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Growth and nutrient concentrations of maize in pressmud treated saline-sodic soils

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Abstract

An open-air pot experiment was conducted to investigate effects of pressmud (PM) on saline-sodic soil reclamation, mitigating the adverse effects of saline irrigation and increase of maize (Zea mays L.*) growth. Pressmud was added at the rate of 0, 5, 10 and 20 Mg ha^{-1} to pots containing 6.8 kg air dried surface (0-20 cm) soil collected from two sites. The increasing levels of PM enhanced maize plant height, shoots and roots biomass in both soils. However, the Soil 2, with initial EC and SAR of 5.43 dS m^{-1} and 18.67(m mol L^{-1})$^{1/2}$, respectively, produced comparatively more biomass at all PM levels than Soil 1 [silty-clay loam, EC = 6.22 dS m^{-1}, SAR = 20.72 (m mol L^{-1})$^{1/2}$]. The [P] in shoots was maximum at the highest PM in both the soils but the [K] increased with PM levels in Soil 1 and decreased in Soil 2 due to the dilution effect. The Soil 1 maintained several folds more [Na] in shoots and consequently lower K:Na ratio than Soil 2. The post harvest soil pH, Na, Ca+Mg and SAR in saturation extracts decreased with increasing levels of PM as compared to control. Soil 2 released more volume of leachate as compared to Soil 1 but the leachate EC and [Na] were comparable while [Ca+Mg] were relatively higher in Soil 2. The higher removal of total salts from Soil 2 resulted in lower soil pH, EC and SAR in this soil as compared to Soil 1. The increases in crop growth with each increment of PM up to 20 Mg ha^{-1} in the present study proved the benefits of PM in increasing crop yields and suggested that doses higher than 20 Mg PM ha^{-1} could be applied to the saline-sodic soils of the area to get maximum possible crop yields depending on soil and water quality.*

Key words: Pressmud, saline-sodic soil, saline-water, soil-plant-leachate, maize, NPK

Introduction

Pressmud (PM) also known as filter cake (FC) or filter mud (FM) produced by the sugar mills has been used as fertilizers and ameliorant in sodic and saline-sodic soils (Raman *et al*., 1999; Barry *et al*., 2001) and for extraction of various valuable chemicals (Partha and Sivasubramanian, 2006). It is the residue obtained from sedimentation of the suspended materials such as fiber, sugar, wax, ash, soil and other particles from the cane juice. About 3.5 Mg pressmud is produced from processing of 100 Mg sugarcane (Paturau, 1989). Nasir and Qureshi (1999) estimated that the Pakistan sugar industry produces around 1x 10^6 Mg PM each year.

The pressmud containing high amount of sulphate (SO_4), extracted by the method of sulphidation is called sulphidation pressmud cake (SPMC) and PM which contains high amount of carbonates (CO_3) is extracted by the method of carbonation (lime) or by the addition of carbon dioxide and is known as carbonated pressmud cake (CPMC). In Pakistan carbonation is the only method by which sugar is extracted from the sugar cane juice in the sugar industry and thus contains high amount of lime. The pressmud usually contains about 70% lime, 15-20% organic matter and 2-3% sugar (Muhammed and Khaliq, 1975; Khattak and Khan, 2004). The organic fraction of PM is 15-30% fiber, 5-15% crude protein, 5-15% sugar, 5-15% crude wax and fats and 10-20% ash comprising oxides of Si, Ca, P, Mg and K (Partha and Sivasubramanian, 2006). This organic matter is highly soluble and readily available to the microbial activity and so to the soil (Gaikwad *et al*., 1996; Rangaraj *et al*., 2007). Due to microbial activity more carbon dioxide is produced that may increase the solubility of lime and hence its effectiveness in reclaiming saline-sodic soils (Robbins, 1986a; Qadir *et al*., 2006).

Pressmud, though it contains Ca of low solubility mostly in calcite form, but its higher organic fraction and other nutrients may produce desirable effects in saline-sodic and sodic soils low in organic matter. The yields of various crops including maize and millet showed substantial increases with PM applications (Rangaraj *et al*., 2007; Elsayed *et al*., 2008) that were attributed to the improvement in soil physical, chemical and biological conditions (Barry *et al*., 2001). However, the degree and extent to which the sodic soil is reclaimed depends upon the type of soil, intensity of the sodicity and amount of PM added.

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Pressmud is effective in removing leachable Na, Ca and Mg under percolated condition in a silty loam soil (Patel and Singh, 1993). It improves soil nutrient availability and uptake by plants. Soil macro and micronutrients (Rangaraj *et al*., 2007) and uptake of N, P and K (Tompe and More, 1996b) increased with pressmud application. The NPK and Zn contents of rice increased when 50% of required gypsum was applied with 15 Mg ha^{-1} pressmud (Chauhan, 1995). Duran (1993) concluded that when pressmud inoculated with bacteria was allowed to decompose for 3 weeks, 3 Mg ha^{-1} of the final product replaced 25-50% of the N, P and K fertilizers usually applied to low fertility soil. Similarly, according to Orlando *et al*. (1991), addition of P was unnecessary, even potentially adverse and also uneconomical, when the soil received 100 Mg of PM ha^{-1}. This observation is based on excessively high amount of PM and the adverse effect may be associated with imbalance in plant nutrition not P per se. Singh *et al*. (2005) reported that application of 5 Mg ha^{-1} PM was as effective as 13 kg P ha^{-1} in P deficient soil.

The literature review indicates that substantial work has been done on PM utilization in saline-sodic soil but comprehensive investigation taking into account soil-plant-leachate system simulating field conditions and natural saline-water is limited. This pot experiment was conducted to investigate effectiveness of PM in reclamation of saline-sodic soils using natural saline tube-well waters and its effect on maize growth and nutrient uptake.

Materials and Methods

The pots (23 cm dia. x 22 cm depth) containing 6.8 kg air dried surface soil (0-20 cm) were amended with 0, 5, 10 and 20 Mg PM ha^{-1}. The soils were collected from two sites; S1 (33˚23́ 43″ N and 71˚22́ 14″ E) and S2 (33˚24 43″ N and 71˚22́ 29″ E) both belonged to fine loamy, mixed hyperthermic Typic Haplustepts (Soil Survey of Pakistan, 2007). The Soil 1 was silty clay loam and had higher EC (6.22 dS m^{-1}) and SAR [20.72 (m mol L^{-1})$^{1/2}$] compared to the silt loam (Soil 2) having EC and SAR of 5.43 dS m^{-1} and 18.67 (m mol L^{-1})$^{1/2}$, respectively (Table 1). Likewise, the Soil 1 had higher CEC of 13.78 cmol$_c$ kg^{-1} and gypsum requirement of 15.67 Mg ha^{-1} as compared to 8.94 cmol$_c$ kg^{-1} and 10.56 for Soil 2. Both the soils were deficient in N and P but adequate in K.

The required amount of PM was thoroughly mixed with soil and filled in pots up to 17.5 cm depth where the soil attained a bulk density of 1.18 g cm^{-3}. Coarse sands rinsed with water were placed in bottom of each pot to prevent chocking of pores made in the bottom of pots for leachate collection. The experiment was arranged in two factorial RCB design with three replications. The pots were first irrigated by ponding with tap water having EC of 0.6 dS m^{-1} with 0.2 leaching fraction (LF). When pots attained field moisture level, 10 maize (*Zea mays* L.) cv. Sarhad white seeds were sown at 3 cm depth which were then thinned to five seedlings per pot after germination. Equal amount of NPK at rate of 120:90:60 kg N:P_2O:K_2O ha^{-1} as urea, DAP and SOP were added to each pot. Successive irrigations were made with alternate natural saline ground water (Table 1) and tap water as per crop requirement. The volume of saline water used for irrigation was measured whereby each pot received 6 L of saline water collected from tube-wells used for the irrigations at experimental sites 1 and 2 (Table 1). The chemical composition of the saline waters showed that both waters had higher EC and considered unfit for longer period without proper management (US Salinity Laboratory Staff, 1954; Abrol *et al*., 1988). Water leachate from each pot was pooled separately and analyzed for pH, EC, Na, Ca+Mg and SAR. The crop was harvested after 66 d when it reached about 20 cm height. The shoots and roots were collected separately and analyzed for NPK and Na. Soil and water pH were determined by the procedures of Thomas (1996), EC (Rhoades, 1996), Na and K by flame photometry and Ca+Mg by EDTA titration (US Salinity Laboratory Staff, 1954). Soil texture was determined by the procedure of Gee and Bauder (1986), CEC, gypsum requirement (GR) and lime content as described by US Salinity Laboratory Staff (1954). Plant P, K and Na were determined after digesting the sample in 10 mL HNO_3 and 4 mL $HCLO_4$ according to the procedure described by Benton *et al*. (1991) while N was determined after digesting the sample in H_2SO_4 plus digestion mixture containing $CuSO_4$, K_2SO_4 and Se (Bremner, 1996). All the data were analyzed through Analysis of Variance (Steel and Torrie, 1980) using statistical package of MSTATC and Microsoft Excel, 2003.

Results and Discussion

Pressmud composition

Premier Sugar Mill Mardan (PSM) had higher lime (84.7%) than Khazana Sugar Mill, Peshawar (KSP) (Table 2). Both the PM sources had appreciable amount of organic matter (OM) with a range from 142.3 to 159.5 g kg^{-1}. These values were closely equal to the values reported by Muhammed and Khaliq (1975) and Khattak and Khan (2004) who recorded up to 15% organic matter and 70% lime in pressmud. Rasul *et al*. (2006) reported 3.44±1.37 % OM in PM of the Hussain Sugar Mill, Jaranwala, Faisalabad. This lower organic matter may be because of decomposition of OM as it is highly conducive to microbial activity (Gaikwad *et al*., 1996; Tompe and More, 1996a). The Fresh PM will have higher OM as compared to the old one.

The pressmud is also a good source of K and P with values of 1376 to 1267 and 27.8 to 80.8 mg kg^{-1} for PSM and KSP, respectively. As such application of pressmud at 5.0 Mg ha^{-1} will supply 711.5 to 797.5 kg OM ha^{-1} and 6.33 to 6.8 kg ha^{-1}AB-DTPA extractable K. The total K in Khazana Sugar Mill was 0.65 g 100 g^{-1} (reported elsewhere) while Rasul *et al.* (2006) reported a total K of 1.17 g 100 g^{-1} of PM suggesting that amount of K would be much higher if total K is considered. The available amounts of OM and K play important role in reclamation of saline-sodic soils by mitigating the adverse effect of Na and higher salt concentrations and enhance crop growth (Alexander, 1972). It also contained appreciable amount of Ca+Mg (9.0 to 13.9 $mmol_c$ L^{-1}) in 1:5 water suspension that would help in saline-sodic soil reclamation. Pressmud that contains appreciable amounts of N, P and K and other nutrients such as Si., S, Cu, Zn, Fe, and Mn (Hunsigi, 1993; Rasul *et al.*, 2006) is used as fertilizer in many countries (Barry *et al.*, 2001).

Table 1. Physico-chemical characteristics of soils (0-20 cm) before filling up in pots and salinity of tube-well irrigation water collected from experimental fields (Soil 1 and 2) located at Lachi, Kohat

Soil/water	pH	EC	Na	Ca+Mg	SAR	lime	SOM	N	P	K	CEC	GR	Texture
	-	dS m^{-1}	$mmol_cL^{-1}$		$(m\ mol\ L^{-1})^{1/2}$	%		mg kg^{-1}			$cmol_c$ kg^{-1}	Mg ha^{-1}	-
S1	8.24	6.22	53.8	13.5	20.72	15.3	1.15	24.2	2.1	145	13.7	15.6	SiCL
S2	8.12	5.43	42.7	10.5	18.67	14.5	1.02	32.6	2.9	135	8.94	10.4	SiL
W1	-	5.7	36.7	23.0	10.83	-	-	-	-	-	-	-	-
W2	-	5.2	30.2	23.5	8.82	-	-	-	-	-	-	-	-

S1 and S2 represent the soil collected from site 1 and 2 while W1 and W2 are the natural saline ground water used for the irrigation at respective sites
N was 1 M KCl extractable mineral N while P and K were AB-DTPA extractable
CEC stands for cation exchange capacity, GR for gypsum requirement, SiCL for silty clay loam while SiL for Silty loam
- = not determined

Table 2. Chemical characteristics of pressmud collected from Premier Sugar Mill, Mardan (PSM) and Khazana Sugar Mill, Peshawar (KSP)

Sugar Mill	pH	EC	Ca+Mg	Na	SAR	$CaCO_3$	N	P	K	OM
	-	dS m^{-1}	$mmol_cL^{-1}$		$(m\ mol\ L^{-1})^{1/2}$	%		mg kg^{-1}		%
PSM	8.7	0.95	9.0	1.01	0.48	84.7	0.38	27.8	1376	14.2
KSP	8.3	1.37	13.9	1.12	0.42	79.9	0.39	80.8	1267	15.9

pH, EC, Ca+Mg and Na were determined in 1:5 PM+water suspension
P and K are AB-DTPA extractable while N is total nitrogen

Crop growth

Analyses of variance based on two factorial [4PM x 2 soils] RCB design showed that PM and type of soil significantly ($P < 0.01$) affected plant height, shoots and roots dry weight while the interaction effect of PM x soil was non-significant on these parameters (Table 3). Plant height, shoots and roots weight increased with increasing PM levels in both soils (Table 4). When averaged across soils, plant height increased from 18.0 to 23.0 cm, dry weights of shoots from 11.92 to 23.19 and roots from 5.17 to 8.45 g pot^{-1} with 20 Mg ha^{-1} PM as compared with control. The increase in plant shoots yield was more pronounced at the highest PM (20 Mg ha^{-1}) compared to lower levels (5 and 10 Mg ha^{-1}) that might be associated to better amelioration and more supply of nutrients at higher levels of the PM. Irrespective of the PM treatments, Soil 2 produced taller plants and more biomass of maize. The overall better crop in the soil 2 could be attributed to its favourable soil texture and to lower EC_e and SAR values compared to the soil 1. Maize plants grown in Soil 2 maintained higher nutrient concentrations and total accumulation of N, P and K and higher K:Na ratios than maize plants grown in the Soil 1 (Table 6; Figure 1) which corroborate the yield data. This observation confirmed that different soils need variable amounts of PM based on soil and irrigation water properties.

The positive effect of pressmud on various crops under salt-affected soils have been reported by various researchers (Haq *et al.*, 2001; Yaduvanshi and Swarup, 2005). The increase in plant height might be associated with desirable effects of PM on soil chemical, biological and physical

Table 3. ANOVA based on two factorial [4 PM x 2 Soils] RCB design showing F-values for plant height and shoots and roots biomass of 66 d old maize crop grown in saline-sodic soils treated with different levels of PM in a pot experiment

SOV	D.F.	Plant height	Shoots weight	Roots weight
Replications	2	0.421ns	1.280ns	0.185ns
Pressmud	3	7.055*	18.951**	8.136**
Soil	1	21.699**	52.326**	37.083**
PM x Soil	3	0.105ns	0.013ns	0.083ns
CV		10.33	17.05	21.61

*, ** and ns, significant at $P < 0.05$, < 0.01 and not significant, respectively

Table 4. Plant height and shoots and roots biomass of 66 d old maize crop grown in saline-sodic soil treated with different levels of PM in a pot experiment

Pressmud	Plant height	Shoots weight	Roots weight
Mg ha^{-1}	**cm**	**g DM pot^{-1}**	
		Soil 1	
0	16.17	07.83	03.31
5	17.08	09.82	03.81
10	19.17	11.71	06.05
20	21.37	19.25	06.73
		Soil 2	
0	19.83	16.00	07.03
5	21.33	17.94	07.17
10	23.67	20.24	10.17
20	24.67	27.14	10.17
		Average across soils (n = 6, 2 soils and 3 replicates)	
0	18.00	11.92	05.17
5	19.21	13.88	05.49
10	21.42	15.98	08.11
20	23.02	23.19	08.45
LSD$_{(p < 0.5)}$	02.55	03.42	01.82
		Average across pressmud levels (n=12, 4 pressmud and 3 replicates)	
Soil 1	18.45 b	12.15 b	04.98 b
Soil 2	22.38 a	20.33 a	08.63 a

properties (Chand *et al.*, 1977). Addition of PM increases soil organic matter (SOM), moisture holding capacity (Gaikwad *et al.*, 1996) and concentrations of N, P, K, Cu, Zn, Fe and Mn (Rangaraj *et al.*, 2007; Elsayed *et al.*, 2008) that certainly promote the growth of plant. In saline-sodic soil the decrease in bulk density of soil with PM (Tompe and More, 1996a) may facilitate penetration of roots into the soil that will enhance plant growth in return. The increases in crop growth of maize with each increment of PM up to 20 Mg ha^{-1} in the present study proved the benefits of PM in increasing crop yields. The appropriate dose of PM depends on soil and water conditions. Even higher doses than 20 Mg PM ha^{-1} could be applied to the saline-sodic soils of the area to get maximum possible crop yields.

Nutrient uptake

Application of PM significantly affected [P] only in shoots and [Na] both in shoots and roots whereas the effect on [N] and [K] both in shoots and roots and P in roots was non-significant (Table 5). The two soils showed significant variations in [P], [K] and [Na] in shoots and [K] and [Na] in roots but did not induce significant variation in [N] both in shoots and roots and [P] in roots of maize (Table 5). The interaction of PM x soil was significant only for [P] and [Na] in shoots. When the data were converted to total accumulation [concentration x roots and shoots biomass], the N, P, K increased while Na:K decreased with increasing levels of PM (Figure 1).

Table 6. Concentrations of N, P, K and Na in shoots and roots of 66 d old maize crop grown in saline-sodic soils treated with different levels of PM in a pot experiment

Pressmud	N	P	K	Na	N	P	K	Na	K:Na*
Mg ha^{-1}	g kg^{-1} shoot				g kg^{-1} root				
				Soil 1					
0	6.4	1.1	16.2	8.5	4.9	0.7	4.9	18.0	1.09
5	8.1	1.3	17.4	6.9	5.4	0.7	4.6	16.6	1.41
10	7.5	1.1	17.9	7.3	5.1	0.7	4.4	14.0	1.40
20	7.2	1.4	18.2	4.9	4.8	0.8	4.4	14.1	1.92
				Soil 2					
0	8.1	1.8	23.5	1.8	6.0	0.7	8.2	13.9	3.52
5	8.3	1.4	23.2	1.5	5.2	0.7	8.7	12.3	4.19
10	8.0	1.4	22.2	1.9	5.3	0.7	8.0	12.9	3.13
20	7.0	1.5	20.3	1.6	4.7	0.7	7.2	10.3	4.18
LSD	-	-	-	0.8	-	-	-	-	-
				Average across soils (n = 6, 2 soils and 3 replicates)					
0	7.3	1.4	19.8	5.2	5.5	0.7	6.5	16.0	2.30
5	8.2	1.4	20.3	4.2	5.3	0.7	6.7	14.5	2.76
10	7.7	1.2	20.0	4.6	5.2	0.7	6.2	13.5	2.27
20	7.1	1.5	19.3	3.3	4.8	0.7	5.8	12.2	2.96
LSD	Ns	0.2	ns	0.6	-	-	-	-	-
				Average across pressmud levels (n=12, 4 pressmud and 3 replicates)					
Soil 1	7.3	1.2	17.4b	6.9	5.1	0.7	4.6b	15.7	1.47
Soil 2	7.9	1.5	22.3a	1.7	5.3	0.7	8.0a	12.4	3.72

*The value of K:Na ratio was averaged across shoots and roots

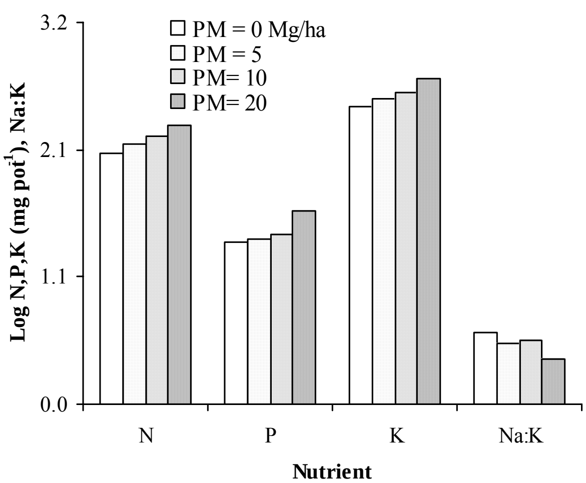

Figure 1. Total accumulation of N, P and K and Na:K ratio in 66 d old maize crop (roots+shoots) as influenced by different levels of PM under saline-sodic soil conditions being irrigated with saline waters (Values are averages of 2 soils and 3 replicates)

The concentrations of N, P and K in shoots and roots showed inconsistent pattern with increasing levels of PM (Table 6) but their total accumulation by shoots plus roots increased consistently with increasing levels of PM (Figure 1) due to increases in biomass (Table 4). The [P] was lowest in shoots in the Soil 1 and highest in Soil 2 in control but with the PM treatments it was the maximum in 20 Mg ha^{-1} in both soils. Roots showed no variations in [P] with the PM addition. The [K] increased with PM in Soil 1 and decreased in Soil 2 but its total accumulations increased pronouncedly with PM in both soils. The consistent increases in biomass and in total accumulation of N, P and K with PM treatments (Figure 1) suggested dilution effect of increased biomass on their tissue concentrations (Jarrel and Beverly, 1981).

The [Na] in shoots and roots was depressed and the ratio of K:Na was increased with PM in both soils. Comparing the two soils, soil 1 which was more saline-sodic than Soil 2 and irrigated with water of higher SAR (Table 1) resulted several folds more [Na] in shoots and consequently lower K:Na ratio. The higher total accumulation of N, P and K and ratio of K:Na in soil 2 than soil 1 explain for the better plant growth observed in Soil 2. The increase in K:Na ratio in shoots progressively increased with the shoots weight of maize (Figure 2) suggesting PM increased the beneficial effect of K on crop yield. The role of K in response to salt stress is well documented, where Na is substituted by K during ion uptake by plants (Maathuis *et al*., 1996; Fox and Cuerinot, 1998). The K:Na ratio usually is decreased with salinity (Jan *et al*., 1999) and the increases in K:Na ratio observed in the present study revealed the ameliorating effect of PM on mitigating the negative effect of Na. The higher Na levels in roots as compared to shoots in all treatments suggested that plant restricted transport of Na to upper shoots to minimize its detrimental effects (Ramoliya *et al*., 2004).

reported an increase in plant N and P concentrations with PM application particularly in the first 45 days of growth. In the present study, the increases in N concentrations with PM were masked by higher plant size causing dilution effect (Jarrell and Beverly, 1981). However, total accumulations of N, P and K which linearly increased with PM application support positive effect of PM on plant nutrition and growth.

Table 5. Analyses of variance based on two factorial [4 PM x 2 soils] RCB design showing F-values for [N], [P], [K] and [Na] in shoots and roots of 66 d old maize crop grown in saline-sodic soils treated with different levels of PM in a pot experiment

SOV	D.F.	N	P	K	Na	N	P	K	Na
		Shoot				Root			
Replications	2	1.21ns	0.76ns	0.45ns	0.37ns	0.22ns	1.20ns	0.12ns	0.48ns
Pressmud	3	2.36ns	3.04*	0.30ns	17.83**	1.99ns	0.32ns	1.01ns	6.77**
Soil	1	2.93ns	19.49**	35.75**	735.28**	1.16ns	0.62ns	84.90**	29.80**
PM x Soil	3	1.59ns	4.87*	1.87ns	13.85**	1.95ns	0.84ns	0.52ns	1.51ns
CV%		10.75	10.90	10.07	10.85	10.14	12.30	14.47	10.63

*, ** and ns, significant at P < 0.05 , < 0.01 and not significant, respectively

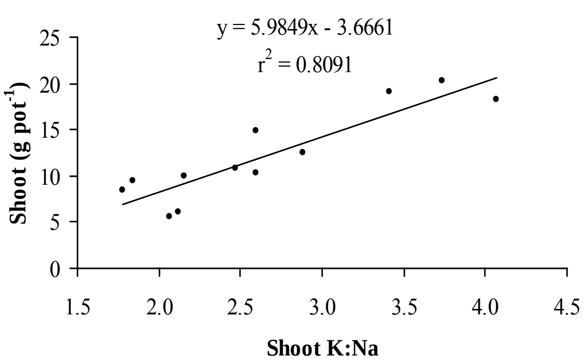

Figure 2. Relationship between shoots K:Na ratio and shoots weight of 66 d old maize plant in saline-sodic soil (soil 1) treated with different levels of PM

Improvements in soil N, P and K concentrations by PM (Singh *et al*., 2005; Rangaraj *et al*., 2007) promoted their uptake by plants (Tompe and More, 1996b; Elsayed *et al*., 2008). Orlando *et al.* (1991) reported that K utilization was improved through enhancing CEC of soil with pressmud. The decrease in adverse effect of [Na] on plant with PM application was attributed to the amelioration of saline-sodic soil with PM (Rai *et al*., 1999; Yaduvanshi and Swarup, 2005).

The PM high in organic matter and N (Table 1) could have increased the N uptake. Deshmukh *et al.* (1993)

Soil pH, EC and SAR values at the end of experiment

The results showed that PM significantly affected soil pH, Na, Ca+Mg and SAR (Table 7). The two soils showed significant variations in values of pH, EC, Na, Ca+Mg and SAR however the interactions of PM x soil for these parameters were non-significant.

The mean values of pH and SAR consistently decreased with increasing levels of PM in the post harvest soils. The Soil 1 maintained higher pH, EC_e and SAR than the Soil 2 (Table 8). The pH decreased by 0.07 and 0.06 units and EC_e increased by 0.47 and 0.28 dS m^{-1} with 20 mg ha^{-1} PM over control in soils 1 and 2, respectively.

It is important to note that the post harvest values of EC_e increased with PM while SAR dropped down from initial (prior to experiment) values of 20.72 and 18.67 to mean values of 11.68 and 2.14 (m mol $L^{-1})^{1/2}$ in soils 1 and 2, respectively. The drop in SAR was mainly due to increasing $[Ca+Mg]_e$ from initial values of 13.5 and 10.5 $mmol_c L^{-1}$ (Table 1) to an average value of 52.57 and 45.61 $mmol_c L^{-1}$ in soils 1 and 2, respectively (Table 8). The $[Na]_e$ in the Soil 1 was four times higher than the Soil 2, while $[Ca+Mg]_e$ was comparable which reduced SAR in the Soil 2 by nine times. The increases in post harvest EC_e in both soils and $[Na]_e$ in the Soil 1 were due to irrigation with saline waters having EC_{iw} of 5.7 and 5.2 dS m^{-1} and SAR 10.83 and 8.88 (m mol $L^{-1})^{1/2}$ in W1 and W2, respectively

Table 7. ANOVA based on two factorial [4 PM x 2 soils] RCB design showing F-values for pH, EC_e, Na, Ca+Mg and SAR in saturation extract of saline-sodic soil treated with different levels of PM in a 66 d pot experiment

SOV	D.F.	pH	EC_e	Na	Ca+Mg	SAR
Replications	2	0.01ns	0.602ns	0.275ns	1.758ns	0.124ns
Pressmud	3	4.62*	1.702ns	5.597**	60.966**	19.99**
Soil	1	285.4**	1159.36*	1264.32**	65.055**	1494.19**
PM x Soil	3	0.4ns	0.800ns	0.891ns	2.124ns	2.870ns
CV%		0.42	4.24	9.81	4.31	8.75

*, ** and ns, significant at P < 0.05, < 0.01 and not significant, respectively

Table 8. pH, EC_e, Na, Ca+Mg, and SAR in saturation extract of saline-sodic soils treated with different levels of PM in a 66 d pot experiment

Pressmud	pH	EC_e	Na	Ca+Mg	SAR
Mg ha^{-1}		dS m^{-1}	mmol$_c$ L^{-1}		(m mol L^{-1})$^{1/2}$
			Soil 1		
0	8.51	10.38	63.48	45.48	13.31
5	8.49	10.69	60.16	51.17	11.89
10	8.43	10.69	59.31	52.36	11.58
20	8.44	10.85	54.99	61.26	9.93
			Soil 2		
0	8.26	5.74	15.12	37.28	3.50
5	8.23	5.48	7.06	42.50	1.53
10	8.21	5.99	9.76	49.13	1.97
20	8.20	6.02	8.03	53.52	1.55
			Average across soils (n = 6, 2 soils and 3 replicates)		
0	8.39	8.06	39.30	41.38	8.41
5	8.36	8.08	33.61	46.83	6.71
10	8.32	8.34	34.53	50.75	6.78
20	8.32	8.43	31.51	57.39	5.74
$LSD_{(0.05)}$	0.04	-	4.21	2.61	0.75
			Average across pressmud levels (n=12, 4 pressmud and 3 replicates)		
Soil 1	8.47 a	10.65 a	59.48 a	52.57 a	11.68 a
Soil 2	8.23 b	5.81 b	9.99 b	45.61 b	2.14 b

(Table 1). The Soil 2 with lower CEC (8.94 cmol$_c$ kg^{-1}) compared to the Soil 1 (13.78 cmol$_c$ kg^{-1}) retained less Na on exchange complex and in soil solution and the Na released in leachate was equal to the Soil 1 (Table 10).

The increase in soils EC_e with saline irrigation is not uncommon (Qadir and Schubert, 2002; Murtaza *et al.*, 2006), however, the extent and type of induced salinity varies with soil type, amount and chemical composition of irrigation water applied to crop during the growing season and the amount of salts leached from the roots zone. Choudhary *et al*. (2004) reported an increase in soil pH, EC_e and ESP with irrigation with saline water where the harmful effects were more severe under saline-sodic irrigations. Despite some increases in post experiment soil EC with application of PM and saline irrigation, the maize shoots yield increased by 155 and 67% in soils 1 and 2, respectively, suggested that PM can be used to mitigate the adverse effect of saline-sodic/sodic irrigation. The decrease in soil pH with PM was in line with reports of Patel and Singh (1993). The decrease in soil pH with PM was possibly due to the replacement of exchangeable Na during Na-Ca exchange (Kumar and Abrol, 1984) and subsequent leaching of HCO_3 or the effect of salts on pH per se (Khattak and Jarrell, 1988). The increase in leachate pH (Table 10) with PM, also supports this view.

Leachate pH, EC, [Na], [Ca+Mg] and SAR

Application of PM significantly (P < 0.05) affected leachate pH, [Na], [Ca+Mg] and SAR but its effect on leachate volume and EC was not significant. Soil type induced significant differences in leachate volume and its

Table 9. ANOVA based on two factorial [4 PM x 2 soils] RCB design showing F-values for volume, pH, EC, [Na], [Ca+Mg] and SAR of leachate collected from pots filled with saline-sodic soils treated with different level of PM during 66 d of experiment

SOV	D.F.	Volume	pH	EC	Na	Ca+Mg	SAR
Replications	2	0.99ns	5.98**	0.41ns	0.48ns	3.17ns	0.84ns
Pressmud	3	1.06ns	10.11**	1.782ns	16.12**	9.67**	36.25**
Soil	1	47.38**	59.68**	7.90*	20.49**	47.43**	4.17ns
PM x Soil	3	1.26ns	3.35*	0.80ns	6.70*	3.22ns	5.24*
CV%		11.46	0.68	6.84	5.35	9.68	5.93

*, ** and ns, significant at $P < 0.05$, < 0.01 and not significant, respectively

Table 10. Volume, pH, EC, [Na], [Ca+Mg] and SAR of leachate collected from pots filled with saline-sodic soils treated with different levels of PM during 66 d of experiment

Pressmud	volume	pH	EC	Na	Ca+Mg	SAR
Mg ha^{-1}	mL pot^{-1}		dS m^{-1}	$mmol_c$ L^{-1}		$(m\ mol\ L^{-1})^{1/2}$
Soil 1						
0	1229	7.89	13.46	126.46	17.50	42.78
5	1169	7.74	13.60	127.30	16.70	44.00
10	1238	7.93	13.27	119.03	24.73	33.94
20	1212	7.92	14.27	111.90	25.20	31.66
Soil 2						
0	1852	7.67	14.34	124.98	26.00	34.77
5	1733	7.65	15.77	161.17	27.07	44.03
10	1550	7.68	13.97	127.75	27.43	34.52
20	1573	7.81	14.99	122.95	30.13	31.70
Average across soils (n = 6, 2 soils and 3 replicates)						
0	1541	7.78	13.90	125.72	21.75	38.77
5	1451	7.70	14.68	144.23	21.88	44.02
10	1394	7.80	13.62	123.39	26.08	34.23
20	1392	7.87	14.63	117.43	27.67	31.68
LSD $_{(0.05)}$	Ns	0.07	1.20	8.72	2.91	2.73
Average across pressmud levels (n=12, 4 pressmud and 3 replicates)						
Soil 1	1212b	7.87 a	13.65b	121.17b	21.03b	38.09a
Soil 2	1677a	7.70 b	14.76a	134.21a	27.66a	36.26b

pH, EC, [Na] and [Ca+Mg] but did not affect SAR significantly. Interactions of PM x soil were significant for pH, [Na] and SAR of leachate (Table 9).

Leachate volume was strongly influenced by soil texture whereby the Soil 2, silt loam, released leachate with a mean volume of 1677 mL as compared to 1212 mL in the Soil 1 when averaged across PM levels (Table 10). Although the PM did not significantly influence the volume of leachate but in Soil 2 it showed decreasing trend with increasing PM levels. This may be due to the reason that pots were irrigated as per crop need, depending on water holding capacity and amount of water transpired in relation to the PM treatments and plant biomass. The leachate EC and [Na] were comparable in leachate of both soils while [Ca+Mg] were relatively higher in Soil 2. If the leachate volume is taken into account, the total soluble salts Na and Ca+Mg leached from silt loam Soil 2 would be much more higher than the silty clay loam Soil 1. That is why, the soil 2 with higher leachate volume and higher ions concentrations maintained lower EC and SAR compared to the Soil 1 at the end of experiment (Table 8), which resulted in better crop growth (Table 4).

Increasing PM levels from 0 to 20 Mg ha^{-1} increased leachate pH, EC and [Ca+Mg] and decreased [Na] and SAR (Table 10). In the Soil 1, the [Na], [Ca+Mg] and SAR in the leachate were similar to each other in 0 and 5 Mg ha^{-1} treatments of PM but the [Na] and [SAR] were lower than 10 and 20 Mg ha^{-1}, suggesting superiority of 10 and 20 Mg ha^{-1} PM over lower doses in reclaiming the saline-sodic soils. In the Soil 2, [Na] in leachate collected from 5 Mg ha^{-1} PM was much more higher than all treatments which resulted in lowest $[Na]_e$ in soil (Table 8) and in plants (Table 6). When averaged across soils, compared to 0 PM, addition of 20 Mg ha^{-1} PM increased leachate pH from 7.78 to 7.87, EC from 13.90 to 14.63 dS m^{-1} and Ca+Mg from 21.75 to 27.67 $mmol_c$ L^{-1} and decreased SAR from 38.77 to 31.68 (m mol $L^{-1})^{1/2}$ (Table 10).

Addition of PM to soil has been reported to decrease soil SAR (Patel and Singh, 1993). Though PM is considered slightly soluble, almost equivalent to lime solubility (0.013 g L^{-1}) as it contains high amount of lime (> 70%) but the readily available fraction of OM that is up to 15 % (Table 1) makes it highly conducive to microbial activity (Rangaraj *et al*., 2007). This higher microbial activity releases CO_2 (Abbas and Fares, 2009) that increases the Ca solubility by the following known $CaCO_3$-HCO_3 equilibrium (Jenny, 1941; Krauskopf, 1967).

$$CO_2 (g) + H_2O = H_2CO_3 (aq) \quad \textbf{[Eq. 1]}$$

$$CaCO_3 (s) + H_2CO_3 (aq) = Ca^{2+} (aq) + 2HCO_3^- (aq) \quad \textbf{[Eq. 2]}$$

Where s, g and aq refers to solid, gaseous and aqueous phases, respectively. As explained by Khattak (1996), along with supply of Ca from the above equation, the pH of soil could also be reduced up to some extent with H^+ dissociation from HCO_3 at higher pH values. Such increases in soil [Ca] from dissolution of native lime or from the applied PM have been observed/explained by many researchers (Robbins, 1986a,b; Qadir *et al*., 2006) that ultimately improve the soil properties and increase the plant growth.

Conclusions

Application of PM mitigated the adverse effects of saline irrigation by reducing the soil SAR compared with the pre-treatment value (SAR= 18-20 (m mol $L^{-1})^{1/2}$). The increase in leachate [Ca+Mg] and decrease in SAR with increasing PM levels revealed supply of Ca from the PM suggestomg that it can be used for reclamation of saline-sodic soils. The improvement in total accumulation of N,P and K and decrease in [Na] and Na:K ratio in maize shoots and roots, explain for the observed substantial increases in plant height and shoots and roots biomass of maize plant with each increment of PM. The significant variations in plant growth, nutrient uptake and post harvest soil properties of the two soils suggested that extent of reclamation with PM depends on soil initial physico-chemical properties and quality of irrigation water.

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