in soil. Biomass of Sesbania was the maximum followed by wheat and rice (Table 1). This factor of Sesbania and wheat imposed increased evapotranspiration over the infiltration rate (Table 2) that resulted in salts accumulation in soil. These factors have been described by Rhoades *et al.* (1973) that increase in salt concentration occurs during plant growth as plants absorb and transpire water from soil leaving nearly all the salt of irrigation water in soil unless there is sufficient leaching.

Qadir *et al.* (2001) suggested inclusion of Sesbania in crop rotation to reduce evaporation losses from the bare soil during hot months from May to July before rice cropping and enhance leaching of salts. However, Sesbania grown in this study did not help leach much salt to decrease EC_e of the soil rather affected salt deposition due to high ET.

CO₃²⁻ and HCO₃⁻ : Total removal of CO₃²⁻ and HCO₃⁻ remained similar to that of salts removal in the leachates. Net HCO₃⁻ removal decreased compared to the added one while those of CO₃²⁻ increased with the passage of time (Fig. 3). Maximum net removal of CO₃²⁻ was found in T₃ followed by T₂ and T₁. The HCO₃⁻ removal was observed almost reverse of it, i.e. where CO₃²⁻ removal increased the HCO₃⁻ removal decreased.

In early studies (Robbins, 1986a; Nadler *et al.*, 1996; Qadir *et al.*, 2001) increase in HCO₃⁻ in sodic soils during crop growth has been considered because of lime dissolution in the absence of common ions in irrigation waters in response to P_{CO₂} in soil-water system as shown below:



However, in this study increased leaching of CO₃²⁻ compared to those of HCO₃⁻ might be due to high pH of soil that helped dissociate newly formed H₂CO₃ into HCO₃⁻ and CO₃²⁻ as Ionization products CO₃²⁻ and

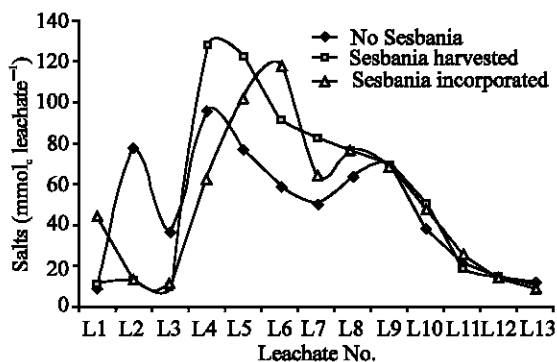


Fig. 1: Crops affect salt contents of leachates (Total Lached)

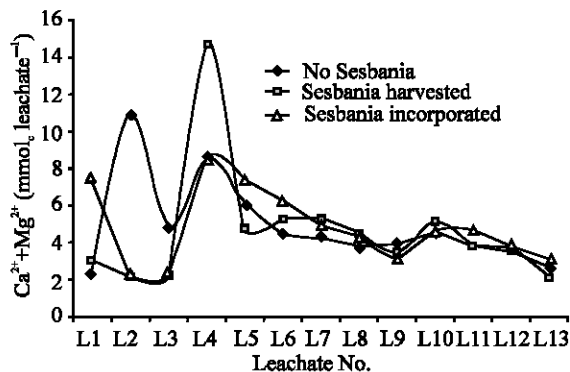


Fig. 4: Effect of treatments on Ca²⁺+Mg²⁺ contents of leachates

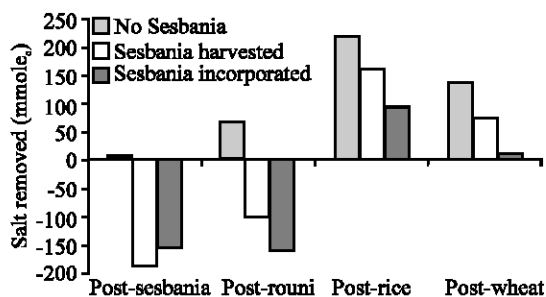


Fig. 2: Net salts removed from soil after each crop

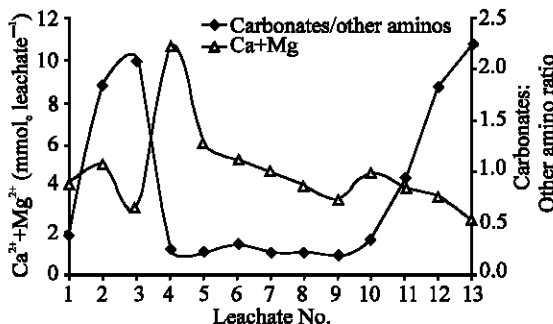


Fig. 5: Effect of carbonates (CO₃²⁻ + HCO₃⁻) on Ca²⁺ + Mg²⁺ in leachate

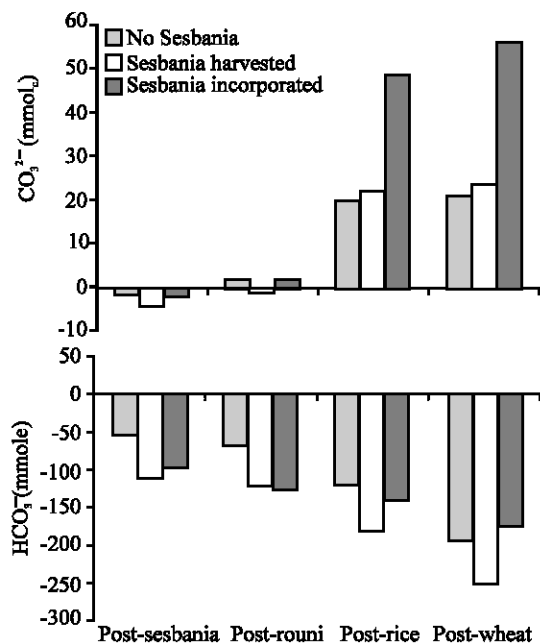


Fig. 3: Net CO₃²⁻ and HCO₃⁻ removed from soil after each crop

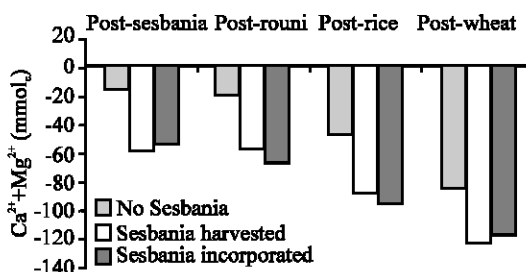
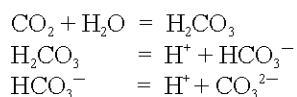
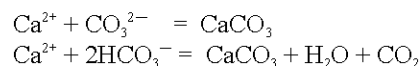


Fig. 6: Net Ca²⁺+Mg²⁺ removed from soil after each crop



HCO₃⁻ must combine with Ca²⁺ in soil to form CaCO₃ even in the presence of low concentration due to low k_{sp} values (Nakayama, 1971) as reaction given below



Suarez and Rhoades (1991) reported that precipitation of

Ca^{2+} at $\text{CO}_3^{2-} + \text{HCO}_3^-$ concentration $> \frac{1}{2} \text{Ca}^{2+}$ in solution increased the activity of CO_3^{2-} and HCO_3^- in the soil-water system. The water used for irrigation had $\text{CO}_3^{2-} + \text{HCO}_3^-$ higher than half of $\text{Ca}^{2+} + \text{Mg}^{2+}$ ions that have affected participation of Ca^{2+} ions coming into solution through in-situ mineral weathering (Rhoades, 1972), dissolution of lime because of root activity (Robbins, 1986b; Ilyas *et al.*, 1997) or added through irrigation water.

$\text{Ca}^{2+} + \text{Mg}^{2+}$ removal: Overall, removal of $\text{Ca}^{2+} + \text{Mg}^{2+}$ in all the leachates (Fig. 4) was similar among the treatments. Higher removal of $\text{Ca}^{2+} + \text{Mg}^{2+}$ was found in the initial leachates up to L_5 , maximum being in L_4 which gradually declined in the later leachates and decreased to the minimum in L_{13} . It could be due to presence of their soluble forms in soil solution at early stage of experimentation, which decreased with time. Precipitation of Ca^{2+} and Mg^{2+} as CO_3^{2-} compounds due to the use of high RSC irrigation water could have affected to decrease their concentration as described by Suarez and Rhoades (1991). It can be depicted from Fig. 5 that $\text{Ca}^{2+} + \text{Mg}^{2+}$ concentration decreased as those of carbonates compared to other ions (Cl^- , SO_4^{2-}) increased in the leaching solution. This shows that Sesbania had little effect on the dissolution of native lime in the soil.

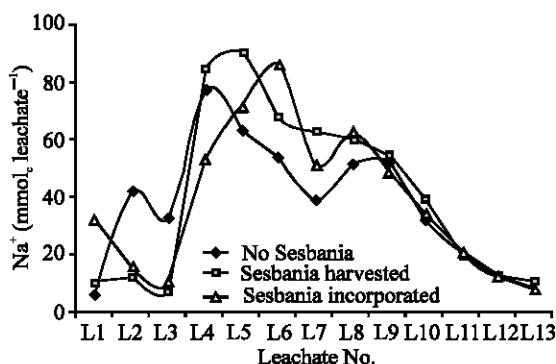


Fig. 7: Effect of treatments on Na^+ contents of leachates

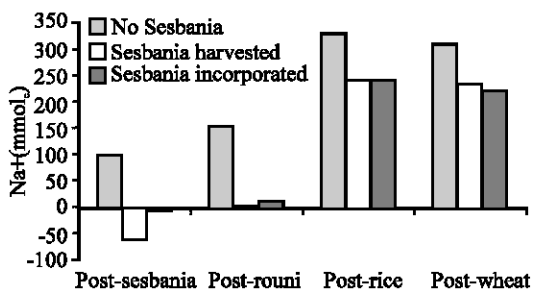


Fig. 8: Net Na^+ removed from soil after each crop

A net negative removal of $\text{Ca}^{2+} + \text{Mg}^{2+}$ (less were observed in leachates than added with water) was observed with all the treatments, minimum removal being with T_2 (Fig. 6). It showed that $\text{Ca}^{2+} + \text{Mg}^{2+}$ added in soil through irrigation water has either adsorbed or precipitated as CaCO_3 . Most probably precipitation has occurred as the concentration of CO_3^{2-} and HCO_3^- increased in the leachates through the decreased amount of $\text{Ca}^{2+} + \text{Mg}^{2+}$ (Suarez and Rhoades, 1991). As a result of such $\text{Ca}^{2+} + \text{Mg}^{2+}$ depletion, relatively a small change in soil SAR could result at the end of the experiment.

Removal of Na^+ : The importance of a treatment could be considered to depend upon its effectiveness to Na^+ desorption followed by leaching to a depth below the root zone. The leachates differed significantly in displacing Na^+ from soil (Fig. 7). The Na^+ removal was higher in earlier leachates from T_1 as even leaching of salts including Na^+ occurred from it due to fallow soil. In other treatments (T_2 and T_3), due to deep root system, Sesbania could have paved the way for water movement along the roots without much contact with salts and therefore affected their less leaching. In later stages from L_4 to L_8 Na^+ removal increased over the initial leachates and also had a reverse phenomenon, i.e. concentration increased in leachates from treatments T_2 and T_3 where it was low in initial three leachates. At this stage, due to continuous submergence during rice growth, salt dissolution and movement from micro-pores to macro-pores could have caused an increase in Na^+ leaching from the soil. In the last five leachates all the treatments caused similar leaching of Na^+ . Moreover net removal of Na^+ was more with T_1 in all the cropping seasons, while remained approximately similar with other treatments (Fig. 8). It shows the non-significance of Sesbania crop for soil reclamation when high RSC water is used.

All these observations point to the enhanced activity of Na^+ with time compared to those of Ca^{2+} and Mg^{2+} , hydrolysis of which produced OH^- ions, which reacted with HCO_3^- to produce CO_3^{2-} with the passage of time. This factor is of important consideration because the presence of CO_3^{2-} ions in the system increases the pH_i of soil (Chorom and Rengasamy, 1997) and therefore, impairs its physical properties (Suarez *et al.*, 1984).

The treatment T_2 from where Sesbania was harvested caused more salts leaching compared to the others. Net salt removal was observed only during rice crop while during rest of the crops there was salt deposition in soil. Net CO_3^{2-} removal increased while that of HCO_3^- decreased through out the study period. Removal of $\text{Ca}^{2+} + \text{Mg}^{2+}$ remained less, while that of Na^+ more than that of added through irrigation water. Overall, similar amounts

of $\text{Ca}^{2+} + \text{Mg}^{2+}$ and Na^+ removal in the leachates of all the treatments indicate that a readily soluble Ca^{2+} source is necessary for better exchange of Na^+ from the adsorption sites.

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