Amelioration of salt affected soils in rice paddy system by application of organic and inorganic amendments

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ABSTRACT

Combined application of organic and inorganic amendments was known to play a significant role in improvement of soil properties. A field experiment was conducted to explore the effects of gypsum, farmyard manure and commercial humic acid application on the amelioration of salt affected (saline sodic) soil. During this study, soil pH, electrical conductivity, sodium adsorption ratio, responses of root length and rice paddy yield were examined. Application of gypsum with or without farm manure and commercial humic acid decreased soil pH (8.26%), electrical conductivity (from 6.35 dS/m to 2.65 dS/m) and sodium adsorption ratio (from 26.56 to 11.60), and increased root length (from 9.17 cm to 22.6 cm) and paddy yield (from 695.7 kg/ha to 1644 kg/ha). A negative but significant correlation was observed between root length and electrical conductivity, sodium adsorption ratio ($r = -0.93$; -0.94, respectively, $P \leq 0.05$), whereas positive and significant correlation with paddy yield ($r = 0.96$; $P \leq 0.05$).

Keywords: gypsum; farmyard manure; commercial humic acid; soil properties; saline sodic soil

One of the major reasons for low productivity of crops grown on salt-affected soil is the salt toxicity and poor soil properties (Gao et al. 2008). A need, therefore, exists for low-cost, efficient treatment strategies to reduce the salt toxicity of soils and to improve the soil properties. Leaching of sodium from the root zone is one of the most common and effective methods for controlling sodium accumulation in salt affected soils (Ghafoor et al. 2008). Gypsum is typically used as a source of calcium to remove the exchangeable sodium. The application of calcium amendments can improve various soil properties and act as soil modifiers that prevent the development of sodicity which is directly related to plant growth, crop productivity and crop yields (Muhammad and Khattak 2011).

The combined application of inorganic, for instance gypsum, and organic amendments, like farm manure and humic acid, improves their effectiveness for increasing soil properties (Ullah and Bhatti 2007). The decaying organic matter increases soil CO_2 concentrations and releases H^+ when it dissolves in water. The released H^+ enhances $CaCO_3$ dissolution and liberates more calcium (Ca) for sodium (Na) exchange (Ghafoor et al. 2008). Moreover, organic materials improve the soil physicochemical properties that accelerate exchange of cations on soil solids and leaching of salts from the root zone (Clark et al. 2007), hence preventing root from salt injuries and roots can grow more smoothly. The conjunctive uses of farm manure with gypsum significantly improve soil physicochemical properties of sodic soils as compared to their alone application (Ullah and Bhatti 2007).

Humic acid is one of the main constituents of organic fertilizers and is produced by the chemical and biological decomposition of organic material. Humic acid is an important constituent of soil organic matter which enhances the growth and yield of crops and improves soil physical and chemical characteristics of soil, such as aeration, permeability, water holding capacity, aggregation, availability and transportation of ions through pH buffering (Khan et al. 2012). The role of humic acid in various physiological and biochemical processes and nutrient uptake is well reported. However, its specific role in poorly structured soils is yet to be explored.

Based on the above information, we planned a short term study to examine the effect of gypsum (G), farm manure (FM) and commercial humic acid (HA) application on amelioration of salt affected (saline sodic) soil and root length and paddy yield of rice (*Oryza sativa* L.).

MATERIAL AND METHODS

Experimental site description and soil treatments. The experiment was carried out at the Graduate Experimental Research Farm, University College of Agriculture, Bahauddin Zakariya University, Multan, Pakistan. Farmyard manure used in the current study had organic matter 40% and C/N = 13. The commercial humic acid used that was obtained from the Yantai Humus Agrotech Co. Ltd. Yantai, China had composition of 50% humic acid w/w (500 g/kg). The site is situated at longitude 71°37.79'E; latitude 30°16.49'N. The soil of the experimental site was classified as hyperthermic, typic according to the USDA classification (Abid et al. 2007). Before the application of treatments, the area was leveled and ploughed with chisel plough up to 45 cm to break hard pan. The main characteristics of the experimental site are given in Table 1. Soil samples were analyzed according to the methods described by U.S. Salinity Lab. Staff, Agriculture Handbook (Richards 1954), unless otherwise described. Soil pH was determined using a combined electrode and pH meter (PB-10; Sartorius AG 21992271, Goettingen, Germany) in a 1:2.5 (soil: distilled water) mixture. Soil gypsum requirement was determined by saturated gypsum solution method. Saturated gypsum solution of known calcium concentration 100 mL was added into a bottle containing already weighed 5 g of air-dried soil. The bottle containing contents was put into mechanical shaker for 30 min. All content of bottle was filtered by filter paper. The calcium plus magnesium concentration of a suitable volume of the clear filtrate was determined. Gypsum requirement was calculated as follows:

$$\text{mmol}_+/100\text{ g} = (\text{Ca cont. of added gypsum solution in mmol}_+/\text{L} - \text{Ca + Mg cont. of filtrate in mmol}_+/\text{L}) \times 2.$$

The G, FM and HA were applied at 0 (control), 50% and 100% soil gypsum requirement (SGR); 0 (control), 10 and 20 t FM/ha and 0 (control), 24 and 48 kg HA/ha, respectively. Three amendments (each at three rates) formed a factorial experiment with three replicates for each treatment [(G: 3 × FM: 3 × HA: 3 × replication 3) = 81 treatments]. The net plot size was 300 m^2 for G, 110 m^2 FM, and 30 m^2 for HA treatments. The G was applied in the main plot; whereas FM and HA in sub-plot and sub-sub-plot, respectively. All the three amendments were incorporated in the soil 15 days before rice (*Oryza sativa* L. variety Super Basmati-385) transplanting followed with two heavy irrigations each of 15 cm with ground water [EC: 1.1 dS/m, SAR: 2.67 and residual sodium carbonate (RSC): 0.25 $(\text{mmol/L})^{1/2}$]. Composite soil samples of study site were taken (from depth 0–15 cm and 15–30 cm) before the start of experiment, and from each treatment after harvesting. Soil samples were analyzed according to the methods described by U.S. Salinity Lab. Staff, Agriculture Handbook (Richards 1954).

Plant cultivation, measurement of root length and rice paddy yield. In May, the wet bed method was adopted in the selected field for sowing the nursery. In this method the plot was puddled and pre-germinated seeds were sown. After flooding, 30-days old rice (variety Super Basmati) was transplanted in June to each plot and was grown up to maturity. The N, P, and K fertilizers (urea,

Table 1. Chemical and physical properties of experimental site

pH	EC (dS/m)	SAR	OM	$CaCO_3$	BD (t/m^3)	Clay	Silt	Sand	Texture
			(%)				(%)		
9.2	6.35	26.56	0.45	6.5	1.66	18	53	29	Silt Loam

EC – electrical conductivity of saturation extract; SAR – sodium adsorption ratio = $Na^+/[(Ca^{2+} + Mg^{2+})/2]^{1/2}$; OM – organic matter; BD – soil bulk density; all ionic concentrations in mmol/L

Table 2. Probability (P-value) for gypsum, farmyard manure, and commercial humic acid on soil properties and root length and paddy yield

Treatments	0–15 cm			15–30 cm			RL	Paddy yield
	pH	EC	SAR	pH	EC	SAR		
G	*	*	*	*	*	*	*	*
FM	*	*	*	*	*	*	*	*
HA	*	ns	*	*	*	ns	*	*
G × FM	*	ns	*	*	*	*	ns	*
G × HA	*	ns	*	ns	*	ns	ns	*
FM × HA	ns	ns	*	*	ns	ns	ns	*
G × FM × HA	ns	ns	ns	ns	ns	ns	ns	*

EC – electrical conductivity of saturation extract (dS/m); SAR – sodium adsorption ratio; G – gypsum (soil gypsum requirement); FM – farmyard manure (t/ha); HA – commercial humic acid (kg/ha); ns – non-significant; $^*P \leq 0.05$ (n = 3)

single super phosphate and potassium sulphate, respectively) were applied at the rate of 120, 60 and 60 kg/ha, respectively. The N was split into two equal doses. First half was applied at nursery transplanting and the remaining half was applied at the time of panicle initiation. Water regime was managed throughout the rice growing season. First month after rice transplanting, flooding condition was maintained (3 cm to 4 cm) in the plots. After that flooding and leaching rotation of irrigation was applied in the field until crop harvesting. Irrigation was stopped 15 days before harvesting of crop. The crop was protected against insect with Lambda cyhalothrin insecticide (2.5% EC) at 123 mL/ha.

The crop was harvested at full maturity (in November) and remained spread for one day in the field to lose the extra moisture contents. The crop was threshed manually striking with hard woody hedge/slap. After threshing the grains were collected from each plot separately. The yield was recorded and grains were stored in plastic bags. The sampling of root was done according to the method described by Tennant (1975). Soil adhering to the root system was washed with tap water and the roots were collected and refrigerated before root length (RL) measurement (Tennant 1975).

Statistical analysis. The data obtained from the experiment was analyzed statistically following appropriate methods. The analysis of variance technique (ANOVA) and the least significant difference (*LSD*) test were applied to differentiate the treatments effects using the MSTAT package. Spearman's correlation between root length and soil properties was also carried out.

RESULTS AND DISCUSSION

Depending on the different applied rates of organic and inorganic amendments, different responses in terms of changes of soil pH, electrical conductivity, sodium adsorption ratio, root growth and paddy yield were observed.

Soil pH. The soil pH was significantly ($P \leq 0.05$) affected by the interaction G, FM, HA, G × FM and G × HA in 0–15 cm soil depth, whereas for 15–30 cm soil depth the interaction of G, FM, HA, G × FM and FM × HA. However, there was a non-significant ($P \leq 0.05$) effect of FM × HA and G × FM × HA interaction on pH of 0–15 cm soil depth, while for 15–30 cm soil depth the interaction of G × HA and G × FM × HA was non-significant (Table 2). The highest decrease of 8.26% in pH was observed with 100% SGR + 20 t FM/ha + 48 kg HA/ha compared to the control treatment (Table 3). The pH decreased with increasing rates of G, FM, and HA. Niazi et al. (2001) also reported a decrease in pH of clay loam soil with G at 100% SGR and 20 t FM/ha. Our results are also in agreement with Haynes and Naidu (1998). However, some researchers demonstrated that application of manure increased the soil pH (Ondrášek and Čunderlík 2008). Lafayette et al. (2009) reported that gypsum did not cause any significant change on the soil pH in acidic soils. The decrease in pH may probably be due to an increase of organic carbon (OC) concentration and improved biological activity after application of organic manure. Decomposition of soil organic matter produces carbonic acid via CO_2 dissolution in water, which could decrease the pH towards neutral point (Niazi et al. 2001).

Electrical conductivity. There was a significant ($P \leq 0.05$) effect of G and FM on EC, whereas HA, G × FM, G × HA, FM × HA and G × FM × HA did not significantly affect the EC for 0–15 cm depth (Table 1). For 15–30 cm depth, the effect of G, FM, HA, G × FM, G × HA was significant ($P \leq 0.05$) on EC. Data in Figure 1 show a maximum decrease in EC (2.65 dS/m = 58%) with G alone at 100% SGR compared with control treatment (6.35 dS/m) for 0–15 cm soil depth. However EC with G treatments

Table 3. Impact of gypsum, farm manure and commercial humic acid on soil pH

HA (kg/ha)	Farm manure (t/ha)								
	0	10	20	0	10	20	0	10	20
	0% SGR			50% SGR			100% SGR		
	0–15 cm								
0	9.20^{a}	9.16^{a}	8.93^{bc}	8.84^{cd}	8.84^{de}	8.81^{defg}	8.50^{i}	8.52^{i}	8.45^{i}
24	9.17^{a}	9.13^{a}	8.96^{b}	8.83^{def}	8.75^{efgh}	8.83^{defg}	8.53^{i}	8.49^{i}	8.45^{i}
48	9.17^{a}	9.00^{b}	8.78^{defg}	8.75^{fgh}	8.74^{gh}	8.68^{h}	8.52^{i}	8.46^{i}	8.44^{i}
	15–30 cm								
0	9.20^{a}	9.19^{a}	8.96^{b}	8.87^{c}	8.82^{cd}	8.84^{c}	8.55^{f}	8.53^{fg}	8.52^{fg}
24	9.20^{a}	9.15^{a}	8.96^{b}	8.78^{de}	8.82^{cd}	8.84^{cd}	8.54^{fg}	8.53^{fg}	8.53^{fg}
48	9.19^{a}	9.01^{b}	8.88^{c}	8.82^{cd}	8.75^{e}	8.75^{e}	8.53^{fg}	8.49^{g}	8.47^{h}

HA – commercial humic acid; SGR – soil gypsum requirement. Means having the same letters are statistically non-significant at $P \leq 0.05$ ($n = 3$)

at 15–30 cm depths was higher than 0–15 cm. The role of G in salt leaching as a result of flocculation of the dispersed soil matrix and improved hydraulic conductivity (Qadir et al. 2002, Muhammad and Khattak 2011). Previous studies also demonstrated that G with other amendments is effective to decrease the EC of salt affected soils (Zia et al. 2007). In addition, rice is grown under submerged conditions where a high leaching fraction is implicitly achieved, which helps to leach down soluble salts up to a greater extent, and hence decrease EC (Ghafoor et al. 2008).

Sodium adsorption ratio. Gypsum application is proven to decrease SAR of salt affected soils but its effect could be enhanced with application of organic amendments (Muhammad and Khattak 2011). Gypsum, FM, HA, G × FM, G × HA, FM × HA treatments had a significant ($P \leq 0.05$) effect on sodium adsorption ratio for 0–15 cm depth, whereas the effect of G × FM × HA interaction was non-significant. Similarly, G, FM, and G × FM had a significant effect on SAR for 15–30 cm depth (Table 2). Before beginning of study, soil had the SAR value much higher than 13, a limit for sodic soil as described by US Salinity Lab Staff, Agriculture Handbook (Richards 1954). Gypsum alone decreased the SAR by 47% (13.9 vs. 26.56) compared with the control plot (Figure 2), which is above critical level as described by US Salinity Lab. However, the lowest SAR (11.6) was observed in gypsum and FM combination treatment after harvest of rice crop, followed by other gypsum based treatments (Figure 2). Gypsum alone was more effective in lowering SAR than FM and HA amendments, but less effective when it combined with FM especially at 0–15 cm depth. The SAR values were higher for 15–30 cm compared to 0–15 cm soil depth, indicating the migration of exchangeable Na^{+} from the top soil layer and accumulated in the lower depth with application of G and FM (Wu and Wang 2012). The anaerobic conditions during rice growth with FM and HA also provided higher CO_2, which could increase the amount of soluble Ca^{2+} for soil reclamation (Ali and Abbas 2003, Muhammad and Khattak 2011).

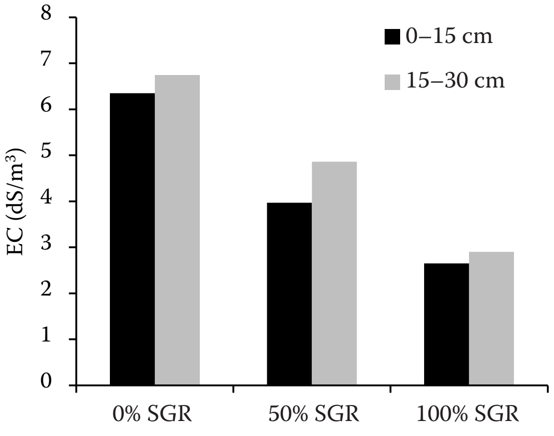

Figure 1. Effect of soil gypsum requirement (SGR) on electrical conductivity (EC) of soil ($n = 3$)

Root length. The significant ($P \leq 0.05$) effect of G, FM and HA was observed on root length, whereas the interactive effects of G × FM, G × HA, FM × HA and G × FM × HA was non-significant

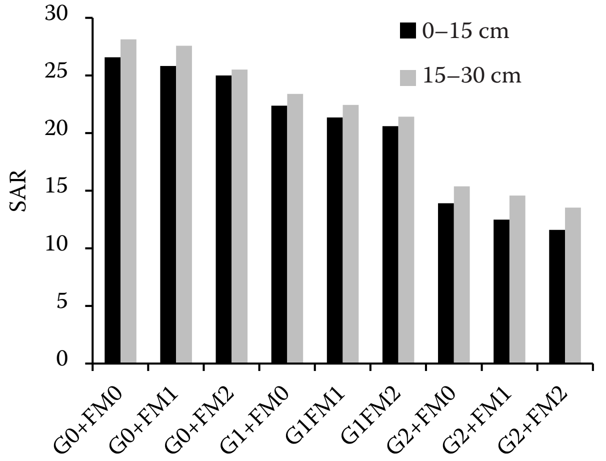

Figure 2. Effect of gypsum (G) and farmyard manure (FM) on sodium adsorption ratio (SAR). FM0 – 0 t FM/ha; FM1 – 10 t FM/ha; FM2 – 20 t FM/ha; G0 – 0%; G1 – 50% and G2 – 100% soil gypsum requirement (n = 3)

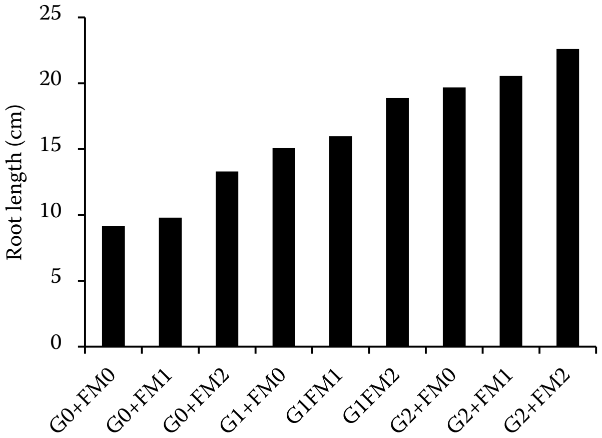

Figure 3. Effect of gypsum (G) and farmyard manure (FM) interaction on root length. FM0 – farm manure 0 t/ha; FM1 – 10 t FM/ha; FM2 – 20 t FM/ha; G0 – 0%; G2 – 50% and G3 – 100% soil gypsum requirement (n = 3)

(Table 2). Although, RL did not significantly differ among treatments, the trend was similar and there was an increase in the length of RL at higher rates of G, FM, HA and their interaction than lower rates. However, the highest increase (22.6 cm) in the root length of rice (*Oryza sativa*) was observed in the 100% SGR + 20 t FM/ha treatment as compared to all other treatments of the current study. Therefore, combined application of G with FM was more effective as compared to G with HA and G with FM and HA (Figure 3). Several previous studies revealed that organic amendments can improve root growth of crops. This may be associated with the enhancement of biological activities in crop rhizosphere by amino acid and some physiological active substances in the organic fertilizers such as humic acid (Yang et al. 2004). The farm manure and HA caused an increase in the organic carbon content in the soil (Gondek and Filipek-Mazur 2005) and positively affected the root growth of rice crop. The incorporation of organic manure into soil can bring beneficial effects on crop root growth by improving physical and chemical environments of rhizosphere (Sidiras et al. 2002). A decrease in soil organic matter content can cause a decrease of root growth (Önemli 2004).

Paddy yield. A significant ($P \leq 0.05$) impact of G, FM, HA, G × FM, G × HA, FM × HA, and G × FM × HA on paddy yield was observed (Table 2). There was higher paddy yield with higher rates of G, FM and HA compared with low rates and the control plot (Table 4). Paddy yield (1644 kg/ha) was higher from 100% SGR + 20 t FM/ha + 48 kg HA/ha treatment compared to control (695.7 kg/ha). This was 58% increase in paddy yield relative to the control plot. Application of G, FM and HA helped in improvement of soil properties and leaching of

Table 4. Impact of gypsum, farm manure and humic acid on paddy yield (kg/ha)

HA (kg/ha)	Farm manure (t/ha)								
	0	10	20	0	10	20	0	10	20
	0% SGR			50% SGR			100% SGR		
0	695.7^{m}	697.7^{m}	808.3^{l}	1002.3^{k}	1062.3^{i}	1117.3^{h}	1346.3^{e}	1544.0^{c}	1628.3^{a}
24	696.7^{m}	696.6^{m}	827.0^{l}	1024.6^{j}	1075.7^{i}	1180.3^{g}	1405.7^{d}	1587.0^{b}	1632.7^{a}
48	698.0^{m}	706.6^{m}	823.6^{l}	1062.0^{i}	1098.0^{h}	1227.7^{f}	1546.0^{c}	1590.7^{c}	1644.0^{a}

HA – commercial humic acid; SGR – soil gypsum requirement. Means having the same letters are statistically non-significant at $P \leq 0.05$ (n = 3)

Table 5. Spearman's rank correlation among variables pH, electrical conductivity (EC), sodium adsorption ratio (SAR), paddy yield and root length (RL)

Properties	pH	EC	SAR	Paddy yield	RL
pH	1.00	–	–	–	–
EC	0.91	1.00	–	–	–
SAR	0.94	0.94	1.00	–	–
Paddy yield	–0.94	–0.95	–0.98	1.00	–
RL	–0.91	–0.93	–0.94	0.96	1.00

excessive ions to the deeper layer. Thus, concentration of salts was decreased in the upper layers which favored the growth of plant and ultimately a significant increase in rice grain was observed (Ghafoor et al. 2008). A recent study demonstrated that there was a statistically significant correlation ($P \leq 0.01$) between the grain yields and organic C content of soil after application of organic amendments to soil (Mikanová et al. 2012). The combined application of farm manure and mineral fertilizer could induce an increase in the humus content, nitrogen, and available phosphorus and potassium levels (Gondek and Filipek-Mazur 2005, Verma et al. 2012). As a result of an increase in nutrient level of soil, a significant effect ($P \leq 0.05$) on yield per hectare was determined (Milosevic and Milosevic 2009). Our results are also in agreement with Matula and Pechová (2007). Organic amendments increased the yields of oat as compared to mineral fertilizers (Hanč et al. 2008). However, Ćustić et al. (2003) observed no significant differences in yield after application of stable manure and mineral fertilizer to soil.

Relationship between root length and soil characteristics. Spearman's correlation showed different relationships between RL and soil properties (Table 5). There was a negative but significant ($P \leq 0.05$) correlation between RL and soil characteristics (pH, EC and SAR), indicating that RL decreased with an increase of salinity and sodicity. The correlation between RL and paddy yield was positive and significant. This shows that an increase in RL caused the higher paddy yield. In addition to supplying nutrients, the applied manure was known to have beneficial effects on soil physical properties (Haynes and Naidu 1998).

The current study concludes that application of inorganic amendments along with organic amendments is a strong and helpful strategy for reclamation of salt affected soils and consequently increases in crop yield. Application of gypsum with organic amendments is more likely to be beneficial to improve the soil properties of salt affected soils and sustaining crop yields. Our study also revealed that farm manure as compared to commercial humic acid has better and significant effects in improving soil physical and chemical properties. The findings of the current study may be applicable in other types of soil and climatic conditions but the improvement of soil properties and their amelioration with amendments and effects on root length and rice yield may vary and should be monitored.

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