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Original Article

Effectiveness of compost and gypsum for amelioration of saline sodic soil in rice wheat cropping system

Muhammad Anwar Zaka[1], Khalil Ahmed[1]*, Hafeezullah Rafa[1], Muhammad Sarfraz[1], Helge Schmeisk[2]
[1]Soil Salinity Research Institute, Pindi Bhattian, Punjab, Pakistan
[2]Faculty of Organic Agriculture Sciences, University of Kassel, Germany

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*Corresponding author email:
khalilahmeduaf@gmail.com

Abstract
A lot of crop residues, kitchen wastes and tree leaves are wasted annually. These materials can be composted and used for improvement of soil health. The possibility of using compost in reclamation of salt affected soil was studied with the treatments *i.e.* control (no amendment), gypsum @ 100 % GR, compost 20 t ha^{-1}, gypsum 50 @ % GR+ compost @ 20 t ha^{-1}, gypsum 50 @ % GR+ compost @ 10 t ha^{-1}, gypsum 25 @ % GR+ compost @ 20 t ha^{-1} and gypsum @ 25 % GR+ compost @ 10 t ha^{-1} in rice-wheat rotation at farmer field in Haveli Karimdad, Pindi Bhattian district Hafizabad, Punjab, Pakistan. The selected field was prepared and leveled. The design of the experiment was randomized complete block (RCBD) with four replications having the plot size of 8m x 6m. The prepared compost was applied and incorporated according to the treatments plan thirty days before transplanting of rice. Uniform cultural practices were applied to all the treatments. Rice-wheat crop rotation was used. The data for paddy yield of rice and wheat grain were recorded at maturity. The results showed that gypsum application @ 50% GR + compost @ 20 t ha^{-1} remained statistically at par with gypsum application @ 100% GR for producing biomass, paddy and wheat grain yield. However other treatments remained inferior but significantly better than control. The pH_s and SAR were decreased significantly after harvesting of 2nd rice crop in two treatments *i.e.* gypsum application @ 100% GR and gypsum @ 50% GR+ compost @ 20 t ha^{-1}. The EC_e was reduced to less than 4 dS m^{-1} in all the treatments except control after 1st rice crop. The physical properties of soil such as bulk density, porosity and hydraulic conductivity were also improved with passage of time. Results of current study suggested that salt affected soil can rehabilitate to their original potential if gypsum is applied at the full rate (100% GR) alone or decrease its quantity 25 or 50% by combining it with compost at rate of 20 or 10 t ha^{-1}.

Keywords: Saline sodic soil, Gypsum, Compost, Reclamation, Rice-wheat rotation

Introduction

The amelioration of sodic or saline sodic soils is a very important for obtaining reasonable yield from salt affected soils. Such soils with low fertility and poor physical properties, adversely affect the growth and yield of most crops (Grattan and Grieve 1999). The worldwide occurrence of such soils urge the need for cost-effective, efficient and environmentally acceptable management practices (Abbas et al., 2016). More than half of the rice cultivated area (~ 1.0 mha) in the Punjab, Pakistan is subjected to salinity, causing 30-70% paddy yield reduction (FAO, 2011; NFDC, 2012)

Application of organic matter is considered as one of effective strategy for reclamation of salt affected soils and increasing crop growth (Ahmad et al., 2014).
Tejada et al. (2006) in a long-term study of five year reported steady removal of salt and Na^+ with noticeable increased in plant growth and soil porosity with the addition of compost. In a study conducted by Boateng et al. (2006) poultry manure and compost stimulated the removal of Na^+ from root zone, reduced EC, improved soil aggregate stability and water-holding capacity. Integrated use of gypsum and organic material has been successfully used to improve the physical and chemical properties of salt affected soils and the effect was more pronounced as compared to sole application of gypsum (Vance et al., 1998; Wright et al., 2007).
Use of gypsum with organic material like water hyacinth compost and rice straw compost showed that integrated use of these treatments was more efficient in decreasing the EC_e, pH, SAR, and ESP of clay saline-sodic soils as compared to their individual use. Rice straw compost was more effective in diminishing EC, pH, SAR and ESP than water hyacinth compost (Mikanova et al., 2012; Shaaban et al., 2013; Abdel-Fattah 2012). The most efficient and economical methods for reclamation of salt affected soil is addition of Ca^{2+} source which change the ionic composition of soil solution and replace the Na from exchange site which is leached down out of soil profile (Ghafoor et al., 2008).
Physical characteristic of salt affected soil *e.g.* water permeability, porosity, void ratio, bulk density, were significantly improved with chemical amendments and FYM @10 t ha^{-1} subsequently rice and wheat yields was also increased (Hussain et al., 2001). Similarly other organic materials *e.g.* wheat straw, rice husk, rice straw and chopped grass also has positive effect on chemical and physical properties of saline sodic soil (Ould Ahmed et al., 2010; Akhtar et al., 2014; Lakhdar, et al., 2009). Soil organic matter increases cation exchange capacity (CEC), promotes granulation and is responsible for up to 90% adsorbing power of soil (Diacono and Montemurro, 2015). During decomposition of organic matter, mineral nutrients such as Ca, Mg and K are released and become available for plants (Awaad et al., 2009; Mahmood et al., 2015). Compost is not only good alternative of organic matter in soil but also play very vital role for amelioration of saline sodic oils. Organic acid released during decomposition can improve the physical properties of such soils, which have been deteriorated to such an extent that passage of water and air become extremely difficult. The water stands on the surface of soils for weeks long. The plants when grown under such conditions ultimately die due to suffocation/deficiency of air for root respiration. So, compost can be a good organic amendment for reclamation of salt affected soils. The present study was conducted with the following objectives:
1-To determine the feasibility of compost as a reclaiming agent for saline sodic soil.
2- Monitoring the gradual improvement in soil health.

Material and Methods

The research work was conducted in the farmer' s field at Havaily Karim dad, Pindi Bhattian (Punjab), for two consecutive years in rice-wheat cropping system to devise the effective technology for reclamation of salt affected soils with compost, gypsum and their different combinations. A saline sodic field was selected and composite soil samples were collected from upper (0-15 cm) and lower (15-30 cm) soil depth before starting the experiment. Soil samples were air dried, passed through 2 mm sieve and analyzed for physio- chemical parameters (Table-1). The selected field was prepared and leveled. The design of the experiment was randomized complete block (RCBD) with four replications having the plot size of 8m x 6m. Compost was prepared using residues of crops (rice and wheat) and wastes (tree leaves, grasses and kitchen waste).They were piled in the pit (How to build a compost www.exsands. com/ Gardening/ how to buildac).The treatments tested were control (no amendment), gypsum @ 100 % GR, compost 20 t ha^{-1}, gypsum 50 @ % GR+ compost @ 20 t ha^{-1}, gypsum 50 @ % GR+ compost @ 10 t ha^{-1}, gypsum 25 @ % GR+ compost @ 20 t ha^{-1} and gypsum @ 25 % GR+ compost @ 10 t ha^{-1}.
The prepared compost was applied and incorporated according to the treatments 30 days before transplanting of rice. Field was irrigated with canal water (EC_{iw} = 0.23 dS m^{-1}, RSC= nil and SAR = 0.14 $(mmol\ L^{-1})^{1/2}$ as and when needed. Gypsum was applied in their respective treatments and leaching was provided for 15 days before transplanting of rice. The soil samples were collected at 0-15 and 15-30 cm depths before sowing of each crop for analysis of pH, EC_e, SAR, bulk density, hydraulic conductivity and % pore space according to U.S. Salinity Laboratory Staff (1954) and bulk density (d_b) by (Klute,1986).

Table-1 Soil analysis of the experimental site

Determinations	Units	0-15 cm	15-30 cm
pH_s	-	9.3	9.3
EC_e	dSm^{-1}	8.52	7.80
SAR	(m mol L-1) ½	96.2	104.8
Sand	%	62	-
silt	%	20	-
Clay	%	18	-
Textural Class	-	Sandy Clay Loam	
Hydraulic Conductivity	cm hr^{-1}	0.037	
Bulk Density	M gm^{-3}	1.72	-
Gypsum Requirement	Tons $acre^{-1}$	3.7	-

Table-2 Chemical composition of compost

Determinations	Units	
pH	-	7.93
Ece	dSm^{-1}	6.83
Organic-C	%	30.56
Total-N	%	2.63
C/N ratio	-	11.62
P	Ppm	12.6
K	Ppm	9.7

Rice and wheat crops were grown. Recommended dose of fertilizer (110-90-70 NPK Kg ha^{-1}) was used to grow rice crop. The concentration of nitrogen, phosphorus and potash of compost was also considered in calculations of fertilizers. Half of the recommended nitrogen (N) and full dose of P (P_2O_5) and K (K_20) were applied at transplanting while the remaining half dose of N was applied 30 days after transplanting (DAT). Macheiti weedicide was applied seven days after transplanting of rice seedling to control the weed growth. Padan insecticide was applied 45 DAT to control the attack of stem borer. Sundaphos insecticide was sprayed to cover the risk of rice leaf roller and ensure the good yield of rice. Zinc sulphate was applied to avoid the deficiency of Zn. At maturity crop was harvested and paddy yield data were recorded.

After harvesting of rice, wheat seed was treated with Benlate to avoid the effect of fungal disease and wheat was sown with single row drill in the same layout plan in all the treatments without addition of any amendment. Fertilizer was added to wheat according to recommended dose (120-90-70 NPK Kg ha^{-1}). Single super phosphate, potassium sulphate and urea were applied as a source of P, K, and N. Full dose of P, K and half of the recommended dose of N was applied at sowing while remaining N was applied at first irrigation. Pumasuper and Isoprotone weedicides were applied 30 days after sowing of wheat. At maturity, paddy and grain yield of wheat data were recorded. Subsequent 2nd rice and wheat crop were also sown in same layout with above mentioned all agronomical and/cultural practices. After harvest of each crop soil samples were collected from 0-15 cm and 15-30 cm soil depths and were analyzed for physico-chemical properties. All the data were processed for statistical analysis using Duncan's Multiple Range Test (DMR Test, 1955).

Results and Discussion

Effect of compost and gypsum on soil properties

1- Soil Electrical Conductivity (EC_e)

Soil EC_e is very important parameter that indicates an overall estimate of soluble salts. It is of prime importance in water relation of plants as well as nutrient uptake. If the quantity of soluble salts in soil increases over the critical limit that is specific for a plant (threshold), water and nutrients uptake suffers very badly; rather plants may die under environment of very high osmotic pressure (Munns et al., 2006). Original EC_e of the soil of experimental site was 8.52 dS m^{-1} that reduced to lesser than 3.0 dS m^{-1} (critical limit 4.0 dS m^{-1}) due to gypsum application @ 100 % GR or compost @ 20 t ha^{-1} alone or their combinations at reduced rates. The EC_e in control plots was 5.9 dS m^{-1} even after two years (Fig-1). The recorded reduction was 62% (T_4 gypsum 50 % GR+ compost 20 t ha^{-1}) to 51% (T_5 gypsum 50% GR + compost 10 t ha^{-1}) over control (Table-3). The application of amendments (gypsum or compost) and subsequent cropping may have improved physical properties that eased leaching of salts in to lower profile. Increase in EC_e of 15-30 cm depth during first year supported this view point also. Even the salt leached down from this layer during the last year. Sarwar (2005) also obtained a reduction in soil EC_e of saline sodic soil with the application of compost. Efficiency of gypsum in decreasing soil EC_e in the long run was recorded by Chaudhry et al. (1990) as well and reported that removal of salts was more in upper layer than that from 30-60 cm soil layer.

Soil pH

Soil pH is the sole property that indicates overall impact of many factors like parent material constitution, dominance of particular ion, natural climate, drainage, quality of irrigation water and main activities related to soil management. Initial pH of experimental soil was 9.3 that reduced significantly with application of gypsum or compost alone or with their different combinations (Figure 2). Maximum reduction of 13.33 % was due to application of gypsum @ 50 % GR + compost @ 20 t ha^{-1} whereas minimum reduction was recorded when gypsum was reduced to 25 % GR along with compost 10 t ha^{-1} (Table 3). The high pH of saline sodic soil is the result of sodium dominance (ESP >15 %) on the clay micelle. Application of Ca as gypsum (Ca $SO_4.2H_2O$) replaced the Na from clay complex that was pushed into soil solution and subsequently leached down into lower profile. Similarly organic acids released during decomposition of compost performed the same role. The other possibility in calcareous soil is dissolution of $CaCO_3$ with the reaction of organic acids released by plant roots (Abbas et al., 2016). The released Ca ultimately behaved like gypsum. Increase in dealkanized of soil depth from 12.5 to 32.5 cm was obtained during two years after application of chicken manure, water hyacinth, FYM and dry sludge (Rehman et al. 1996; Abd El-Rheem et al., 2016). Addition of organic matter in saline sodic soils would help to chelate Ca^{2+} and decrease soil pH leading to increase in solubility of $CaCO_3$ (Ghafoor et al., 2008; Zia-ur-Rehman et al., 2016). Wong et al (2009) determined that addition of organic materials increased soil microbial biomass while added gypsum decrease pH. Our results are supported by previous findings that application of gypsum with organic and inorganic amendments decreased the soil salinity and sodicity indicators (Nan et al., 2016; Qadir et al., 2017).

Soil sodium adsorption ratio (SAR)

Soil SAR is very important criteria to classify the soil as sodic or non-sodic. The degree of sodicity is also deciding yardstick about growth and success of crops in the sodic environment. The magnitude of this parameter at the initiation of the experiment was very high (96.0 m mol L^{-1}) $^{1/2}$ and indicated that no crop could be successful unless it was reduced substantially. The devised strategies were found to be effective in this regard. Soil SAR was reduced to half of its original level or even lesser following the application of amendments (gypsum or compost) and subsequent leaching with water. Thus, the soil environment was converted into favorable one with respect to rice and wheat crops. The growing of crops helped to continue positive effects of amendments due to root activity and crop residues decomposition. Ultimately, the soil SAR varied from 11.5 to18.0 (m mol L^{-1}) $^{1/2}$ in different treatments as against the value of 50.9 (m mol L^{-1}) $^{1/2}$ in control plots after two years (Figure 3). Thus, the treatments of the experiment were successful to bring this parameter in safe limits or nearer to it. The highest decrease (77.4%) in SAR was recorded with gypsum @ 50% GR + compost @ 20 t ha^{-1} (Table 3).

Soil SAR depends upon relative quantities of Na and Ca + Mg in the soil solution and clay complex. The increase in Ca^{2+} occurred due to direct application of gypsum or release during $CaCO_3$ dissolution through reaction with organic acids formed by decomposition of compost. This Ca^{2+} replaced Na^+ on exchange sites that was leached down during continuous irrigation. So, there was net increase in Ca and Mg content and very high decrease in the amount of Na from the soil solution that all resulted in significant reduction of SAR. Similar findings were also recorded by earlier researchers (Wright et al., 2008; El-Sanat et al., 2017). Furthermore, more positive effect on soil properties was noted when leaching began with gypsum and compost (Ashtar and ELEtreiby, 2006).

Bulk density (BD) and percent pore space

Bulk density of soil depends upon soil texture, structure, clay type, clay content, drainage and organic matter content of the soil. The effect of soil EC_e, pH and SAR is directly translated into increase or decrease of this soil characteristic. The higher value of BD indicates harder and less porous soil. Generally, BD of saline sodic soil with dominancy of Na^+ are higher than equivalent normal soil. Bulk density of the experimental soil was very high with the value of 1.72 Mg m^{-3} indicating its dispersed condition due to very high SAR and pH. Improvement of this soil would only be possible if its BD values decrease along with soil pH, EC_e and SAR. It has been observed that a significant decrease in this soil property occurred in two years in all the treatments of the experiment (Figure 4). Resultantly, the porosity of the soil also increased (Table 4). A decrease of 7.69 to 12.8% in BD was recorded in different treatments of the experiment (Table 3). The most effective treatment was gypsum @ 50% GR + compost @ 20 t ha^{-1}. The decrease in soil pH and SAR decreased soil dispersion, increase soil porosity and resultant net reduction in BD was recorded. It was explained that amendments improved soil physical condition by eliminating Na^+ dominance that caused undesirable changes in sodic soils through decrease in EC_e and SAR ratio. An improvement in soil porosity through gypsum application was also obtained (Shainberg et al., 1989). The combined application of amendments in lesser quantity might be a good strategy in this regard (Hussain et al., 2001). Similarly decreased BD values with the use of calcium sources (Peters and Kelling, 2002) and compost (Wang et al., 2016) were previously reported.

Hydraulic conductivity (HC)

Hydraulic conductivity plays its role in water relation of soil and plants in general but is of prime importance in soil reclamation process. Because if water cannot permeable in to lower profile it will not take salt with it. The initial soil data presented very low value of HC. It was as low as 0.073 cm hr^{-1}. However, it increased manifold during two years with a maximum of 0.878 cm hr^{-1} (485% increase) when gypsum 50% GR + compost 20 t ha^{-1} were applied in combination (Figure 5). It might be due to reduction in SAR which resultantly decrease soil dispersion and encouraged coagulation of soil particles. The increase in pore spaces caused by aggregation increased the HC (Kauraw and Verma, 1982). Hence, a clear and highly significant increase in yield was recorded after application of amendments and subsequent cropping. Various research workers have reported an appreciable increase in HC due to application of inorganic or organic amendments, cultural practices and growing of crops (Qadir and Schubert, 2002; Carter et al., 2004; Evanylo et al., 2008).

Effect of gypsum and compost on paddy and wheat grain yield

Crops yields are ultimate result of soil factors, irrigation water quality, climatic conditions and crop varieties. At the first step, appropriate soil physical and chemical conditions are required for seed emergence and seedling establishment; subsequently the growth of the plant depends upon the conditions of the rhizosphere that are being faced by the plant. A good and healthy growth is translated into higher yields, when reclamation process is started in barren salt affected soils. The germination, establishment of seedlings, tillering, growth and yield all will depend upon magnitude of the reclamation occurred before sowing/transplantation of seedlings/seed or during the growth of crops. The quantum of reclamation depends on methods adopted for reclamation, type of amendment including its quality and quantity of irrigation water, cultural practices, soil fertility and salt tolerance of the plant. The most important factor, however, is the degree of rehabilitation prior to sowing of crops.

The data indicated that better yield with different compost combinations proved effective and efficient for decreasing soil pH, EC_e, SAR and BD while increasing porosity and HC. In the first step, plant height and tillering improved due to reduction of harmful elements through soil amelioration. The uptake of elements such as Na^+ decreased while the concentration of K increased to adjust Na and K ratio favorable for the plant growth. Eventually, the yield of rice and wheat crops increased significantly in the treatments that proved more effective for soil reclamation. The most effective treatment was the gypsum @ 50% GR+ compost @ 20 t ha^{-1} (Figure 6). Thus, combination of chemical and organic amendments was successful to increase paddy yield by 219% and wheat grain by 208% over control (Table 3). The other combinations of gypsum and compost proved inferior. Application of rice straw and FYM with 25% GR gave similar results as 100% GR in term of rice and wheat yield (Zaka et al., 2003). Mahdy, (2011) proved that sodium removal efficiency was the highest with soil+ NPK + compost + anthracite + coal powder + WTRs + $FeSO_4.7H_2O$ and ultimately, biomass and yield of alfalfa was also more at the same treatment. Beneficial effect of compost on crop growth and yield have been reported by many researchers (Sarwar et al., 2017; Islam et al., 2017). However, combination of chemical amendments (gypsum) with compost is more beneficial to cut short the reclamation period and for achieving rapid rehabilitation (Ameen et al., 2017).

Table-3: Percent increase / decrease over control (soil parameters and yield of paddy and wheat) after harvesting of four crops

Treatments	Increase			Decrease			
	Paddy	Wheat grain	HC	BD	pH	EC_e	SAR
T_2- Gypsum 100% GR	200	162.4	423	7.69	7.78	60.0	76.4
T_3- Compost 20 t ha^{-1}	175.6	154.6	376	9.62	6.67	58.0	70.5
T_4- Gypsum 50% GR + Compost 20 t ha^{-1}	219.1	207.8	485	12.82	13.33	62.0	77.4
T_5- Gypsum 50% GR + Compost 10 t ha^{-1}	154.2	124.8	333	10.25	7.78	51.0	68.6
T_6- Gypsum 25% GR + Compost 20 t ha^{-1}	157.3	115.6	414	8.97	6.67	56.0	66.6
T_7- Gypsum 25% GR + Compost 10 t ha^{-1}	126.7	86.5	275	8.3	6.67	52.0	64.6

Table-4 Effect of compost and gypsum alone and their combinations on pore spaces (%)

Treatments	After amendments	After 1st Rice	After 1st Wheat	After 2nd Rice	After 2nd Wheat
T_1 Control	37.36D	39.62C	41.13D	40.76C	41.132D
T_2 Gypsum 100% GR	41.13BC	42.64 B	44.15C	44.15B	45.67C
T_3 Compost 20 t ha^{-1}	40.38C	42.64 B	45.28BC	44.52B	46.79BC
T_4 Gypsum 50% GR + Compost 20 t ha^{-1}	43.02A	43.78A	46.79A	47.17A	48.68A
T_5 Gypsum 50% GR + Compost 10 t ha^{-1}	41.51BC	43.40AB	44.15C	44.91B	47.17B
T_6 Gypsum 25% GR + Compost 20 t ha^{-1}	41.89AB	42.64B	46.42AB	44.91B	46.42BC
T_7 Gypsum 25% GR + Compost 10 t ha^{-1}	40.76BC	43.40AB	44.72C	44.53B	46.04BC

Original Pore spaces 35.09%

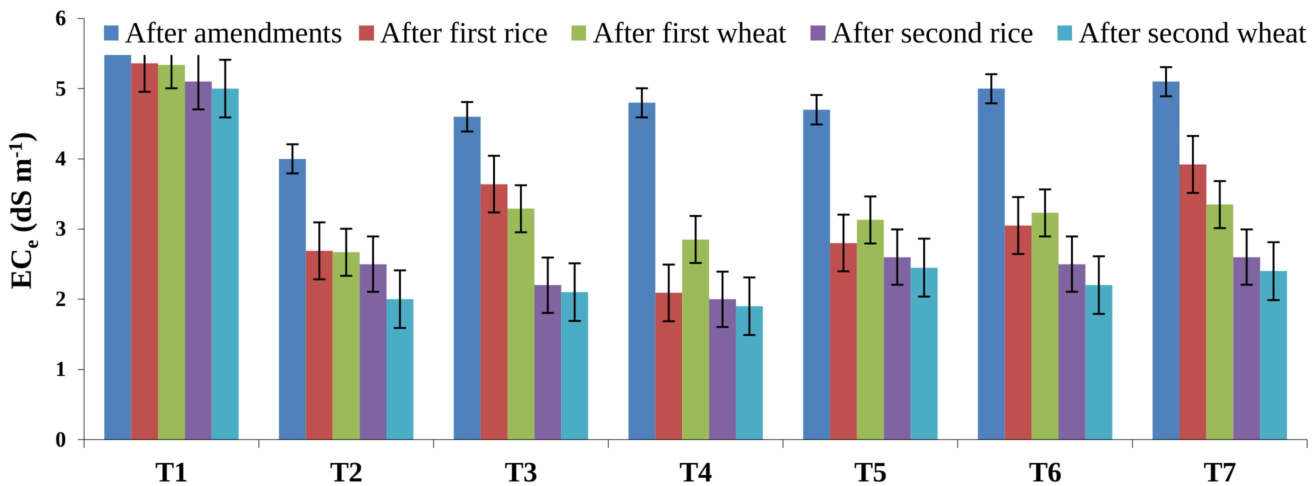

Fig. 1: EC_e changes with gypsum alone and in combination with compost

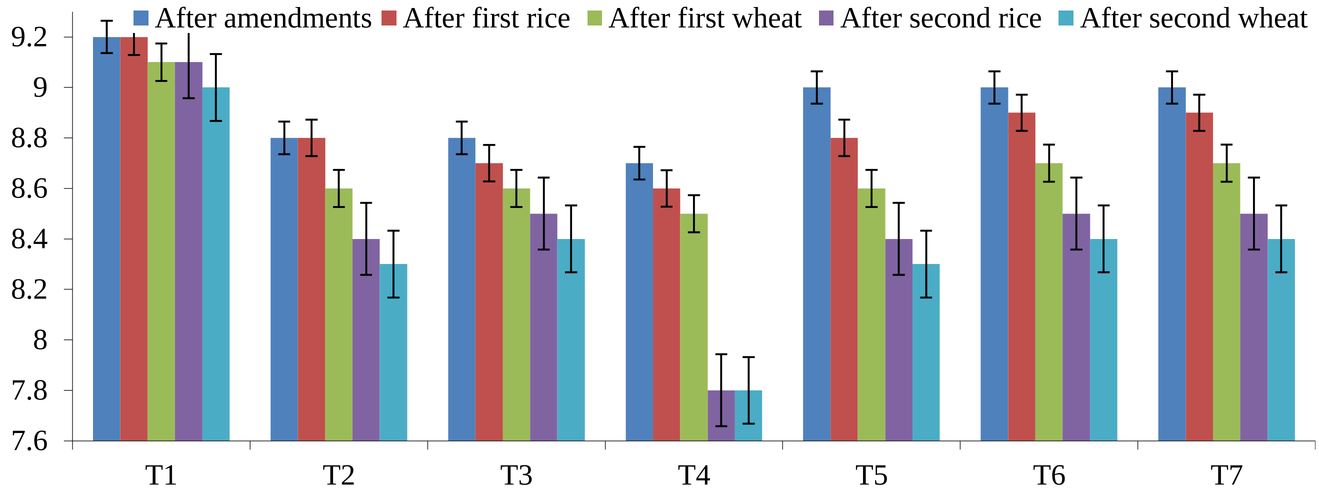

Fig. 2: pHs changes with gypsum alone and in combination with compost

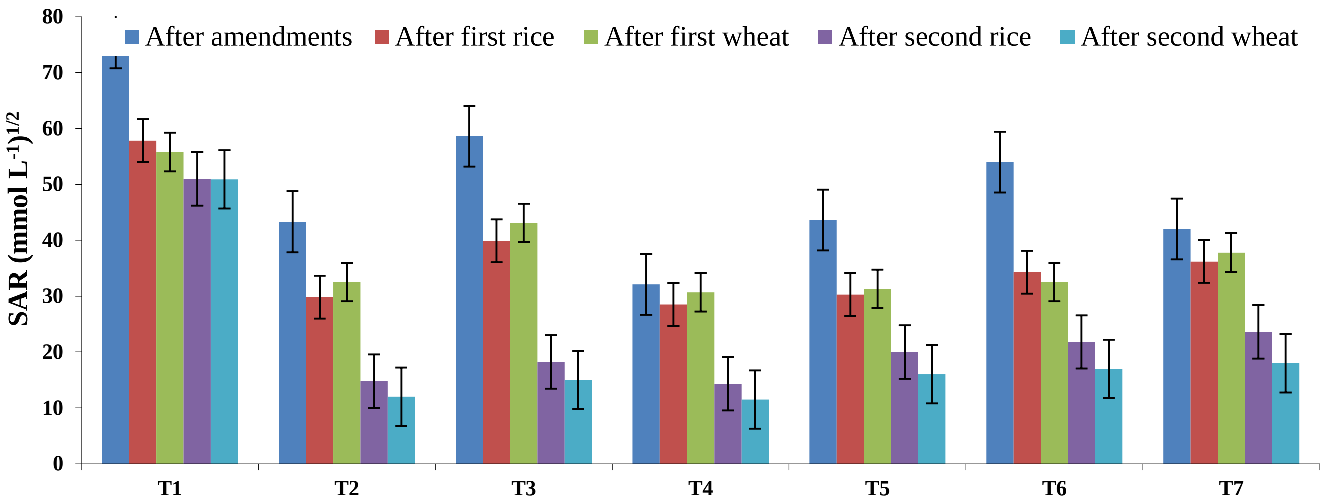

Fig. 3: SAR changes with gypsum alone and in combination with compost

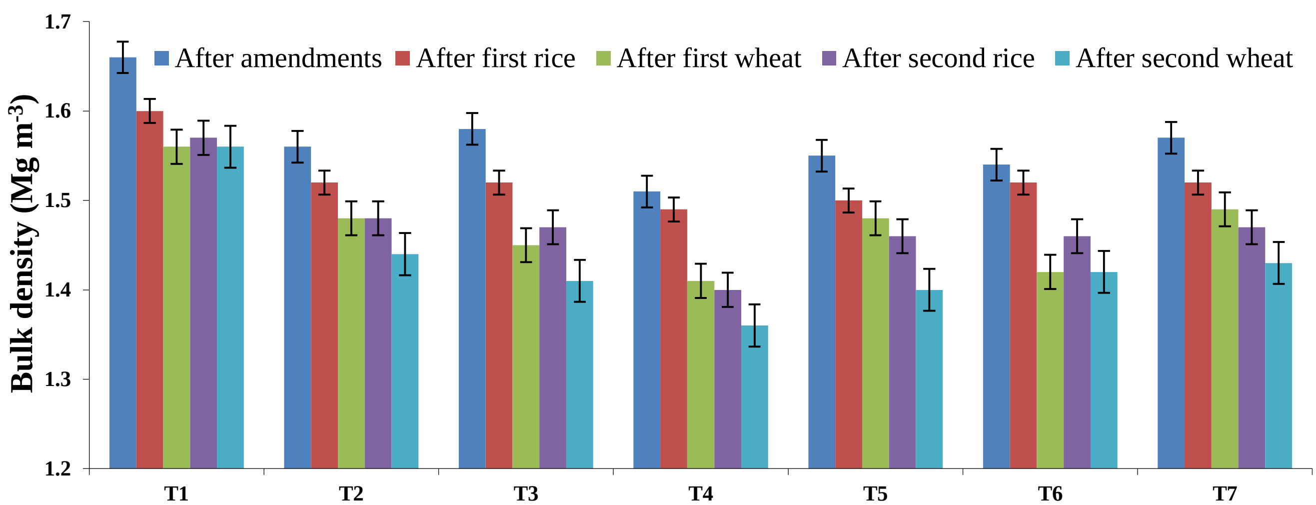

Fig. 4: Bulk densitychanges with gypsum alone and in combination with compost

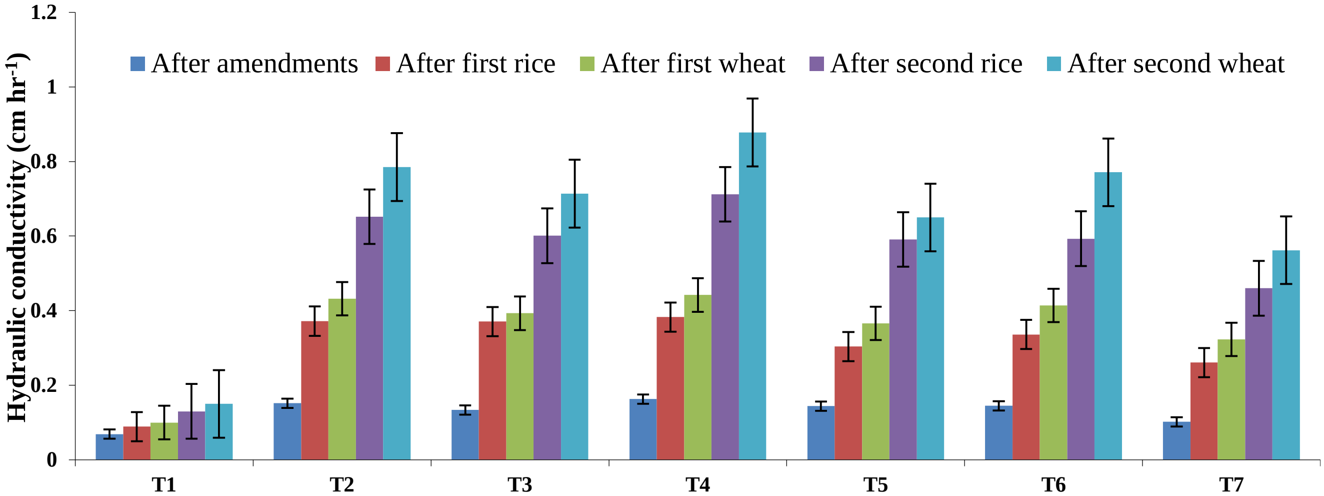

Fig. 5: Hydraulic conductivity changes with gypsum alone and in combination with compost

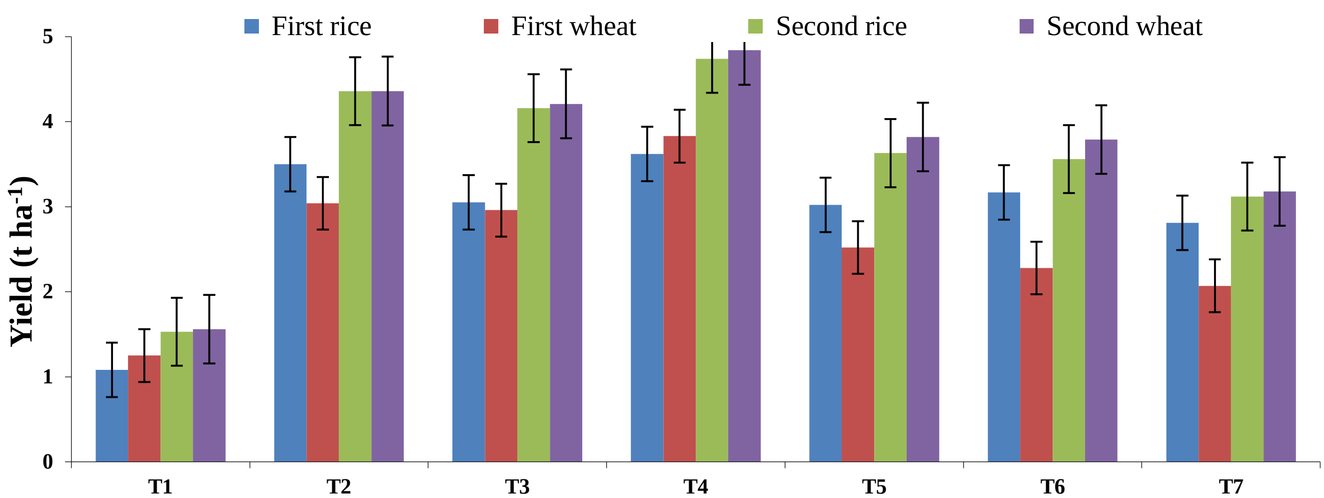

Fig. 6: Yield response to gypsum alone and in combination with compost

Conclusion

An effective reclamation procedure for saline sodic soils is removal of undesirable Na^+ by addition of some Ca^{2+} source paralleled with leaching of this Na^+ out of root zone. However, the combination of compost + gypsum proved to be the best soil amendment for reducing soil pH, salinity, SAR and improving bulk density, hydraulic conductivity. Resultantly, the paddy and grain yield of wheat increased with the improvement of soil health.

The message derived for the farmers from this study is that they can effectively rehabilitate their salt affected soils to obtain original potential if they apply gypsum at the full rate (100% GR) alone or they can decrease its quantity 25 or 50% by combining it with compost (20 or 10 t ha^{-1}).

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