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Reclamation of salt-affected soils using amendments and growing wheat crop

Behzad Murtaza*, Ghulam Murtaza, Muhammad Zia-ur-Rehman, Abdul Ghafoor, Saqib Abubakar and Muhammad Sabir
Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pakistan

Abstract

With more pressing demands for non-agricultural sectors, availability of good-quality water is falling short of the crop water requirement, particularly in arid and semi-arid regions of the world, like Pakistan. Studies were conducted at three sites following randomized complete block design (RCBD) with three replications. The treatments employed were: Tube well water (TW) alone; TW + Gypsum @ 50% soil gypsum requirement (TW + G50); TW–Canal water (CW) + G50; TW–CW + farm manure (FM) @ 25 Mg ha^{-1} (TW-CW + FM) before sowing wheat. After the harvest of wheat 2008-09, non-significant decrease in bulk density was recorded with applied treatments while infiltration rate remained unchanged. There was maximum and significant decrease in EC_e and SAR with TW–CW + FM at all the three sites. Maximum decrease in EC_e (72.65%) at 0-15 cm soil depth was at site 2, while maximum decrease in EC_e (77.62%) at 15-30 cm soil depth was at site 1. Maximum percent decrease in SAR was 75.76% at 0-15 cm followed by 63.93% at15-30 cm at sites 2 and 3, respectively, with TW–CW + FM. Maximum wheat grain yields (3656, 3531 and 3826 kg ha^{-1}) and straw yields (4826, 4624 and 4707 kg ha^{-1}) were recorded at sites 1, 2 and 3, respectively, with TW–CW + FM. The net benefit was maximum with TW–CW + FM at all the three sites.

Keywords: Salt-affected soils, reclamation, brackish water, wheat

Introduction

Pakistan is facing an acute shortage of good quality irrigation water to raise crops (Ghafoor *et al*., 2001). Groundwater used as a supplement source of irrigation is mostly of poor quality owing to high EC, SAR and/or RSC. About 6.79×10^{10} m^3 groundwater is pumped, of which 70-75% is hazardous for irrigation (Latif and Beg, 2004) on the basis of the criteria of the Department of Agriculture, Punjab (Muhammed and Ghafoor, 1992). Continuous use of low quality water without the application of amendment(s) could make soils saline/sodic. At present, about 6.67 mha soils are affected to different levels and types of salinity and sodicity, out of which nearly half are under irrigated agriculture.

Use of high electrolyte waters with low concentration of sodium (Na^+) in conjunction with appropriate soil amendments could be useful during the initial amelioration phase of sodic and saline-sodic soils (Ghafoor *et al*., 2008; Murtaza *et al*., 2009) due to favorable effects of electrolytes on soil infiltration rate, bulk density and structure (Oster and Schroer, 1979). Therefore, use of saline–sodic waters and salt-affected soils for crop production has the potential to save fresh water for good soils, decreasing disposal problems of low-quality drainage (Qadir and Oster, 2004). This will help to bring barren lands under cultivation with favorable contribution to environment conservation through carbon sequestration (Lal, 2001), an increase in farm employment, decreased rural to urban migration and thus rural poverty alleviation.

Valuable work has been done on the use of low quality water for irrigating crops in Pakistan (Qadir and Schubert, 2002; Ghafoor *et al*., 2004; Murtaza *et al*., 2006) and abroad (Chang and Sipio, 2001; Lange *et al*., 2005), but farm level adoption needs some site-specific considerations because of spatial differences in edaphic factors.

Some studies on the economical use of brackish water for reclamation of salt-affected soils have been successfully completed in the Fourth Drainage Project Area, Faisalabad (FDPA) with the participation of farmers with good adoption rate by the local farmers (Ghafoor *et al*., 2008). The present study was planned at three sites in Toba Tek Singh district with the objectives to:

1. Evaluate the reclamation effectiveness of groundwater with or without using inorganic amendments.
2. Assess spatial variability response to applied treatments using TW alone and cyclic with CW.
3. Growth response of wheat crop to amelioration strategies of saline-sodic soils with the participation of local farmers.

Materials and Methods

The studies were initiated during the month of September, 2008 at three different sites. Two sites were

*Email: behzadmurtaza@yahoo.com

selected at Chak No. 316 and one at Chak No. 314 of Tehsil Toba Tek Singh. The experiment was laid out on permanent lay out having plot size of 18.0 m × 30.0 m at site 1, 15.75 m × 16.50 m at site 2 and 13.00 m × 28.78 m at site 3 using randomized complete block design with three replications. After laying out the experiment, composite soil samples were collected from 0-15 and 15-30 cm soil depths from each treatment plot. Samples were air-dried, ground and passed through a 2 mm sieve and mixed thoroughly. 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). Soil gypsum requirement was determined by Schoonover's method (1952). Sodium adsorption ratio (SAR) was calculated using Equation 1 while concentrations of Na^+, Ca^{2+} and Mg^{2+} were taken as $mmol_c\ L^{-1}$.

$$\text{SAR } (\text{mmol L}^{-1})^{1/2} = Na^+ / [(Ca^{2+} + Mg^{2+})/2)]^{1/2} \quad (1)$$

Soil particle-size was determined using hydrometer method (Bouyoucos, 1962). Infiltration rate was measured for the initial soil and after harvest of wheat crop by double ring infiltrometers (Bouwer, 1986). Soil bulk density was measured by drawing 0.050 m × 0.072 m undisturbed cores (Blake and Hartge, 1986) from 5-10 cm and 15-20 cm soil depths. All determinations were made in duplicate for each treatment and hence values presented here are average of 6 observations. The equation 2 was used to calculate RSC with concentrations of ions in $mmol_c\ L^{-1}$:

$$\text{RSC } (\text{mmol}_c\ \text{L}^{-1}) = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+}) \quad (2)$$

Four treatments were applied viz. T_1 = Tube well water (TW) alone, T_2 = TW + Gypsum @ 50% soil gypsum requirement (TW + G50), T_3 = TW–Canal water (CW) + G50 (TW–CW + G50), T_4 = TW–CW + Farm manure @ 25 Mg ha^{-1} (TW–CW + FM). The calculated amount of gypsum and FM were applied in respective plots as per designed treatments at all the three sites. Fertilizers NPK @ 130-115-62.5 kg ha^{-1} as urea, diammonium phosphate (DAP) and sulphate of potash, respectively, were applied uniformly in all the treatments. Full doses of P and K while half of N was applied at the sowing time. The remaining N was applied in two equal splits at tillering (50 days after sowing) and booting stages (90 days after sowing). Saline-sodic tube well water and canal water as per treatments were used for irrigation. Wheat (cv. SIS-13) was sown using 100 kg ha^{-1} seed in the first week of December, 2008 and harvested during second week of May, 2009. At maturity, economic yield and other growth components were recorded. Crop was harvested and threshed manually to record grain and straw yields. After the harvest of crop, soil samples were drawn from each treatment plot at 0-15 and 15-30 cm soil depths and were analyzed for chemical and physical properties following methods mentioned above. The data collected were analyzed statistically following ANOVA technique and treatment differences were evaluated using LSD test (Steel *et al*., 1997).

Results and Discussion

Physico-chemical properties of soils used in the experiment are given in Table 1. The tube-well water used for irrigation shows that it is saline-sodic and unfit for irrigation without the application of any amendment at all the three sites (Table 2).

Soil physical properties

Bulk density (BD) and infiltration rate (IR) of soils for each treatment plot were determined before and after the harvest of wheat crops. Before the start of experiment, IR of soils at three sites was about 0.3 cm h^{-1} which remained unchanged after the harvests of wheat (2008-09) crop at all the three sites. The IR is an important soil physical property that deals with leaching of excessive salts to affect desalination and desodication and IR of < 0.3 cm h^{-1} is considered low enough to leach the salts (Ghafoor *et al*., 2004). These soils also show the poor IR which was a problem in reclamation process. Before the start of experiment, BD at 5-10 cm soil depth ranged from 1.63 to 1.70 Mg m^{-3} at site 1, 1.63 to 1.67 Mg m^{-3} at site 2 and 1.70 to 1.77 Mg m^{-3} at site 3 (Figure 1). After the harvest of wheat, non-significant decrease in BD was observed at all the sites. However, at site 1, maximum percent decrease in BD was recorded with T_3 (2.23%) followed by T_4 (0.87%) and T_1 (0.51%) but increased with T_2 (1.80%) at 5-10 cm soil depth. The BD decreased at 15-20 cm soil depth and decreasing order remained as T_1 (1.24%) > T_3 (0.72%) > T_2 (0.66%) > T_4 (0.00%). At site 2, maximum percent decrease was with T_4 (2.34%) followed by T_3 (1.11%), T_1 (0.72%) and T_2 (0.00%) at 5-10 cm soil depth. The BD decreased at 15-20 cm and treatment effectiveness order was T_3 (4.54%) > T_2 (1.23%) > T_1 (0.34%) but increased with T_4 (0.71%). At site 3, maximum percent decrease in BD at 5-10 cm soil depth was with T_4 (0.83%) followed by T_3 (0.48%), T_2 (0.29%) and T_1 (0.00%) while the order was T_1 (1.09%) > T_4 (0.73%) > T_3 (0.55%) and increased with T_2 (1.67%) at 15-20 cm soil depth (Figure 1). After the harvest of wheat (2008-09) crop, there was an improvement in BD of soils but difference among the applied treatments remained non-significant as physical properties require long time to be changed significantly. The partial improvement in BD at the soil surface might be due to the use of high EC water for irrigation (Al-Nabulsi, 2001). Secondly, decrease in BD seems to be associated with the removal of Na^+ and consequently decreased dispersion of soil.

2). At site 3, maximum decrease in EC_e was with T_4 at 0-15 cm (69.68%) and 15-30 cm (73.20%) soil depths followed by T_3, T_2 and T_1 (Figure 2). Overall, maximum decrease in EC_e (72.65% at 0-15 cm and 77.62% at 15-30 cm) was at

Table 1: Physico-chemical properties of soils

Site	Treatment	pH_s		EC_e		B.D	
		Soil depths (cm)					
		0-15	15-30	0-15	15-30	5-10	15-20
1	TW	8.78	9.05	18.54	13.62	1.70	1.70
	TW + G50	8.96	8.64	17.60	12.55	1.70	1.74
	TW–CW + G50	8.81	8.79	24.13	18.76	1.65	1.67
	TW–CW + FM	8.97	8.45	16.88	19.75	1.63	1.67
2	TW	8.77	8.58	18.85	13.89	1.63	1.70
	TW + G50	8.74	8.51	14.18	17.55	1.65	1.71
	TW–CW + G50	8.77	8.84	16.99	16.34	1.65	1.72
	TW–CW + FM	8.77	8.85	17.44	17.33	1.67	1.65
3	TW	8.68	8.83	17.68	17.28	1.77	1.75
	TW + G50	8.71	8.78	17.39	17.04	1.70	1.65
	TW–CW + G50	8.68	8.64	16.11	17.91	1.75	1.67
	TW–CW + FM	8.67	8.78	15.70	18.06	1.74	1.64

Table 2: Analysis of tube-well water used for irrigation

Site	Parameter	unit	value	Permissible limit
1	EC	dS m^{-1}	2.38	<1.5
	SAR	$(mmol\ L^{-1})^{1/2}$	10.01	<10
	RSC	m $mol_c\ L^{-1}$	Nil	<2.5
2	EC	dS m^{-1}	2.33	<1.5
	SAR	$(mmol\ L^{-1})^{1/2}$	9.61	<10
	RSC	m $mol_c\ L^{-1}$	Nil	<2.5
3	EC	dS m^{-1}	2.29	<1.5
	SAR	$(mmol\ L^{-1})^{1/2}$	9.76	<10
	RSC	m $mol_c\ L^{-1}$	Nil	<2.5

Muhammed and Ghafoor (1992)

Soil chemical properties

The EC_e of soils before the start of the experiment ranged from 17.60 to 24.13, 14.18 to 18.85, 15.70 to 18.68 dS m^{-1} at 0-15 cm and from 12.55 to 19.75, 13.89 to 17.55, 17.04 to 18.06 dS m^{-1} at 15-30 cm soil depth at sites 1, 2 and 3, respectively (Figure 2). After the harvest of wheat (2008-09) crop, significant decrease in EC_e at both the soil depths was recorded at all the three sites. At site 1, maximum decrease in EC_e was observed with T_4 at both 0-15 cm (71.27%) and 15-30 cm (77.62%) soil depths followed by T_3, T_2 and T_1 (Figure 2). At site 2, maximum decrease in EC_e was with T_4 at 0-15 cm (72.65%) and 15-30 cm (73.17%) soil depths followed by T_3, T_2 and T_1 (Figure

sites 2 and 1, respectively. The application of FM along with cyclic use of canal and tube well waters gave significantly better results due to high rate of decomposition of organic matter that decreased soil pH_s and solubilized native calcium carbonate. Murtaza *et al*. (2009) found similar results with the application of FM plus cyclic use of fresh and tube well waters compared to that with gypsum. Gypsum application resulted in relatively less decrease in EC_e compared to that with FM because of its low solubility and less time available during one crop. However, low solubility of gypsum is useful to sustain electrolyte concentration in soil solution over time to favorably affect the hydraulic conductivity (HC) of soils (Rhoades, 1993; Ghafoor *et al*., 2008) and reasonably high HC is pre-requisite for the reclamation of sodic and saline-sodic soils (Ghafoor *et al*., 2004).

The initial pH_s ranged from 8.78 to 8.97, 8.74 to 8.77 and 8.67 to 8.71 at 0-15 cm depth and 8.45 to 9.05, 8.51 to 8.85 and 8.64 to 8.83 at 15-30 cm soil depth at sites 1, 2 and 3, respectively. After the harvest of wheat (2008-09) in May 2009, non-significant decrease in pH_s for 0-15 and 15-30 cm soil depths was observed at all the three sites except at 0-15 cm of site 1 (Figure 3). Overall, maximum decrease in pH_s was 8.32% at 0-15 cm and 8.32% at 15-30 cm at site 1 followed by sites 2 and 3, respectively.

The initial SAR of soils ranged from 32.5 to 45.3, 36.1 to 55.7 and 23.2 to 30.7 $(mmol\ L^{-1})^{1/2}$ at 0-15 cm depth while it was 31.2 to 46.7, 34.3 to 37.6 and 36.5 to 41.2

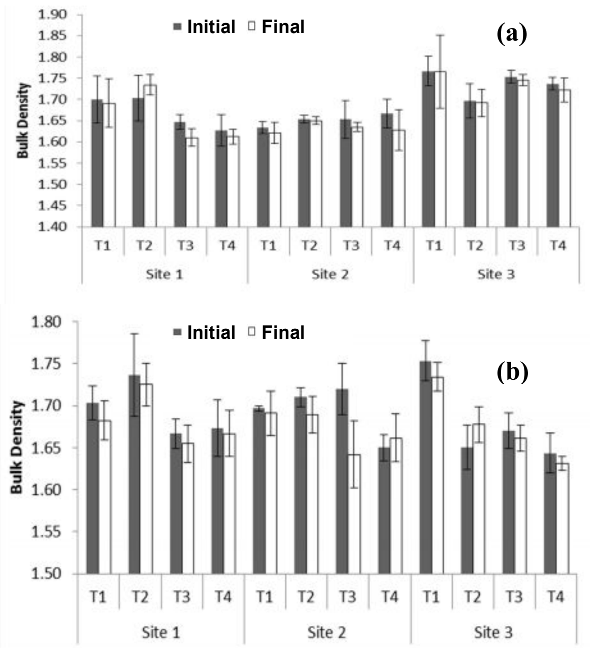

Figure 1: Bulk density of the soil before and after experiment at (a) 5-10 cm and (b) 15-20 cm soil depths

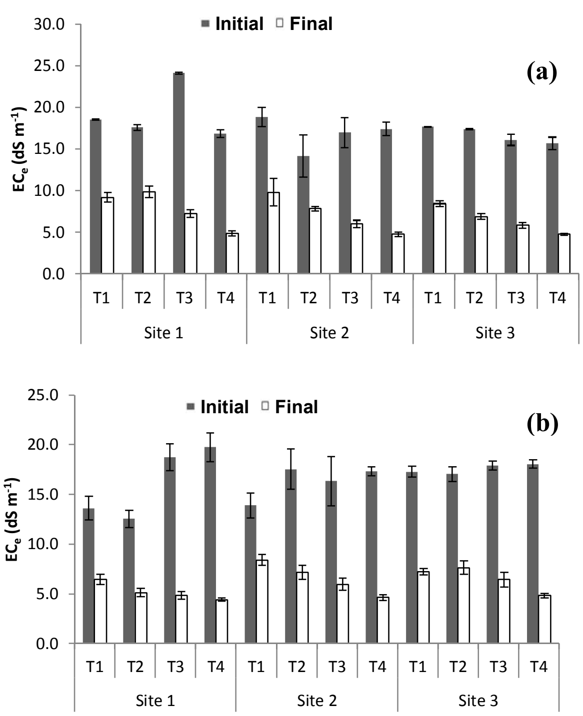

Figure 2: EC_e of the soil before and after experiment at (a) 0-15 cm and (b) 15-30 cm soil depths

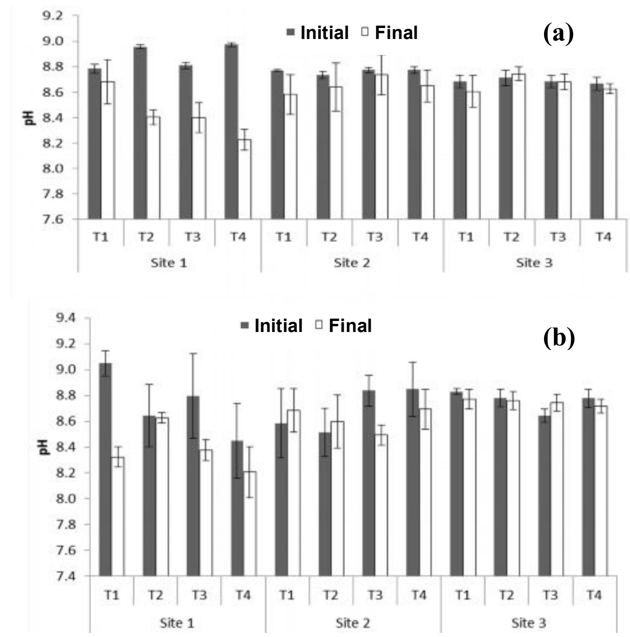

Figure 3: pH_s of the soil before and after experiment at (a) 0-15 cm and (b) 15-30 cm soil depths

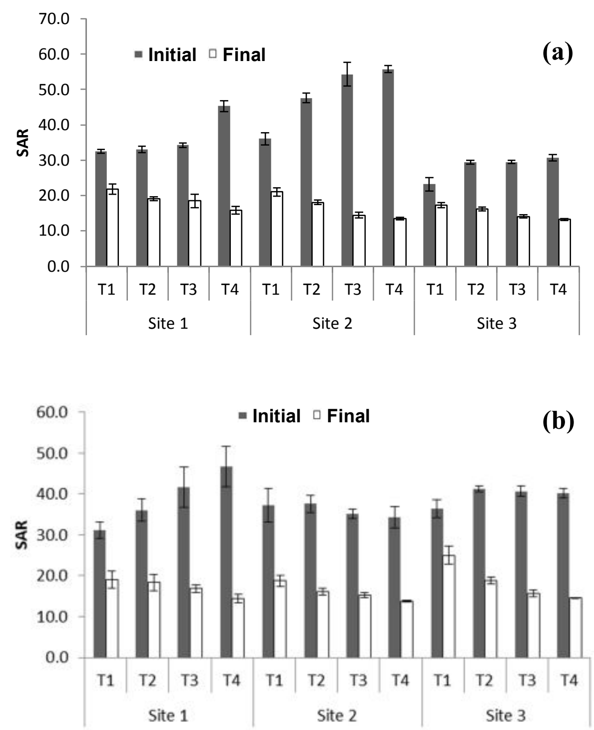

Figure 4: SAR of the soil before and after experiment at (a) 0-15 cm and (b) 15-30 cm soil depths

(mmol $L^{-1})^{1/2}$ at 15-30 cm soil depth at sites 1, 2 and 3, respectively. After the harvest of wheat (2008-09), treatments significantly affected SAR at both the soil depths at all the three sites. At site 1, maximum decrease in SAR was recorded with T_4 at both 0-15 cm (64.90%) and 15-30 cm (69.16%) soil depths followed by T_3, T_2 and T_1 (Figure 4). At site 2, maximum decrease was with T_4 at 0-15 cm (75.76%) and 15-30 cm (59.48%) depths followed by T_3, T_2 and T_1 (Figure 4). At site 3, maximum decrease in SAR was with T_4 at 0-15 cm (56.68%) and 15-30 cm (63.93%) soil depths followed by T_3, T_2 and T_1 (Figure 4). Maximum decrease in SAR was with the application of FM and gypsum at all the three sites. The FM tended to increase CEC of soils and dissolved native calcite that provided Ca^{2+} in soil solution to induce Na^+-Ca^{2+} exchange (Ghafoor, 1999). The decrease in SAR with simple leaching with TW alone and in cyclic use with canal water could be attributed to in-situ mineral weathering (Rhoades *et al*., 1968; Oster and Shainberg, 1979), supplying Ca^{2+} in soil solution (Ghafoor, 1999), causing valence dilution (Eaton and Sokoloff, 1935) and the action of plant roots (Qadir and Oster, 2002, 2004) through evolving CO_2 during root respiration.

Crop growth

At site 1, there was significant effect of treatments on growth parameters of wheat (Figure 5). Maximum grain yield (kg ha^{-1}) was recorded with T_4 (3656) followed by T_3 (3389), T_2 (3310) and T_1 (2883). The same trend was observed in straw yield (kg ha^{-1}), i.e. maximum with T_4 (4826) followed by T_3 (4472), T_2 (4369) and minimum with T_1 (3545). At site 2, treatments significantly affected the straw and grain yield of wheat (Figure 5). Maximum grain yield (kg ha^{-1}) was obtained with T_4 (3531) followed by T_3 (3311), T_2 (3159) and T_1 (2841). The straw yield (kg ha^{-1}) was in the decreasing order of T_4 (4624) > T_3 (4372) > T_2 (3759) > T_1 (3750). Similarly, at site 3, grain and straw yields were significantly affected by the treatments (Figure 5). Maximum grain yield (kg ha^{-1}) was recorded with T_4 (3826) followed by T_3 (3650), T_2 (3459) and T_1 (3060) while straw yield (kg ha^{-1}) was maximum with T_4 (4707) followed by T_3 (4489), T_2 (4289) and T_1 (3672).

Grain and straw yields of wheat remained below the varietal production potential due to high EC_e and SAR of soils. Ayers and Westcot (1985) reported 50% reduction in grain yield at soil SAR 50 (mmol $L^{-1})^{1/2}$ and EC_e 13 dS m^{-1}. Gypsum and farm manure improved physical as well as chemical properties of soils which proved beneficial for wheat. Both the amendments increased the concentration of Ca^{2+} in soil solution which decreased SAR of soil more rapidly than EC_e. This factor is quite favorable for wheat crop which is better tolerant to EC_e but sensitive to SAR of the soil. The FM was the best amendment in this regard as it provided additional nutrients in the form of improving organic matter of soil which improved grain and straw yields of wheat. In the present studies, economics was computed using the market prices of common and variable inputs while using support price of wheat yield. Economic analysis of the applied treatments showed that maximum net benefit (Rs ha^{-1}) of 93765, 89629 and 83761 remained at sites 3, 1 and 2, respectively with TW–CW + FM followed by TW–CW + G application (Table 3). In addition, the indirect benefits of soil reclamation include appreciation in land value, increased farm employment and an increase in food production.

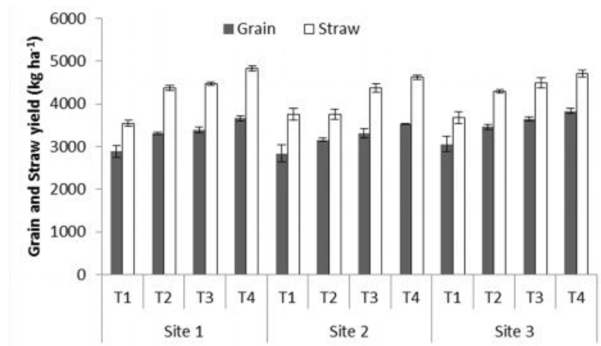

Figure 5: Effect of treatments on grain and straw yields of wheat crop

Conclusions

Crop production on salt-affected soils is adversely affected due to salt toxicity, poor soil physical/chemical properties and nutritional imbalances. Non-significant changes in bulk density while no change in infiltration rate were recorded mainly because of single cropping period. The cyclic irrigation of canal and tube well waters along with the application of gypsum or farm manure significantly decreased EC_e and SAR of soils and produced maximum grain and straw yields of wheat. Economically, cyclic use of TW and CW with FM and gypsum proved reasonably good indicating that external direct or indirect source of Ca^{2+} is required for colonization of saline-sodic soils. The effect of external and internal source of Ca^{2+} is dependent on soil type and length of time.

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Table 3: Economic evaluation of treatments (Rs ha^{-1}) during reclamation of saline-sodic soils

Site	Treatment	Gross income (Rs ha^{-1})		Total	Expenditure (Rs ha^{-1})	Net Income (Rs ha^{-1})
		Grain	Straw			
1	TW	72075	23042	95118	31306	63811
	TW + G50	82750	28398	111149	31306	79842
	TW–CW + G	84725	29068	113793	32950	80843
	TW–CW + FM	91400	31369	122769	33140	89629
2	TW	71025	24375	95400	34060	61340
	TW + G50	78975	24433	103409	33370	70038
	TW–CW + G	82775	28418	111193	34750	76443
	TW–CW + FM	88275	30056	118331	34570	83761
3	TW	76500	23868	100368	32338	68030
	TW + G50	86475	27878	114354	32716	81637
	TW–CW + G	91250	29178	120429	32535	87893
	TW–CW + FM	95650	30595	126246	32480	93765

The rate of wheat grain was @ Rs. 1000/40 kg and straw @ 260/40 kg. The cost of wheat sowing including ploughing, planking and other cultural operations was Rs. 4396 ha^{-1}; wheat harvesting/threshing Rs. 3705 ha^{-1}, urea @ Rs. 440/bag, DAP @ Rs 1100/bag. The cost of gypsum was Rs. 50/bag and gypsum broadcasting was Rs. 240 ha^{-1}.

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