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PJBS

ISSN 1028-8880

Pakistan Journal of Biological Sciences

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Pakistan Journal of Biological Sciences 6 (13): 1159-1162, 2003
ISSN 1028-8880

Effect of Phytoremediation on Chemical Characteristics of a Calcareous Saline-sodic Soil

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Abstract: A calcareous saline-sodic soil (pH_s= 8.26, EC_e = 9.07 dS m^{-1}, SAR = 37.90, $CaCO_3$ = 8.58%, texture = sandy clay loam) packed in concrete lysimeters was tested for phytoremediation. The treatments were: No-Sesbania (S_O), Sesbania-harvested (S_H) and Sesbania-incorporated (S_I) before flowering. Rice-wheat crop rotation was followed after Sesbania. Each crop was irrigated with high RSC water (3.1 $mmol_c$ L^{-1}) according to its water requirement and 20% additional water was allowed to infiltrate to carry down salts. Thirteen leachates were collected during the course of study. At termination of the experiment, pH_s of soil increased while EC_e and SAR decreased with all the treatments, change was more at 15-30 cm soil depth compared to that of 0-15 cm. The EC_e: SAR ratio decreased with all the treatments showing an increase in Na^+ hazard. It suggests that the use of water having high RSC could not be useful for reclamation without the use of a chemical amendment (Ca^{2+} source) and phytoremediation seems of little usefulness to improve soil under such conditions.

Key words: Sandy clay loam, high RSC water, soil depth, EC_e: SAR ratio, phytoremediation

Introduction

Effectiveness of crops for phytoremediation is a matter of controversy. Crops could ameliorate salt-affected soils through promoting their hydraulic conductivity upon introducing root channels (Lal *et al*., 1979) as well as releasing CO_2 during respiration (Robbins, 1986) and exudates (Amrhein *et al*., 1985). Deep-rooted crops are preferred over shallow rooted ones. Leguminous crops could be useful as they decrease pH of the rhizosphere through protonation (Hinsinger, 1998). Sesbania could be preferred in this case (Ahmad *et al*., 1989 and Qadir *et al.,* 1996).

A decrease in pH_s, EC_e and SAR of a saline-sodic soil have been observed by Akhtar *et al.* (1988) while growing *Leptochloa fusca* for four years. Similarly, Nye (1981) and Kumar and Abrol (1984) observed change in pH of the rooting medium. Rhoades *et al*. (1973) found that salt concentrations in drainage water and lime dissolution were the greatest when alfalfa was rapidly growing. Contrarily, Wienhold and Trooien (1995) observed an increase in EC_e and SAR in soils with fine-textured subsoil during alfalfa (*Medicago sativa* L) cropping using two water qualities (EC 1 dS m^{-1}, SAR 4 and EC 0.34 dS m^{-1}, SAR 16). Ghafoor *et al*. (1987) also observed similar results during a three-year wheat-rice cropping experiment.

Crops could cause significant alterations in soil physical properties. Several researchers have reported improvements in soil structure under pasture grasses and some other crops (Reid and Goss, 1981 and Yadav, 1975). Deterioration of structure also occurs under arable crops such as wheat, barley and soybeans (Low, 1972 and Ojeniyi, 1978). Presence of a crop can cause significant increase in bulk density of soil compared with the un-cropped soils due to soil compaction immediately around the roots (Bauder and Brock, 1992).

It is devised that proper crop rotations (depending on specific salt tolerance and ameliorative role) are essential for achieving continued improvements of saline and sodic soils besides crop varieties (Yadav, 1975). Saraswat *et al*. (1972) suggested that alternating crops such as barley and rice would accelerate the reclamation process although little work is found regarding their effect on EC_e: SAR ratio of soil. Keeping these facts in view a lysimeter study was conducted to investigate effect of Sesbania especially and crop rotations in general on chemical properties of calcareous saline-sodic soil.

Materials and Methods

A calcareous saline-sodic soil (Table 1) was packed in concrete lysimeters to prepare 35 cm soil columns for the experimental purpose. The treatments included were no Sesbania (S_O), Sesbania harvested (S_H) and Sesbania incorporated (S_I) before flowering. Rice-wheat crop rotation was followed after Sesbania. Wheat and Sesbania seeds (10 per pot) were sown, whereas thirty days old five seedlings per pot of salt-tolerant rice variety KS-282 were transplanted. Sesbania was harvested thrice in treatment S_H as fodder, while it was chopped and incorporated into the soil after growing for 45 days in S_I. Then S_I pots were irrigated to facilitate decomposition of Sesbania and after 15 days of irrigation rice seedlings were transplanted. After harvesting rice, wheat cultivar SARC-1, a salt-tolerant variety, was sown.

Each crop was irrigated with water (Table 2) according to its water requirements and 20% extra water (1.08 L irrigation^{-1}) was passed to leach down the salts. Three leachates were collected during Sesbania, five during rice and four during wheat crop. One leachate was collected at pre-planting irrigation of rice. Sesbania was grown up to flowering whereas rice and wheat were grown up to maturity. Biomass produced was recorded for all the crops at harvesting stage. Soil and water chemical analyses were carried out according to the methods described by US Salinity Lab. Staff (Richards, 1954) whereas data were analysed by using MSTATC computer package.

Results

The pH_s of soil increased with all the treatments at termination of the experiment (Table 3) over that of the initial soil level (Table 1). On an average, increase in pH_s of lower soil layer (15-30 cm) was more compared to that of the upper layer (0-15 cm), although the increase was only 5.0-6.7 % over the initial soil pH_s. The highest pH_s was observed for S_O (8.81) at 15-30 cm soil depth while the lowest for S_H (8.67) at the same depth, which were higher than the critical level of 8.5 for saline-sodic/sodic soils.

Maximum EC_e was in S_I followed by S_H and S_O (Table 3). The EC_e of 0-15 cm soil layer remained higher than that of 15-30 cm depth. The EC_e of Sesbania incorporated treatment increased by 1.2% over initial one at 0-15 cm depth while in other treatments it decreased by 3.5 to 5.1%. At lower depth, this decrease was significant and ranged from 39.7 to 56.6 %.

The SAR of soil with all the treatments although remained statistically non-significant yet it decreased over that of the initial level; decrease being greater at lower depth as compared to the upper one (Table 3). It ranged from 28.0 to 30.5 at 0-15 cm and 22.3 to 27.5 at 15-30 cm soil depth, respectively. Percent decrease in SAR ranged from 8.9 to 41.1. Moreover, EC: SAR ratio was low in 15-30 cm soil depth compared to that at 0-15 cm. It was 0.32 in upper depth of S_I followed by S_H (0.31) and S_O (0.28). At 15-30 cm depth it was the highest in S_I (0.22) followed by S_H (0.19) and S_O (0.18).

Discussion

The pH_s measures alkalinity of soils, which in turn affects dissolution/precipitation of compounds like $CaCO_3$ (Bresler *et al.*, 1982). The equilibrium between lime precipitation/dissolution exists at pH_s 8.4. The pH of the system above this point tends to induce precipitation of

Table 1: Physical and chemical characteristics of experimental soil

Characteristic	Value	Characteristic	Value
pH_s	8.26	Soluble Na^+ ($mmol_c\ L^{-1}$)	88.97
EC_e, dS m^{-1}	9.07	" K^+ (")	1.54
Soluble CO_3^{2-} ($mmol_c\ L^{-1}$)	0.00	SAR	37.90
" HCO_3^- (")	3.42	CEC ($cmol_c\ kg^{-1}$)	6.52
" Cl^- (")	38.33	Gypsum requirement (g kg^{-1})	3.21
" SO_4^{2-} (")	67.25	$CaCO_3$ (%)	8.58
" $Ca^{2+}+ Mg^{2+}$ (")	11.02	OM (?)	0.58
Textural class	Sandy clay loam		

*By difference = TSS – (CO_3^{2-} + HCO_3^- + Cl^-), ions expressed as $mmol_c\ L^{-1}$

Table 2: Characteristics of water used for irrigation

Characteristic	Value	Characteristic	Value
pH	8.59	SO_4^{2-} (By difference), $mmol_c\ L^{-1}$	2.20
EC, dS m^{-1}	0.96	$Ca^{2+}+ Mg^{2+}$, (")	2.90
CO_3^{2-}, $mmol_c\ L^{-1}$	0.30	Na^+, (")	5.01
HCO_3^-, (")	5.70	SAR	4.16
Cl^-, (")	1.40	RSC, $mmol_c\ L^{-1}$	3.10*

$CaCO_3$ 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 (Ghafoor, 1984 and Kumar and Abrol, 1984). Although pH_s is not considered a valid criteria to characterize saline-sodic or sodic soils, since its values depend upon EC_e to SAR ratios (Bohn *et al.*, 1985).

Increase in pH_s at termination of the experiment (Table 3) depicts precipitation of Ca^{2+} rather than its dissolution. It could be due to the use of high RSC irrigation water (Table 2) that counterbalanced the effect of CO_2 produced during root respiration and caused precipitation of Ca^{2+} in the system. This enhanced the Ca^{2+}–Na^+ exchange that resulted in a gradual increase in the sodicity hazard in terms of pH. The elevated activity of CO_3^{2-} in the soil system also showed a precipitation tendency of Ca^{2+} (Table 4). However, only a slight increase in pH_s could be due to precipitation of CO_3^{2+} as $CaCO_3$ that acted as buffer and resisted any remarkable change in soil pH_s in alkaline range (Deveral and Fujii, 1990).

High EC_e at 0-15 cm depth (Table 3) could be due to high root density in this depth, which caused most of the water to be used in transpiration coupled with evaporation from the surface. Only a part of applied water (Table 4) passed through upper into the lower depth to carry down the salts. Rhoades *et al.* (1973) reported that an increase in salt concentration occurred in the root zone because of continuous uptake and transpiration of water by plants leading to concentrate the soil solution leaving more salts in this zone. Moreover, soil samples were collected after soil had attained working condition and a part of salts must have trans-located from lower depth to upper depth through capillary action under fallow conditions during hot and dry month of May.

Decrease in SAR of post-experiment soil (Table 3) might

Table 3: Effect of treatments on soil chemical properties after experiment

Treatment	Depth	pH_s	EC_e dS m^{-1}	CO_3^{2-} $mmol_c$ L^{-1}	HCO_3^- $mmol_c$ L^{-1}	SAR	$CaCO_3$ %	EC: SAR Ratio
S_O	D_1	8.70 (+5.3)	8.61 (-5.1)	2.33	3.04 (-11.1)	30.54 (-8.9)	8.35 (-2.7)	0.28
	D_2	8.81 (+6.7)	3.93 (-56.6)	2.07	3.55 (+3.8)	22.27 (-41.1)	8.48 (-1.16)	0.18
S_H	D_1	8.69 (+5.3)	8.75 (-3.5)	1.17	3.50 (+3.8)	28.05 (-25.9)	8.24 (-3.9)	0.31
	D_2	8.67 (+5.0)	5.35 (-41.1)	1.70	4.80 (+40.3)	27.54 (-27.3)	8.12 (-5.4)	0.19
S_I	D_1	8.73 (+5.7)	9.18 (+1.2)	2.00	4.42 (+29.2)	28.61 (-24.5)	8.74 (+1.9)	0.32
	D_2	8.79 (+6.4)	5.47 (-39.7)	1.10	4.98 (+45.6)	25.14 (-33.7)	8.49 (-1.0)	0.22
CV, %		0.06^{NS}	1.11^{NS}	0.28^{NS}	0.68^{NS}	2.56^{NS}	--	--

Note: Data in parenthesis show percent increase (+) or decrease (-) over the initial soil level
D_1 = 0-15 cm, D_2 = 15-30 cm

Table 4: Water leached (% of added) during each crop in different treatments

	Treatment		
Crop	S_O	S_H	S_I
Sesbania	27.0	13.8	12.4
Rice	18.3	16.6	16.7
Wheat	16.2	12.2	11.9
Average	19.8	14.3	13.9

be due to valence dilution as demonstrated by Reeve and Bover (1960) for reclaiming sodic soils. The reverse is true when the soil solution is concentrated due to evapotranspiration. That is why SAR in the surface soil remained high in the study. Ghafoor *et al.* (1987) observed similar results that growing rice and wheat crops with tube well water (EC 1.6–2.2 dS m^{-1}, RSC 3.6–9.2 $mmol_c$ L^{-1}, SAR 6.6–12.2) made a saline sodic soil highly sodic without the addition of any amendment.

While considering the reclamation process EC_e: SAR ratio of soil is important. Studies show that soil dispersion occurred at a very low SAR if EC: SAR ratio is also low (McNeal and Coleman, 1966a and Shainberg *et al.*, 1981). Relatively larger and rapid decrease in EC_e compared to SAR (Table 3) in the lower depth could cause dispersion of soil colloids. Soil gleying was observed at 15-30 cm of the Sesbania treatments where EC: SAR ratio was low (0.19 and 0.18, respectively). Although the 0-15 cm soil layer of these treatments seems dry yet the lower depth remained continuously saturated to affect gleying. McNeal and Coleman (1966b) observed that HC of montmorillonite soils started decreasing from normal at EC: SAR ratio of < 0.24 when SAR was greater than 20 and pronounced decrease occurred at SAR > 25. Moreover, sandy loam soils are prone to more dispersion and illuviation of clay particles (Keren and Singer, 1988); which could block pores in the deeper layers. This caused a decrease in hydraulic conductivity and an increase in evapotranspiration from the soil surface leading to salt accumulation in the surface soil. The exact levels of SAR at which HC is appreciably reduced also vary with mineralogy, clay content and bulk density of a soil (Frenkel *et al.*, 1978). The results obtained in present study are not in line with the finding of Qadir *et al.* (1996) who reported a significant decease in EC_e and SAR of soil by growing Sesbania and Elkins (1985) who considered it by improved soil permeability due to root action perhaps they used non RSC waters and different soil series in their studies.

Post-experiment soil pH_s increased while EC_e and SAR decreased with all the treatments, decrease being more at lower soil depth (15-30 cm) compared to upper depth (0-15 cm). The EC_e: SAR ratio decreased with all the applied treatments that could cause clay illuviation. It suggests that the use of water having high RSC could not be useful for reclamation with studied crops without the use of a chemical amendment (Ca^{2+} source) and phytoremediation seems of little usefulness to improve soils under such situations.

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