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Amelioration of Saline-sodic Soil with Amendments using Brackish Water, Canal Water and their Combination

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ABSTRACT

Rice-wheat crop rotation is generally practiced under continuous and intermittent ponding conditions in Pakistan and is also considered suitable during reclamation of saline-sodic soils. This experiment was conducted between 2009 and 2010 on a saline-sodic field at Gojra, District Toba Tek Singh, Pakistan. The soil was silty clay loam in texture, poorly drained, saline-sodic and developed in calcareous mixed alluvium developed during Pleistocene era. The experiment was replicated thrice in split plot design. There were three water treatments, namely canal water (CW), brackish water (BW) and CW + BW (1:1). Amendments used were: Control (without amendment), Gypsum @ 100% SGR, Farm manure @10 t ha^{-1}, Mulching @ 10 t ha^{-1}. The soil reclamation with respect to pH_s, EC_e and SAR remained considerably better with the application of gypsum and FM with all the irrigation waters. It was concluded that one irrigation with SSW and one with CW is better for initial reclamation of silty clay loam soil by following rice-wheat cropping rotation. The salt leaching efficiency decreased over time, being highest after rice crop and decreased with time. Gypsum and FM application significantly increased crop yields even irrigating with SSW. Net benefit (Rs ha^{-1}) from rice-wheat crops was the highest with FM receiving SSW−CW followed by gypsum. It was concluded that gypsum and FM amendments are important for growing rice-wheat crops during soil reclamation, even if saline-sodic water is used for irrigation.

Key Words: Amelioration; Amendments; Brackish water; Saline-sodic soil

INTRODUCTION

Dry and hot climatic zone are characterized by high evaporation which induces salt accumulation in the surface soil layers. Physical and chemical properties may be altered due to accumulation of such salts in soils, including soil structure, porosity and hydraulic conductivity (Quirk, 2001). Soil permeability and available water capacity decreased might be due to high exchangeable Na^+ and pH, and infiltration rates through swelling and dispersion of soils as well as slaking of soil aggregates (Shainberg & Letey, 1984; Qadir & Schubert, 2002).

Rice-wheat crop rotation is generally practiced under continuous and intermittent ponding conditions in Pakistan and is also considered suitable during reclamation of salt-affected soils. Rice cultivation has additional benefits of heavy rains, which help to dilute the concentration of salts in salt-affected soils. Wheat is comparatively more tolerant to salinity, whereas rice is more tolerant to sodicity and thus has proved potential crops with respect to reasonable yields during rehabilitation of all types of salt-affected soils (Ayers & Westcot, 1985; Ghafoor *et al*., 2004).

Management of brackish waters and saline-sodic soils is valuable for several reasons. For example, during intial phase of reclamation of saline-sodic/sodic soils, use of brackish waters with low concentration of Na^+ could be helpful that favorably affecting the infiltration rate, bulk density and soil structure (Ghafoor *et al*., 2008; Murtaza *et al*., 2009). Therefore, the use of brackish water may speed up the reclamation of salt-affected soils with the scenario of contributing to environmental conservation through carbon sequestration (Lal, 2001), increased farm income and thus alleviate rural poverty.

Many investigators used different soil conditioners like organic manures, mineral fertilizers, sulfur and gypsum to avoid the risks of low quality irrigation water for crop growth on both the normal and salt-affected soils (Gharaibeh *et al*., 2009; Ghafoor *et al*., 2010). Gypsum has been proved better and economical, the benefits of which may continue to remain favorable for longer periods of time. The present study was conducted to evaluate certain conditioners i.e., gypsum, farm manure and mulching to reclaim a saline-sodic soil using SSW, canal water and their combination. The study was conducted in a farmer field to (a) assess the effectiveness of gypsum, farm manure and mulching for reclamation of saline-sodic soil using SSW, canal water and their combination, (b) evaluate the growth response of rice and wheat crops to soil reclamation treatments using SSW and CW waters and (c) To calculate economics of soil-applied amendments under different water treatments.

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MATERIALS AND METHODS

This experiment was conducted between 2009 and 2010 on a saline-sodic field at Gojra, District Toba Tek Singh, Pakistan. The experimental site was located at Gojra-Jhang road about 15 km from Gojra and 65 km from Faisalabad. The soil under study was silty clay loam in texture, poorly drained, saline-sodic and developed in calcareous mixed alluvium developed during Pleistocene era. The experiment was laid out in a split plot design, water treatments were maintained in main plots and amendments in sub-plots. The design was replicated three times. There were three water treatments, namely canal water, brackish water and canal+brackish water (1:1). The plot size was 10 m × 18 m with a rice-wheat crop rotation. Amendment treatments were (1) Control (without amendment), (2) Gypsum at 100% soil gypsum requirement (SGR) of 15 cm layer, (3) Farm manure at10 t ha^{-1} and (4) Mulching (chopped wheat straw left after separating grains) at10 t ha^{-1}.

After layout of experiment, textural analysis was done using hydrometer method (Bouyoucos, 1962). Infiltration rate was determined for the initial soil, and post-wheat crop using double ring infiltrometers (Bouwer, 1986). Soil bulk density was measured by using undisturbed cores of 0.050 m × 0.072 m (Blake & Hartge 1986). The soil hydraulic conductivity was measured using brass tubes following falling water head method (Klute & Dirksen, 1986).

After layout of experiment, amendments, viz. gypsum and FM were incorporated into 0-15 cm soil layer. Agricultural grade gypsum (G) having 70% purity, passed through 30-mesh sieve was applied at 100% SGR (5.77 t ha^{-1}). Soil gypsum requirement was determined by Schoonover's method (Schoonover, 1952). For one month, soil was left fallowed and irrigated with canal water on weekly basis. After one month of amendments incorporation, soil was prepared by 3 times ploughing and planking. Fertilizer NPK @ 90-60-40 kg ha^{-1} as urea, single super phosphate (SSP) and KCl, respectively were applied uniformly in all the treatments. Full doses of P and K, while half of N was applied at transplanting, while remaining N was applied at tillering and booting stages. Rice cv. SSR-1 was transplanted on July 26, 2009 without puddling the soil and row to row and hill to hill distance was 22.5 cm. Mulch as wheat straw was added on the surface after transplanting rice. After 40 days of transplanting, complete dose of Zn (5 kg Zn ha^{-1} as $ZnSO_4$) was applied. The crop was harvested at maturity. Harvesting was done manually, where the entire experimental plots were harvested during the third week of November 2009. The harvested crop was threshed to record economic paddy and straw yields. Wheat was sown after rice harvest during the 2nd week of December 2009 by hand drill using 100 kg ha^{-1} seed rate. The nutrients N, P_2O_5 and K_2O were applied @ 90, 60, 40 kg ha^{-1}, respectively (Table I). Full dose of P and K as SSP and K as K_2SO_4 (SOP) respectively, was applied, while half of the N as urea was applied at the time of sowing. The remaining dose of N was applied at tillering and booting stages in two equal splits. At maturity, the crop was harvested from the entire plots during the first week of May 2010. At maturity, the crop was threshed manually to record grain and straw yields. Soil sampling was done from each plot from 0-15 and 15-30 cm soil depths at three sampling times i.e., after layout of the experiment (initial soil), after rice 2009 and then after wheat 2009-2010 harvest. Tube well (EC 3.68 dS m^{-1}, SAR 16.40 & RSC 1.21 $mmol_c$ L^{-1}) and canal waters (EC 0.24 dS m^{-1}, SAR 0.89 & RSC nil) used for irrigation were analyzed 3 times during each of the rice and wheat growth periods. Analysis was done for saturated soil paste pH (pH_s) with SensoDirect 100 pH meter, saturation paste extract EC (EC_e) with Jenway Model-4070 conductivity meter, soluble Ca^{2+} + Mg^{2+} (titration with standard versinate solution), CO_3^{2-} and HCO_3^- (titration with standard H_2SO_4), Cl^- (titration with standard $AgNO_3$) and Na^+ (flame photometrically) with Jenway PFP-7 Flame Photometer, using methods described by the US Salinity Laboratory Staff (1954) and Page *et al*. (1982).

Salt leaching efficiency of treatments on the basis of mass of salts (kg) leached was computed as:

kg of salts leached (m^{-3}) of added water=S_i(kg)–S_f(kg)/Wt added (m^3) Eq. 1

The salt leaching efficiency was calculated after each crop as:

kg of salts leached (m^{-3}) of added water=S_i(kg)–S_f(kg)/W_c added (m^3) Eq. 2

Where S_i is mass of initial salts, S_f the mass of final salts, W_t is total volume of water added and W_c is cumulative water added.

The weight of soil was calculated for each treatment considering the bulk density of the respective treatment, the irrigation (mm) was converted into volume (m^3), initial and final EC_e (dS m^{-1}) was converted into percent by multiplying it with 0.064 factor (US Salinity Lab. Staff, 1954).

Profitability of experiments was calculated using the market price of inputs and economic benefit obtained from paddy and wheat. Crop growth variables and soil charcteristics were analyzed statistically and treatment differences were evaluated using the Least Significant Difference (LSD) test (Steel *et al*., 1997). Overall, irrigation water applied to crops, rainfall, temperature, relative humidity and NPK rates are presented in Table I.

RESULTS AND DISCUSSION

The physical properties of soils were determined at the start of studies and after one year at termination of experiments. The experimental site was lying barren for the past about 25 years as told by the farmers. The site was badly deteriorated regarding the pH_s, EC_e, SAR, bulk density, infiltration rate and hydraulic conductivity. The infiltration rate was very low and variation appears mostly due to differences in soil SAR.

Chemical Characteristics of Soil

Fig. 1: Effect of water source and amendments on EC_e at 0-15 cm soil depth after the harvest of rice 2009 and wheat 2009-2010

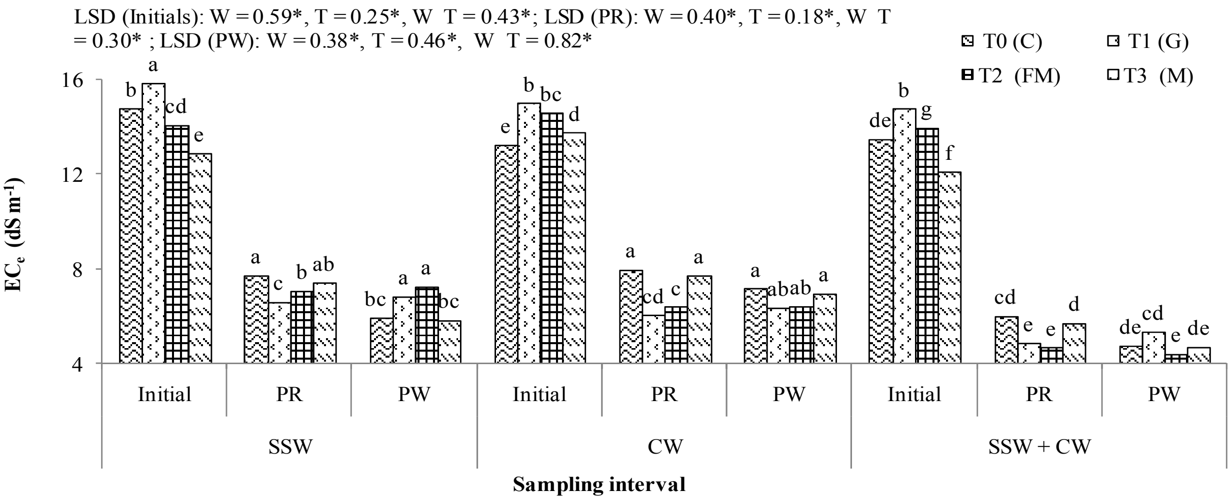
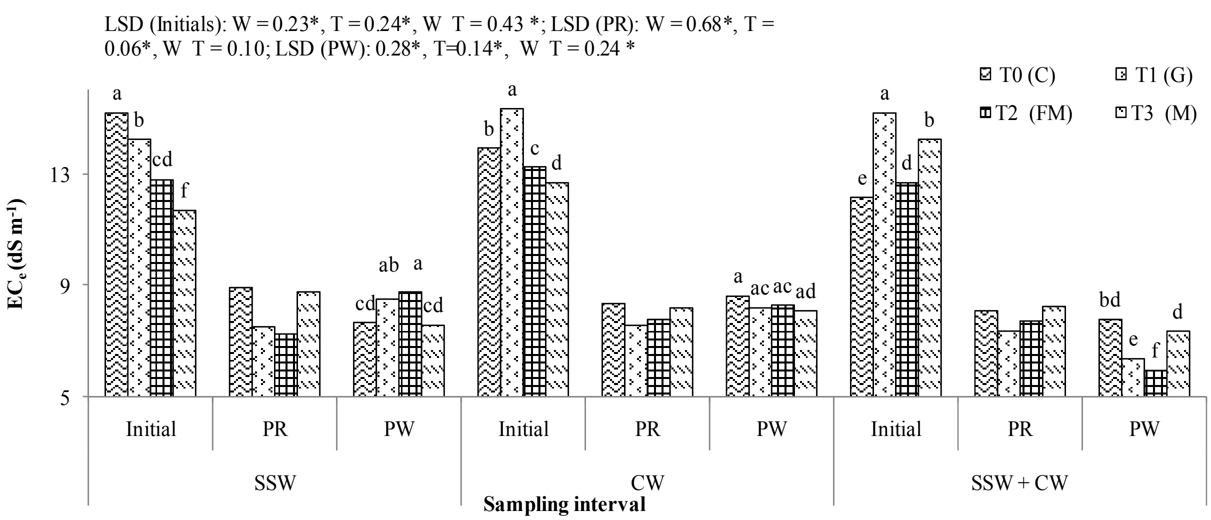


Fig. 2: Effect of water source and amendments on EC_e at 15-30 cm soil after the harvest of rice 2009 and wheat 2009-2010



Soil salinity (EC_e): Soil salinity exerts osmotic effects on plants (Maas & Hoffman, 1977) and reduces water uptake by plants. Therefore, EC_e has vital importance for plant growth. At 0-15 cm soil depth, there were significant main and interactive effects ($P < 0.05$) on EC_e of post rice soil (Fig. 1). Maximum decrease over the control was recorded with gypsum application. The lowest EC_e of 4.46 dS m^{-1} was recorded for FM application with SSW. This was statistically similar to gypsum application with SSW-CW.

At 0-15 cm soil depth, amendments, waters and their combination difference remained statistical on post wheat pH_s (Fig. 1). Similar to post rice plots, EC_e of post wheat soil was significantly lower in SSW−CW plots than that with SSW or CW plots. The EC_e of plots irrigated with SSW receiving gypsum and FM was significantly higher than that of the control. However, EC_e with application of amendments receiving irrigation of CW or SSW−CW did not differ significantly.

At 15-30 cm soil depth, application of gypsum and FM significantly decreased EC_e compared to initial values in post rice soil (Fig. 2). However, mulch was ineffective for deceasing EC_e compared to control or the initial values. The EC_e in post-wheat plots was significantly lower in plots receiving SSW−CW than that receiving SSW and CW irrigation (Fig. 2). However, EC_e in amended plots was lower than that with the control. The EC_e in experimental plots ranged from 5.98 to 8.79 dS m^{-1}, minimum being with FM receiving irrigation of SSW−CW. Submerged

Fig. 3: Effect of water source and amendments on SAR at 0-15 cm soil depth after the harvest of rice 2009 and wheat 2009-2010

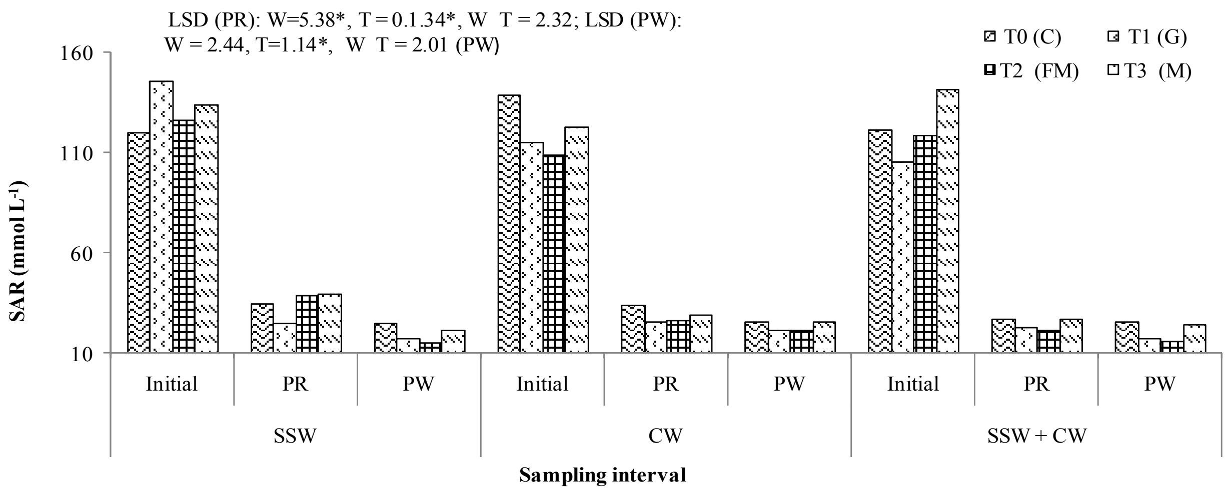
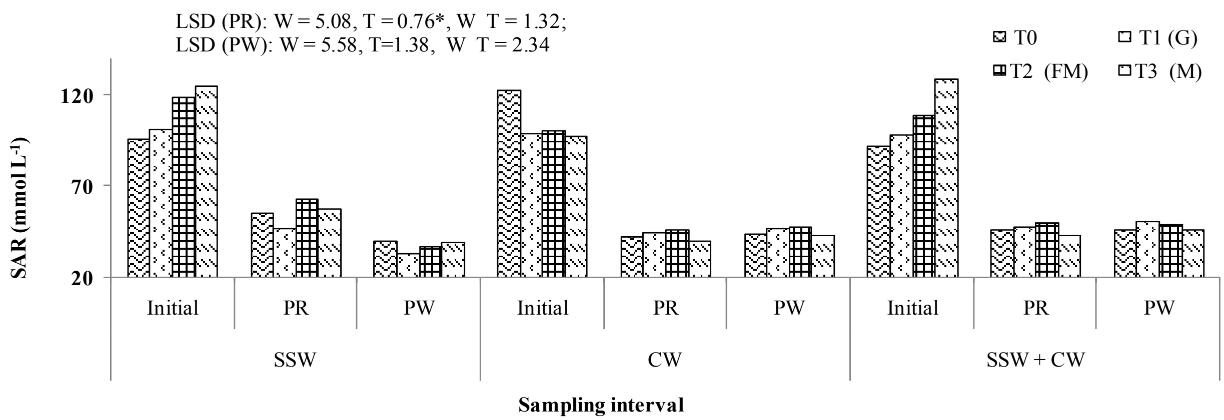


Fig. 4: Effect of water source and amendments on SAR at 15-30 cm soil depth after the harvest of rice 2009 and wheat 2009-2010



conditions during rice crop due to its ecological reasons enhanced salts leaching, which decreased EC_e more effectively in the upper soil layer than the lower depth. This declining trend in EC_e favors rice as the first crop during reclamation of salt-affected soils. Initially, the higher concentration of soluble salts helped the leaching process during the rice crop. Comparatively higher EC_e after wheat than rice crop might be due to time lapse of about a month between the last irrigation and the time of soil sampling during April and May, whereby high evaporation caused upward salt movement (Tyagi, 2003; Murtaza *et al.,* 2009). Ghafoor *et al.* (2010) reported similar trends in EC_e changes i.e., during reclamation of salt-affected soils using low quality irrigation waters in the Fourth Drainage Project Area, Faisalabad. Gypsum application resulted in a relatively smaller decrease in EC_e compared to that with FM because of lower gypsum solubility. The resulting better HC is an asset for the reclamation of saline-sodic soils (Ghafoor *et al*., 2004).

Soil sodicity (SAR): The experimental soil had higher SAR than 13, a limit for saline-sodic/sodic soils given by US Salinity Lab. Staff (1954). Application of gypsum and FM significantly decreased SAR compared to initial values after rice harvest (Fig. 3). The SAR was significantly lower with SSW−CW irrigation compared to SSW, however, this SAR was statistically at par with CW irrigation. There were significant effects of waters and amendments on SAR of 0-15 cm soil depth after wheat (Fig. 3). FM application significantly decreased SAR compared to control. The SAR of plots under CW was significantly lower compared to that of SSW however, it was statistically at par with SSW−CW irrigation. Almost similar pattern in SAR changes was recorded at 15-30 cm soil depth after both the rice and wheat crops with waters, amendments and their interaction (Fig. 4).

Table I: Summary of irrigation water applied to rice and wheat crops, rainfall and nutrient application

Crop	Irrigation input and rainfall			Relative humidity (%)	Temp (°C)	Nutrient applied (kg ha^{-1})		
	Irrigation (mm)	Rainfall (mm)	Total (mm)			N	P_2O_5	K_2O
Rice 2009	1600	170	1770	58	32	90	60	40
Wheat 2009-10	340	155	495	47	19	90	60	40

Table II: Leaching efficiency of salts (kg m^{-3} of added water) by treatments during reclamation of saline-sodic soil

Water source	SSW		CW		SSW−CW	
Treatment	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
T_0 (C)	0.59b-d	0.49bc	0.43g	0.38ef	0.58c-e	0.30gh
T_1 (G)	0.67ab	0.47cd	0.67ab	0.55ab	0.74a	0.62a
T_2 (FM)	0.52d-f	0.35fg	0.62bc	0.40d-f	0.70a	0.45c-e
T_3 (M)	0.47fg	0.26h	0.51e-g	0.38ef	0.52d-f	0.47cd
Mean	0.56A	0.39C	0.55C	0.43B	0.63A	0.46A

LSD Depth 0-15 cm: Water (W) = 9.808×10^{-18}*, T = 0.02*, W×T = 0.05*; Depth 15-30 cm: W = 1.934×10^{-17}*, T = 0.04*, W×T = 0.05*. * Values in columns for same soil depth across water sources differed significantly at P <0.05; SSW = Saline-sodic water; CW= Canal water

Table III: Leaching efficiency of salts (kg m^{-3}) of added water during reclamation of saline-sodic soil for rice and wheat crops

Crop	SSW		CW		SSW−CW	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Rice-2009	0.69	0.51	0.70	0.56	0.79	0.54
Wheat -2009-10	0.59	0.39	0.57	0.42	0.65	0.50

SSW, saline-sodic water; CW, canal water; G, gypsum; FM, farm manure; M, mulch

Table IV: Effect of water source and amendments on infiltration rate after harvesting wheat

Water source	SSW		CW		SSW−CW		Mean
Treatment	Initial	Post wheat	Initial	Post wheat	Initial	Post wheat	Post wheat
T_0 (C)	0.32	0.26d	0.36	0.28d	0.34	0.31d	0.28C
T_1 (G)	0.29	0.64a	0.28	0.67a	0.29	0.66a	0.66A
T_2 (FM)	0.28	0.60a	0.30	0.62a	0.32	0.63a	0.62A
T_3 (M)	0.24	0.46b	0.29	0.34cd	0.23	0.45bc	0.42B
Mean	0.28^{NS}	0.49AB	0.30^{NS}	0.48B	0.29^{NS}	0.52A	

LSD Wheat: Water (W) = 0.06, T = 0.04*, W×T = 0.08*

*Treatment differed significantly at P <0.05; Values in a column sharing same letter(s) are statistically similar at P <0.05; NS, Non significant difference among treatments at P <0.05

SSW = Saline-sodic water; CW= Canal water

Table V: Effect of water source and amendments on bulk density of 10-15 cm soil depth after the harvest of wheat

Water source	SSW		CW		SSW−CW		Mean
Treatment	Initial	Post wheat	Initial	Post wheat	Initial	Post wheat	Post wheat
T_0	1.74	1.74a	1.69	1.60cd	1.66	1.62c	1.65A
T_1 (G)	1.70	1.64c	1.68	1.52ef	1.70	1.51f	1.56C
T_2 (FM)	1.72	1.66bc	1.68	1.53ef	1.68	1.53ef	1.57C
T_3 (M)	1.73	1.69b	1.70	1.54ef	1.69	1.56de	1.60B
Mean	1.72^{NS}	1.68A	1.68^{NS}	1.56B	1.68^{NS}	1.55B	

LSD: Wheat: Water (W) = 0.38*, T = 0.018*, W×T = 0.02*

*Treatments differed significantly at P <0.05; Values in a column sharing same letter(s) are statistically similar at P <0.05; NS, Non significant difference among treatments at P <0.05

SSW = Saline-sodic water; CW= Canal water

Table VI: Effect of water source and amendments on bulk density of 20-25 cm soil depth after the harvest of wheat

Water source	SSW		CW		SSW−CW		Mean
Treatment	Initial	Post wheat	Initial	Post wheat	Initial	Post wheat	Post wheat
T_0	1.69	1.70	1.69	1.71	1.69	1.69	1.70A
T_1 (G)	1.68	1.60	1.68	1.62	1.68	1.60	1.61C
T_2 (FM)	1.66	1.62	1.70	1.64	1.70	1.62	1.63C
T_3 (M)	1.70	1.67	1.768	1.66	1.69	1.65	1.66B
Mean	1.68^{NS}	1.65^{NS}	1.70^{NS}	1.65	1.69^{NS}	1.64^{NS}	

LSD Wheat: Water (W) = 0.038*, T = 0.02*, W×T = 0.02*

*Treatments differed significantly at P <0.05; NS, Treatments differed non-significantly at P <0.05. Values in a column sharing same letter(s) are statistically similar at P <0.05; NS, Non- significant difference among treatments at P <0.05; SSW=Saline-sodic water; CW= Canal water

At the start of studies, soil surface had SAR more than 100 (Fig. 3). After harvest of rice 2009, the SAR decreased sharply by about 60-80% in surface layer and 40-60% in the lower depth. A rapid decrease in SAR during initial phase might be due to statistical probability of Na-Ca exchange process (Bresler *et al.,* 1982; Ghafoor, 1999). The rate of decrease in SAR was more at 0-15 cm than that at 15-30 cm soil depth, because as water/soil solution moved down into soils, water potential decreased and thus decreased its salt carrying capacity. Even the simple irrigation with SSW could decrease SAR of saline-sodic soils considerably through valence dilution (Eaton & Sokoloff, 1935), dissolution of native lime, which was also promoted by crop root activities (Robbins, 1986), Ca^{2+} supplied in irrigation water and in-situ mineral weathering (Rhoades *et al*., 1968). Cyclic irrigation with canal and brackish tube well water along with the application of gypsum sustained the electrolyte concentration, which in turn made it achievable to have high leaching fraction in the experimental soil. After harvest of wheat 2009-2010, there was a greater decrease in SAR with gypsum application compared to other treatments at both the soil depths, which is natural as decrease in SAR or ESP required external Ca^{2+} source like gypsum.

Leaching efficiency of salts: The efficiency of treatments for salt removal remained higher at both the soil depths (Table II). The soil under experiment has tile drains. Generally, salt leaching was higher at upper soil depth than that of lower. Maximum leaching efficiency was with G treatment and minimum with M receiving SSW or SSW−CW for irrigation. While leaching efficiency was the lowest with control receiving CW at 0-15 cm soil depth. It is clear that G and FM application with cyclic use of SSW and CW remained better due to favorable effects on physical properties of soils (Murtaza *et al*., 2009). Salt leaching efficiency decreased over time, being highest after rice crop 2009 and decreased with time (Table III). The results clearly depicts that high EC at beginning of studies helped to attain high salt leaching efficiency through improvement in physical properties. Comparatively higher salt leaching efficiency was recorded after rice than wheat due to high drainable surplus during rice (Zia *et al.,* 2006, 2007) as field was remained submerged.

Infiltration rate: The term infiltration rate has special significance in soils and the critical value of infiltration rate is 0.25 cm h^{-1} (US Salinity Lab. Staff, 1954). The infiltration rate of 0.3 cm h^{-1} is considered low, while greater than 1.2 cm h^{-1} is high (Ayers & Westcot, 1985). The infiltration rate before the start of experiment ranged from 0.23 to 0.36 cm h^{-1} in various plots (Table IV). After harvest of wheat in May 2010, treatments differed significantly, infiltration rate being the highest with G and increase in soil infiltration was more with SSW−CW compared to that with SSW and CW. However, addition of amendments exerted amelioration effect on infiltration rate of soils. The favorable role of gypsum in increasing infiltration rate is due to higher electrolyte concentration in soil solution (Shainberg & Letey, 1984) in addition to maintaining an appropriate Ca: Na ratio in soil solution along with affecting desorption of adsorbed Na^+ (Muhammed *et al.,* 1969) on the clays which is considered the major agent to induce soil dispersion.

Bulk density: There was a significant effect of amendments on bulk density of soil both at 10-15 and 20-25 cm soil depths (Table V & VI). The bulk density of soil at both the soil depths was significantly lower with all the amendments compared to that of the control plots. Maximum decrease of 9% at 10-15 cm soil depth and 5% at 20-25 cm soil depths was recorded with the application of gypsum. Application of FM was equally effective at both the depths. Mulch was least effective; nevertheless, the bulk density was significantly lower than that of the control plots. However, small change in bulk density compared to initial value seems solely because of short duration of only one year but improvement in bulk density and other physical properties required longer times.

In general there was an increase in bulk density at 20-25 cm soil depth. The increase in bulk density might be due to the continuous use of high SAR and RSC tube well waters and decreased EC_e: SAR in soil solution because EC_e decreased faster than SAR (Ayers & Westcot, 1985). There was a gradual increase in bulk density with lower soil depth which is mainly due to leaching of Na^+ from upper to lower soil depths causing deflocculation of soils (Minhas & Gupta, 1993; Qadir & Schubert, 2002).

Hydraulic conductivity: The soil hydraulic conductivity depends on the composition and concentration of the electrolyte in the soil solution (Quirk & Schofield, 1955) as well as on soil texture (Shainberg *et al*., 2001). There were significant effects of waters and amendments on hydraulic conductivity measured at both 0-15 and 15-30 cm depths after wheat (Table VII & VIII). A significant increase in hydraulic conductivity over the initial values was observed with the application of gysum and FM treatments at both the soil depths. Gypsum application increased the highest hydraulic conductivity at both the soil depths receiving SSW−CW followed by FM, M and lowest with C. The treatment order remained the same for plots receiving CW and SSW i.e., highest with G followed by FM, M and C.

Growth Response of Crops to Applied Treatments

Rice growth: Application of gypsum and irrigation with SSW-CW significantly increased paddy and straw yields compared to control plots irrigated with SSW (Table IX).

It has been reported that paddy yield is reduced 50% at SAR 60, while crop fails at SAR 80 (Bresler *et al., 1982*; Gupta & Abrol, 1990), while EC_e is 6-7 dS m^{-1} (Maas & Grattan, 1999). Rice is comparatively better tolerant to SAR and SAR up to 30 is an asset to maintain the fields submerged (Ghafoor *et al.,* 1997) and loves to grow in standing water (Ghafoor *et al.,* 2004). The growth response of rice crop may be attributed to its genetic makeup. Cyclic irrigation with SSW and CW along with application of gypsum or FM resulted in better paddy yield which may be attributed to their favorable effects on soil physical and

Table VII: Effect of water source and amendments on hydraulic conductivity of 0-15 cm soil depth after the harvest of wheat

Water source	SSW		CW		SSW−CW		Mean
Treatment	Initial	Post wheat	Initial	Post wheat	Initial	Post wheat	Post wheat
T_0	0.051b	0.034e	0.029g	0.037de	0.037ef	0.038de	0.036C
T_1 (G)	0.059a	0.070ac	0.034f	0.084a	0.039ef	0.069a-c	0.074A
T_2 (FM)	0.050c	0.060a-d	0.029g	0.070a-c	0.044d	0.079ab	0.070A
T_3 (M)	0.042de	0.043c-e	0.025h	0.057b-e	0.039ef	0.055b-e	0.052B
Mean	0.050A	0.052^{NS}	0.029C	0.062^{NS}	0.039B	0.060^{NS}	

LSD: Water (W) = 0.012, T = 0.014*, W×T = 0.02*

Table VIII: Effect of water source and amendments on hydraulic conductivity of 15-30 cm soil depth after the harvest of wheat

Water source	SSW		CW		SSW−CW		Mean
Treatment	Initial	Post wheat	Initial	Post wheat	Initial	Post wheat	Post wheat
T_0	0.048c	0.036g	0.035e	0.037fg	0.044d	0.043fg	0.038D
T_1 (G)	0.054a	0.073d	0.047c	0.102a	0.051b	0.095a	0.090A
T_2 (FM)	0.052ab	0.059e	0.036e	0.085b	0.047c	0.082bc	0.075B
T_3 (M)	0.047c	0.044f	0.036d	0.074cd	0.044d	0.068d	0.062C
Mean	0.29^{NS}	0.053B	0.30^{NS}	0.074A	0.30^{NS}	0.072A	

LSD: Water (W) = 0.018*, T = 0.0036*, W×T = 0.012*
*Treatments differed significantly at P <0.05 and values sharing same letter(s) in a column are statistically similar; NS, Non significant difference among treatments at P <0.05; SSW = Saline-sodic water; CW= Canal water

Table IX: Effect of water source and amendments on rice growth

Water source/Treatment	SSW	CW	SSW−CW	Mean
Paddy yield (kg ha^{-1})				
T_0 (C)	39i	397d	221ef	219C
T_1 (G)	120h	704b	750a	525A
T_2 (FM)	177g	566c	794fg	512B
T_3 (M)	45i	412d	229e	229C
Mean	96C	520A	498B	
Straw yield (kg ha^{-1})				
T_0 (C)	208i	651fg	612g	490C
T_1 (G)	472h	1154c	2009a	1212A
T_2 (FM)	952d	928d	1761b	1214A
T_3 (M)	245i	675f	850e	590B
Mean	469C	852B	1308A	

LSD: Paddy yield: W = 10.96*, T = 15.8*, W×T=3.8*; Straw yield: W = 22.04*, T = 26.78*, W×T = 26.38*; *Treatments differed significantly at P <0.05 and values sharing same letter(s) in a column are statistically similar at P <0.05; SSW = Saline-sodic water; CW= Canal water

Table X: Effect of water source and amendments on wheat growth

Water source/Treatment	SSW	CW	SSW−CW	Mean
Straw yield (kg ha^{-1})				
T_0 (C)	1963g	3816e	3171g	2983D
T_1 (G)	3839e	4882b	3772e	4164B
T_2 (FM)	3922	5541a	4219c	4561A
T_3 (M)	1872i	3295d	3279f	3025C
Mean	2899C	4541A	3610B	
Grain yield (kg ha^{-1})				
T_0 (C)	1205k	2008i	2334g	1816B
T_1 (G)	1973i	2569e	2656d	2399B
T_2 (FM)	2808c	2916b	2971a	2899A
T_3 (M)	1255j	2066h	2309f	1877C
Mean	1810C	2390B	2542A	

LSD: Grain yield: W = 6.04*, T = 16.58*, W×T = 28.74*; Straw yield: W = 50.56*, T = 30.12*, W×T = 53.74*. Values in a column or row sharing same letter(s) are statistically similar at P <0.05; NS, Non significant difference among treatments at P <0.05; SSW = Saline-sodic water; CW= Canal water

chemical properties. The higher paddy and straw yields with CW confirms earlier findings (Ghafoor *et al*., 1997, 2008) that good internal soil drainage might not be useful for rice provided soil and water EC and SAR remain within threshold limits for this crop i.e., soil $EC_e \approx 6$ dS m^{-1} and SAR ≈ 30-35 (Ayers & Westcot, 1985; Frenkel & Meiri, 1985).

Wheat growth: There were significant differences among waters, amendments and their combination on yield and yield contributing parameters of wheat (Table X). Straw yield was the highest (5541 kg ha^{-1}) from FM amended plots receiving CW and was the lowest in control plots receiving SSW. Farm manure application and SSW-CW irrigation significantly increased grain and straw yields compared to control plots irrigated with SSW. Canal water irrigation produced significantly higher straw, however, grain yield was maximum with SSW-CW irrigation.

Overall, application of FM to plots receiving SSW-CW produced the highest straw and grain yields, indicating that marginal quality waters could be exploited for crop growth during reclamation of salt-affected soils. It is concluded that gypsum and FM are necessary for growing crops during soil reclamation even using low quality water for irrigation. Although achieving a near steady-state, soil and crops will need irrigation with good quality water to sustain the effect of reclamation treatments for longer times otherwise resalination and resodication will start. It has been reported that wheat grain yield is decreased by 50% at SAR 30 (Ayers & Westcot, 1985) and $EC_e \approx 13$ dS m^{-1}. In the present study straw and grain yields of wheat remained below the varietal production potential due to high EC_e and

Table XI: Economics (Rs. ha^{-1}) of amendments and water source for reclaiming saline-sodic soils and growing rice-wheat crops

Treatment	Total income			Total expenses			Net benefit		
	SSW	CW	SSW−CW	SSW	CW	SSW−CW	SSW	CW	SSW−CW
	R+W	R+W	R+W	R+W	R+W	R+W	R+W	R+W	R+W
T_0 (C)	39864	79493	8168	61920	65902	60310	-22038	13592	21373
T_1 (G)	70244	107986	105601	79042	71042	75402	-8798	36944	30199
T_2 (FM)	92800	115812	116371	80572	80572	76572	12228	35241	39799
T_3 (M)	40823	78746	73395	64116	32482	59884	-23294	16264	12511

Sowing including ploughing, planking and other cultural operations was Rs. 9,000 ha^{-1} for rice and Rs. 8000 ha^{-1}for wheat crop; Fertilizer: Rs. 850/50 kg urea, Rs. 950/50 kg single super phosphate, Rs.1310/50 kg sulphate of potash, Gypsum Rs.70/50 kg; Farm manure: application + transportation charges Rs. 500/trolley; Paddy grain: Rs.900/40 kg, rice straw: Rs.900/500 kg; Wheat grain: Rs.950/40 kg, wheat straw: Rs.150/40 kg; SSW = Saline-sodic water; CW= Canal water

SAR of soils even after the harvest of one rice crop from saline-sodic soils.

Economic evaluation of treatments: In this study, economics was computed using market prices of inputs and outputs (paddy & wheat). Economics of treatments has been calculated on the basis of two crops (Rice, 2009; Wheat 2009-2010). The objective of the economic analysis is to compare costs with benefits and to decide, which treatment would yield greater returns to the investment.

Highest net benefit (Rs. ha^{-1}) from rice-wheat crops was obtained from FM (39799) receiving SSW−CW followed by G (30199), C (21373) and M (13511) (Table XI). For canal water, the maximum net benefit (Rs. ha^{-1}) was with G (36944) followed by FM (35241), M (16264) and C (13592). For SSW, net benefit remained in negative with M (-23294), C (-22038) and G (-8798), while was positive with FM (12228).

Total expenditure with various irrigations was the maximum for gypsum application. More economic benefit was obtained from wheat compared to rice. The lower paddy yield was due to very high EC_e and SAR of initial soil. The significance of FM and gypsum to promote crop growth appears through soil amelioration. The benefits of which will become further favorable with time since it is expected that reclamation effect will continue during couple of the next years, during which crop yields will not only be sustained rather could be improved. The indirect benefits of soil amelioration include appreciation in land value, farm employment and thus alleviation in rural poverty. The comparison of data reveal that gypsum based technology i.e., soil or water amelioration treatments/technology proved the best on the basis of net income.

CONCLUSION

The soil reclamation with respect to pH_s, EC_e and SAR remained considerably better with the application of gypsum and FM with all the irrigation waters. It is concluded that one irrigation with SSW and one with CW is better for initial reclamation of silty clay loam soil by following rice-wheat cropping rotation. The salt leaching efficiency decreased over time, being highest after rice crop that decreased with time. Gypsum and FM application significantly increased crop yields even with SSW irrigation. Net benefit (Rs. ha^{-1}) from rice-wheat crops was the highest with FM receiving SSW−CW followed by gypsum.

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