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USE OF BRACKISH WATER FOR THE RECLAMATION OF DENSE SALINE-SODIC SOILS BY AUGER HOLE TECHNOLOGY AND ECONOMIC GROWTH OF WHEAT CROP

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Currently, availability of good-quality water is falling short of the crop requirement, particularly in arid and semi-arid regions of Pakistan. A field experiment was conducted on dense saline-sodic soils at Tehsil Toba Tek Singh at three sites. The initial EC_e, SAR and pH_s of the soils ranged from 9.86 to 25.30 dS m^{-1}, 17.1 to 46.7 and 7.57 to 7.98, respectively at 0-15 cm depth. The treatments were: T_1= Tube well water (TW) alone, T_2= TW–Canal water (CW), T_3= TW–CW + one auger hole per 30 m^2 refilled with gypsum and rice husk, T_4= TW–CW + one auger hole per 60 m^2 refilled with gypsum and rice husk. Overall T_3 was best in decreasing EC_e, SAR and pH_s at all three sites. Maximum decrease (%) in EC_e, SAR and pH_s was 70.23 (T_3) at site 1, 69.67 (T_4) at site 2, and 4.64 (T_1) at site 1, respectively at 0-15 cm depth. Maximum wheat grain yield (4180, 3805 and 4259 kg ha^{-1} at sites 1, 2 and 3, respectively) were recorded with T_3. Maximum benefit cost ratio was 3.47, 3.38 and 2.95 with TW–CW + one auger hole per 30 m^2 refilled with gypsum and rice husk (1:1 ratio by volume) at sites 3, 1 and 2, respectively.
Keywords: Auger hole, Benefit, Husk, Reclamation, Saline-sodic soil, Brackish water

INTRODUCTION

Pakistan has the largest contiguous gravity flow canal irrigation system, but is falling short of good-quality water due to increased cropping intensity (Mohtadullah *et al*., 1993) and increased demands for households and industry over the years. In Pakistan the agriculturally important areas are arid or semi-arid where freshwater supplies are limited to meet crop water requirements especially at critical stages. This shortage is being fulfilled by exploiting groundwater resources which is mostly brackish in nature. At present, more than 8×10^5 tube wells are pumping approximately 6.77×10^{10} m^3 ground water (Anonymous, 2008), of which about 70–80% is hazardous for agriculture owing to high electrical conductivity (EC), sodium adsorption ratio (SAR) and/or residual sodium carbonate (RSC) which are adversely affecting the crops (Latif and Beg, 2004).

Salt-affected soils are characterized either by the presence of excess levels of soluble salts and/or high amounts of sodium ions (Na^+) in the soil solution which have adverse effects of salts. Excess of salts can affect crop yield by increasing the osmotic pressure and thereby making the water in the soil less available for the plants and/ or by specific toxicity of some ions taken up above critical concentrations. Sodicity causes the deterioration in physical properties by slaking, swelling and dispersion of clay; also cause surface crusting and hardsetting (Quirk, 2001) which result in structureless soils. These may lead to negatively affect water and air movement, plant-available water holding capacity, root penetration, runoff, erosion and tillage and sowing operations. In addition, imbalances in plant-available nutrients in both saline and sodic soils affect plant growth (Naidu and Rengasamy, 1993; Qadir and Schubert, 2002).

In Pakistan, salt-affected soils cover an area of about 6.67mha (Khan, 1998), of which about 60% is saline-sodic. Such soils cannot be reclaimed economically by leaching without the application of a Ca^{2+} source (Ghafoor *et al.,* 1997) because of deteriorated physical properties of soils. Most of the saline-sodic and sodic soils have poor internal drainage which otherwise is a pre-requisite for their reclamation. To facilitate adsorbed Na^+ replacement with Ca^{2+}, a good drainage is a pre-requisite because plough pan (dense soil layer) generally exists in saline-sodic fine textured soils (Hussain *et al.,* 2000). Reclamation of saline-sodic soils involves not only the leaching of soluble salts, but also improvement of the soil physical conditions to enhance the rate of passage of applied water through soils, following soil application of gypsum. The use of deep ploughing and subsoiling techniques along with the use of gypsum, for the amelioration of saline-sodic/sodic soils have received considerable attention in several parts of the world (Rasmussen *et al.,* 1972; Qadir *et al.,* 2001), but deep ploughing/subsoiling cost, however, makes the practice unacceptable to farmers under ambient farm financial conditions (Grevers and De Jong, 1993). If the vertical drainage of surface water is successful, then such a practice could be adopted at nominal cost by resource poor farmers, majority of whom possess very limited land holding. Vertical drainage will not only flush down excess saline water within a reasonable time, but will also help to avoid hypoxia/anoxia to wheat crop during early phases of reclamation.

Appropriate management of saline-sodic waters and salt affected soils has proven economical (Murtaza *et al*., 2006). For example, the use of high electrolyte waters with low concentrations of Na^+ could be useful during the initial amelioration phase of sodic and saline-sodic soils (Ghafoor *et al*., 2008; Murtaza *et al*., 2009) because it helps to improve the infiltration rate, bulk density and soil structure (Oster and Schroer, 1979). Rice–wheat rotation is considered suitable during reclamation of saline-sodic soils because of the added benefit of monsoon rains for rice which could dilute the effects of salinity and sodicity. Wheat is relatively tolerant to salinity whereas rice is more tolerant to sodicity and thus has proved promising crops to yield during colonization of saline-sodic soils (Qadir *et al*., 2001).

MATERIALS AND METHODS

The present study was initiated in the month of September 2008, at three different sites. Two sites were located in Chak No.316 and one in Chak No. 314 of Tehsil Toba Tek Singh. The experiment was laid out on permanent lay out having plot size 15.61 m × 30.45 m at site 1, 14.55 m × 16.52 m at site 2 and 14.55 m × 30.91 m at site 3 following randomized complete block design with three replications. After lay out of 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. The pH of saturated soil paste (pH_s) was recorded with SensoDirect 100 pH meter. Extract from the saturated soil paste was obtained by applying positive pressure with pressure pump. The electrical conductivity of saturation extract (EC_e) was determined with Jenway Model-4070 conductivity meter. Soluble Ca^{2+} + Mg^{2+} were determined by titrating against standard versinate solution. Saturation extract was titrated against 0.01 *N* H_2SO_4 using phenolphthalein indicator to colorless end point for CO_3^{2-}. To the same sample, for HCO_3^- methyl orange indicator was added and titrated against 0.01 *N* H_2SO_4 to pinkish yellow end point. Saturation extract was titrated against 0.005 *N* $AgNO_3$ solution using K_2CrO_4 indicator to a brick red end point for chloride. A series of NaCl standard solutions (2, 4, 6, 8, 10, 12, 14 and 16 ppm Na^+) were used to standardize the Jenway PFP 7 Flame Photometer for the determination of Na^+ in saturation extract. Sample readings were recorded and converted to ppm from the graph prepared using instrument reading of the standard solutions using methods described by the US Salinity Laboratory Staff (1954) and Page *et al*. (1982). Soil gypsum requirement was determined by Schoonover's method (Schoonover, 1952). Sodium adsorption ratio (SAR) was calculated using Equation 1 while concentrations of Na^+, Ca^{2+} and Mg^{2+} taken as $mmol_c\ L^{-1}$.

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

Soil particle-size was determined using hydrometer method (Bouyoucos, 1962). Soil bulk density was measured by drawing 0.050 m × 0.072 m undisturbed cores (Blake and Hartge, 1986) from 5-10 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 $mmol_c\ L^{-1}$:

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

The treatments employed were T_1) Tube well water (TW) alone, T_2) TW–Canal water (CW), T_3) TW–CW + one auger hole per 30 m^2 refilled with gypsum and rice husk (Rice husk and gypsum were applied on volume basis at 1:1 ratio. The auger hole was made 90 cm deep and 11 cm in diameter). The equal amounts (on volume basis) of each of gypsum and rice husk were mixed and filled in the holes, T_4) TW–CW + one auger hole per 60 m^2 refilled with gypsum and rice husk (1:1 ratio by volume). Gypsum was applied @ 25% soil gypsum requirement in all the treatment plots including control at all three sites. Fertilizers NPK @ 130, 115, 62.5 kg ha^{-1} as urea, diammonium phosphate and sulphate of potash, respectively were applied uniformly in all the treatments during land preparation. 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 (90 days after sowing) stages. Saline-sodic and canal waters as per treatments were used for irrigation. A total of 5 irrigations each of 3" were applied according to designed treatments. Wheat (cv. SIS-13) was sown using 100 kg ha^{-1} seed in December 2008 and harvested in 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 collected 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 average mean temperature during winter 2008-9 remained 19.20 °C and the total rainfall received during the entire growth period was 83 mm. The data collected was analyzed statistically following ANOVA technique and treatment differences were evaluated using least significant difference (LSD) test (Steel *et al*., 1997).

RESULTS AND DISCUSSION

The analyses of tube-well water used for irrigation shows that water is saline-sodic and unfit for irrigation according to

US Salinity Laboratory Staff (1954) without the application of any amendment at all the three sites (Table 1). The electrolyte concentration of water applied to ameliorate saline-sodic and sodic soils is an important factor that influences water transmission rate through the soils during the amelioration process. Initially, use of high electrolyte concentration of the water affects the soil permeability and subsequently in successive dilutions, of the valence dilution effect (Reeve and Bower, 1960).

***Soil physical properties*:** Salinity and sodicity have great influence on soil physical properties particularly on bulk density (BD) and infiltration rate (IR). The bulk density of soils at each treatment plot was determined before and after the harvest of wheat crop. The BD values (Mg m^{-3}) before the start of experiment ranged from 1.34 to 1.38, 1.44 to 1.47, 1.49 to 1.53 at 5-10 cm soil depth and 1.40 to 1.48,1.40 to 1.43 and 1.46 to 1.49 at15-20 cm soil depth at sites 1, 2 and 3, respectively (Table 2). After the harvest of wheat 2008-09, no significant changes in bulk density were recorded (Table 2). It is natural because changes in physical properties are time dependent processes which require long time to bring a significant change. After the harvest of wheat 2008-09 crop there are slight changes in physical properties of soils in terms of BD of soils although the differences were not statistically significant. The change in BD at the soil surface might be due to the use of high EC water applied for irrigation (Al-Nabulsi, 2001) which increased hydraulic conductivity of soils and facilitated leaching of Na^+ causing the change in BD.

***Soil chemical properties*:** Soil salinity/sodicity significantly limits crop production and consequently has negative effects on osmotic potential that leads to poor crop yields on salt-affected soils. Growth of most of the crop plants in salt-affected fields is usually poor.

***Electrical conductivity (EC_e)*:** The EC_e of the soils before the start of experiment ranged from 18.71 to 25.3, 12.1 to 16.07 and 9.86 to 13.43 dS m^{-1} at 0-15 cm depth and 17.30 to 19.66, 11.74 to 13.58 and 10.23 to 10.88 dS m^{-1} at 15-30 cm soil depth at sites 1, 2 and 3, respectively (Tables 3). After the harvest of wheat 2008-09, there were significant decreases in EC_e at both the soil depths at all three sites. At site 1, maximum decrease in EC_e was with T_3 at both 0-15 cm (70.23%) and 15-30 cm (73.45%) soil depths followed by T_2, T_4 and T_1 at 0-15 cm depth and T_4, T_2 and T_1 at 15-30 cm depth (Table 3). At site 2, maximum decrease in EC_e was with T_3 at both 0-15 cm (69.51%) and 15-30 cm (61.64%) soil depths followed by T_4, T_2 and T_1 (Table 3). At site 3, maximum decrease in EC_e was with T_3 at both 0-15 cm (53.65%) and 15-30 cm (58.73%) soil depths followed by T_4, T_2 and T_1 (Table 3). Overall maximum decrease in EC_e was 70.23% at 0-15 cm soil depth and 73.23% at 15-30 cm depth at site 1. After the harvest of wheat 2008-09, EC_e decreased significantly by the applied treatments at all the three sites and maximum decrease occurred with T_3 followed by T_4, T_2 and T_1 at both the soil depths with one exception for site 1 at 0-15 cm depth where the order was T_3 followed by T_2, T_4 and T_1 (Tables 3). There were significant differences among the treatments, which showed the impact of vertical drainage strategy through auger holes, for saline-sodic soils, regarding significant decrease in soluble salts level from the surface soil. Several factors might be responsible for this, like number of holes per unit area and illuviation of clay particles, which plugged the soil pores. To sustain soil health at last stage of reclamation, good quality water irrigation is pre-requisite, especially for fine textured soils as in the present study. Tube well or canal water application alone resulted in relatively less decrease in EC_e compared to that with canal plus tube well water along with auger hole 30 m^{-2} refilled with gypsum and rice husk (1:1 ratio).

***Soil pH*:** Soil pH has a considerable impact on controlling the dynamics of plant nutrients, especially the availability of micronutrients such as Zn, Cu, Fe and Mn (Naidu and Rengasamy, 1993).

The pH_s of soil before the start of experiment ranged from 7.57 to 7.98, 7.67 to 7.72, 7.61 to 7.89 at 0-15 cm depth and 8.04 to 8.14, 7.66 to 7.79, 7.73 to 7.87 at 15-30 cm soil depth at site 1, 2 and 3, respectively (Table 4). After the harvest of wheat 2008-09 there was non-significant changes in pH_s for both 0-15 and 15-30 cm soil depths at all three sites. At site 1, maximum decrease in pH_s was 4.64% at 0-15 cm with T_1 and 6.34% at 15-30 cm soil depth with T_4 (Table 4). At site 2, maximum decrease in pH_s was 2.21% for T_4 at 0-15 cm and 2.82% at 15-30 cm soil depth with T_3. At site 3, decrease in pH_s was 1.14% at 0-15 cm and 0.13% at 15-30 cm soil depth with T_4 only. Overall, maximum decrease in pH_s was 4.64% at 0-15 cm and 6.34% at 15-30 cm at site 1 followed by 2 and 3, respectively. The results regarding decrease in pH_s are quite inconsistent because of the reason that it is parameter of soil that changes over a period of time and also may be due to buffering of soils.

***SAR*:** Water and soil sodicity are expressed in terms of SAR, with high SAR values having the potential for deterioration in soil structure, low infiltration rate, specific-ion effect, and deficiencies of several micro and macro nutrients (Murtaza *et al*., 2006). The SAR of the soils before the start of experiment ranged from 24.5 to 46.7, 43.1 to 45.5, 17.1 to 22 at 0-15 cm depth and 57.4 to 65.5, 32.8 to 36.8, 25.76 to 30.84 at 15-30 cm soil depth at sites 1, 2 and 3, respectively. After the harvest of wheat 2008-09, there were marked decreases in SAR at both soil depths at all three sites. At site 1, maximum decrease in SAR was 65.74% at 0-15 cm soil depth and 72.17% at 15-30 cm soil depth with T_3 followed by T_4, T_1 and T_2 (Table 5). At site 2, maximum decrease in SAR was 69.67% with T_4 and 61.81% with T_3 at 0-15 and 15-30 cm soil depths, respectively. At site 3, maximum decrease in SAR was 36.33% and 54.93% at 0-15 and 15-30 cm soil depths with T_3 followed by

Table 1. Analysis of tube-well water used for irrigation (Average of 5 observations)

Site	Parameter	unit	Value	Permissible limit[1]		
				Fit	Marginal	Unfit
1 and 2	EC	dS m^{-1}	2.38	<0.8	0.8-1.0	≥1
	SAR	$(mmol\ L^{-1})^{1/2}$	10.01	<8	8.0-10.0	≥10
	RSC	$mmol_c\ L^{-1}$	Nil	<1.25	1.25-2.50	≥2.50
3	EC	dS m^{-1}	2.29	<0.8	0.8-1.0	≥1
	SAR	$(mmol\ L^{-1})^{1/2}$	9.76	<8	8.0-10.0	≥10
	RSC	$mmol_c\ L^{-1}$	Nil	<1.25	1.25-2.50	≥2.50

[1](US Salinity Lab Staff, 1954).

Table 2. Effect of treatments on bulk density (Mg m^{-3}) at 5-10 and 15-20 cm soil depths

Site 1	Treatment	5-10 cm soil depth		15-20 cm soil depth	
		Initial[a]	Post-wheat[b]	Initial[a]	Post-wheat[b]
1	$T_{1:}$ TW	1.38	1.37	1.48	1.45
	T_2:TW–CW	1.34	1.34	1.45	1.40
	$T_{3:}$ TW–CW + Auger hole 30 m^{-2}	1.34	1.34	1.43	1.41
	$T_{4:}$ TW–CW + Auger hole 60 m^{-2}	1.38	1.37)	1.40	1.38
2	$T_{1:}$ TW	1.45	1.45	1.43	1.43
	T_2:TW–CW	1.45	1.44	1.43	1.43
	$T_{3:}$ TW–CW + Auger hole 30 m^{-2}	1.44	1.42	1.43	1.42
	$T_{4:}$ TW–CW + Auger hole 60 m^{-2}	1.47	1.46	1.40	1.39
3	$T_{1:}$ TW	1.52	1.51	1.48	1.49
	T_2:TW–CW	1.52	1.52	1.48	1.47
	$T_{3:}$ TW–CW + Auger hole 30 m^{-2}	1.49	1.49	1.46	1.44
	$T_{4:}$ TW–CW + Auger hole 60 m^{-2}	1.53	1.51	1.49	1.49

[a]Initial bulk density (Mg m^{-3}) before the start of experiment; [b]post-wheat (2008-09) bulk density (Mg m^{-3}). Treatment effects were not significant.

Table 3. Effect of treatments on EC_e (dS m^{-1}) of soils at different sites

Site 1	Treatment	0-15 cm soil depth		15-30 cm soil depth	
		Initial[a]	Post-wheat[b]	Initial[a]	Post-wheat[b]
1	$T_{1:}$ TW	19.01	9.52 a(-49.92)	17.30	9.40 a(-45.66)
	T_2:TW–CW	25.30	9.12 a(-63.95)	19.66	8.84 ab(-55.04)
	$T_{3:}$ TW–CW + Auger hole 30 m^{-2}	18.71	5.57 b(-70.23)	17.44	4.63 c(-73.45)
	$T_{4:}$ TW–CW + Auger hole 60 m^{-2}	23.27	8.53 a(-63.34)	18.45	6.23 bc(-66.23)
	LSD		1.60*		2.82*
2	$T_{1:}$ TW	14.64	7.61 a(-48.02)	11.74	6.63 a(-43.53)
	T_2:TW–CW	13.93	6.62 b(-52.48)	12.62	6.29 a(-50.16)
	$T_{3:}$ TW–CW + Auger hole 30 m^{-2}	16.07	4.90 c(-69.51)	13.27	5.09 b(-61.64)
	$T_{4:}$ TW–CW + Auger hole 60 m^{-2}	12.10	5.66 c(-53.22)	13.58	5.80 ab(-57.29)
	LSD		0.83*		1.08*
3	$T_{1:}$ TW	11.24	8.12 a(-27.76)	10.36	7.82 a(-24.52)
	T_2:TW–CW	13.43	8.93 a(-33.51)	10.23	7.70 a(-24.73)
	$T_{3:}$ TW–CW + Auger hole 30 m^{-2}	9.86	4.57 c(-53.65)	10.88	4.49 c(-58.73)
	$T_{4:}$ TW–CW + Auger hole 60 m^{-2}	11.00	6.42 b(-41.64)	10.62	5.89 b(-44.54)
	LSD		1.47*		1.25*

[a]Initial EC_e (dS m^{-1}) before the start of experiment; [b]post-wheat (2008-09) EC_e (dS m^{-1}); Values in a column sharing same letter(s) are statistically similar at P = 0.05; * Treatments differed significantly at P = 0.05; Values in parentheses indicate per cent increase (+) or decrease (-) over the respective initial EC levels.

Table 4. Effect of treatments on pH_s of soils at different sites

Site 1	Treatment	0-15 cm soil depth		15-30 cm soil depth	
		Initial[a]	Post-wheat[b]	Initial[a]	Post-wheat[b]
1	T_1: TW	7.98	7.61(-4.64)	8.12	7.71(-5.05)
	T_2:TW–CW	7.57	7.61(0.53)	8.07	7.79(-3.47)
	T_3: TW–CW + Auger hole 30 m^{-2}	7.74	7.39(-4.52)	8.14	7.78(-4.42)
	T_4: TW–CW + Auger hole 60 m^{-2}	7.65	7.58(-0.92)	8.04	7.53(-6.34)
2	T_1: TW	7.72	7.64(-1.04)	7.77	7.63(-1.80)
	T_2:TW–CW	7.71	7.67(-0.52)	7.66	7.62(-0.52)
	T_3: TW–CW + Auger hole 30 m^{-2}	7.67	7.56(-1.43)	7.79	7.57(-2.82)
	T_4: TW–CW + Auger hole 60 m^{-2}	7.69	7.52(-2.21)	7.79	7.60(-2.44)
3	T_1: TW	7.85	7.91(0.76)	7.84	7.84(0.00)
	T_2:TW–CW	7.85	7.94(1.15)	7.87	7.88(0.13)
	T_3: TW–CW + Auger hole 30 m^{-2}	7.61	7.74(1.71)	7.73	7.79(0.78)
	T_4: TW–CW + Auger hole 60 m^{-2}	7.89	7.80(-1.14)	7.86	7.85(-0.13)

[a]Initial pH_s before the start of experiment; [b]post-wheat (2008-09) pH_s. Treatment effects were not significant.
Values in parentheses indicate per cent increase (+) or decrease (-) over the respective initial pH_s levels.

Table 5. Effect of treatments on SAR of soils at different sites

Site 1	Treatment	0-15 cm soil depth		15-30 cm soil depth	
		Initial[a]	Post-wheat[b]	Initial[a]	Post-wheat[b]
1	T_1: TW	25.8	19.5 a(-24.42)	64.6	20.1(-68.89)
	T_2:TW–CW	24.5	18.8 ab(-23.27)	65.5	22.8(-65.19)
	T_3: TW–CW + Auger hole 30 m^{-2}	46.7	16.0 b(-65.74)	61.8	17.2(-72.17)
	T_4: TW–CW + Auger hole 60 m^{-2}	32.6	17.8 ab(-45.40)	57.4	18.5(-67.77)
	LSD		3.06*		NS
2	T_1: TW	44.5	18.1 a(-59.33)	34.5	19.3 a(-44.06)
	T_2:TW–CW	43.1	16.1 ab(-62.65)	36.8	19.0 a(-48.37)
	T_3: TW–CW + Auger hole 30 m^{-2}	45.0	13.7 b(-69.56)	36.4	13.9 b(-61.81)
	T_4: TW–CW + Auger hole 60 m^{-2}	45.5	13.8 b(-69.67)	32.8	16.2 b(-50.61)
	LSD		3.71*		2.39*
3	T_1: TW	17.1	16.1 ab(-5.85)	25.76	19.2 a(-25.47)
	T_2:TW–CW	19.5	16.9 a(-13.33)	26.64	17.5 a(-34.31)
	T_3: TW–CW + Auger hole 30 m^{-2}	21.5	13.69 b(-36.33)	30.84	13.9 b(-54.93)
	T_4: TW–CW + Auger hole 60 m^{-2}	22.0	14.6 ab(-33.64)	28.85	14.7 b(-49.05)
	LSD		2.69*		2.58*

[a]Initial SAR before the start of experiment; [b]post-wheat (2008-09) SAR; Values in a column sharing same letter(s) are statistically similar at P = 0.05; NS, Treatments differed non-significantly at P = 0.05; * Treatments differed significantly at P = 0.05; Values in parentheses indicate per cent increase (+) or decrease (-) over the respective initial SAR levels.

T_4, T_2 and T_1. Overall maximum decrease in SAR was 69.67% at 0-15 cm and 72.17% at 15-30 cm soil depth at sites 2 and 1. The rate of decrease in SAR remained higher during the reclamation of saline-sodic soils at all the three sites. A decrease in SAR with simple leaching, especially in control plots was likely due to in-situ mineral weathering (Oster and Shainberg, 1979), naturally present Ca^{2+} + Mg^{2+} in irrigation water, valence dilution (Eaton and Sokoloff, 1935) and partially due to dissolution of native lime from soil under the influence of CO_2 released by roots (Qadir and Oster, 2004). Removal of soluble salts as well as replaced cations from the root zone to deeper soil layers acts as a sink, resulting in promotion of Na^+- Ca^{2+} exchange reaction. The occupation of exchange sites by Ca^{2+} also acts as a sink to increase the dissolution of applied gypsum and native soil lime. This clearly favors well-established efficiency of gypsum to sustain soil health within a reasonable time. Soil improvement with respect to SAR was more at site 1 than that at site 2. Final EC_e and SAR values indicated that reclamation of saline-sodic soils starts as soon as agricultural operations are initiated (Ghafoor *et al.,* 1997), but to expedite the Na^+-Ca^{2+} exchange, external source of calcium like gypsum is useful. It could be concluded that one irrigation of CW and one with TW along with auger hole 30 m^{-2} refilled with gypsum and rice husk (1:1 ratio) affect soil reclamation even using highly saline-sodic water within a reasonable time.

***Crop Yield*:** Wheat is a common winter crop in the Indus

Plains of Pakistan and is preferred by the farmers on normal soils as well as during reclamation of saline and sodic soils. Regarding the yield of grain crops, the auger hole treatments differed significantly, since the leaching of soluble salts and final SAR values of the soils decreased with significant differences compared with other treatments (Table 3 and 5).

At site 1, there was significant effect of treatments on grain yield of wheat (Table 6). Maximum grain yield (kg ha^{-1}) was obtained with T_3 (4180) followed by T_4 (3924), T_2 (3121) and T_1 (2636). The order for straw yield (kg ha^{-1}) was T_4 (3043) > T_3 (3030) > T_1 (2930) > T_2 (2910). At site 2, the treatments significantly affected the grain and straw yields of wheat. Maximum grain yield (kg ha^{-1}) was recorded with T_3 (3805) followed by T_4 (3364), T_2 (3122) and minimum with T_1 (2709) while straw yield was maximum with T_4 (3092) followed by T_3 (3034), T_2 (2761) and minimum with T_1 (2533). At site 3, the grain and straw yields of wheat were significantly affected by the applied treatments. Maximum grain yield (kg ha^{-1}) was recorded with T_3 (4259) followed by T_4 (4022), T_2 (3562) and minimum with T_1 (3096). Straw yield (kg ha^{-1}) also remained maximum with T_3 (3294) followed by T_4 (3197), T_2 (2842) and minimum with T_1 (2718). Within a treatment, grain and straw yields of wheat remained the highest at site 3. The best yield at site 3 seems due to low initial EC_e and SAR. The cyclic irrigation of CW and TW along with auger hole 30 m^{-2} produced the highest grain yield at all the three sites indicating that low quality waters could be exploited for irrigation on salt-affected soils by following this strategy. The amelioration of salt-affected soils could help remove the rural to urban migration by providing farm employment, which in turn will help rural poverty alleviation.

***Economic Evaluation of Treatments*:** In the present study, economics was computed using the market prices of common and variable inputs and prices of outputs (wheat grains and straw). Maximum benefit cost ratio (Benefit:cost) was 3.47, 3.38 and 2.95 with TW–CW + one auger hole per 30 m^2 refilled with gypsum and rice husk (1:1 ratio by volume) at sites 3, 1 and 2, respectively (Table 7). Overall, the treatment involving gypsum remained promising, the benefits of which may continue to become further favorable with time. In addition, the indirect benefits of soil reclamation include appreciation in land value, increased farm employment and an increase in food production.

Table 6. Effect of treatments on grain and straw yields (kg ha^{-1}) of wheat 2008-09

Treatment	Site 1		Site 2		Site 3	
	Grain	Straw	Grain	Straw	Grain	Straw
T_1: TW	2636 b	2930	2709 c	2533 b	3096 c	2718 c
T_2:TW–CW	3121 b	2910	3122 bc	2761 ab	3562 bc	2842 bc
T_3: TW–CW + Auger hole 30 m^{-2}	4180 a	3030	3805 a	3034 a	4259 a	3294 a
T_4: TW–CW + Auger hole 60 m^{-2}	3924 a	3043	3364 ab	3092 a	4022 ab	3197 ab
LSD	679.98*	NS	517*	421*	478*	410*

Values in a column sharing same letter(s) within a column are statistically similar at P = 0.05; *Treatments differed significantly at P = 0.05; NS, Treatments differed non-significantly at P = 0.05.

Table 7. Economic evaluation of treatments

Site	Treatments	Gross income (Rs ha^{-1})		Total	Expenditure (Rs ha^{-1})	Net Income (Rs ha^{-1})	Benefit cost ratio
		Grain	Straw				
1	T_1: TW	62597	13184	75781	32270	43510	2.35
	T_2:TW–CW	74124	13095	87219	32028	55190	2.72
	T_3: TW–CW + Auger hole 30 m^{-2}	99267	13637	112904	33370	79533	3.38
	T_4: TW–CW + Auger hole 60 m^{-2}	93203	13694	106896	33220	73676	3.22
2	T_1: TW	64339	11400	75739	35090	40648	2.16
	T_2:TW–CW	74148	12423	86571	34058	52512	2.54
	T_3: TW–CW + Auger hole 30 m^{-2}	90377	13652	104028	35260	68768	2.95
	T_4: TW–CW + Auger hole 60 m^{-2}	79887	13914	93801	34230	59571	2.74
3	T_1: TW	73538	12233	85770	34370	51400	2.50
	T_2:TW–CW	84590	12791	97380	34230	63150	2.84
	T_3: TW–CW + Auger hole 30 m^{-2}	101159	14823	115982	33440	82542	3.47
	T_4: TW–CW + Auger hole 60 m^{-2}	95523	14388	109911	33886	76024	3.24

The price of wheat grain was @ Rs. 950/40 kg and straw @ 180/40 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.

CONCLUSIONS

Crop production on salt-affected soils is adversely affected due to salt toxicity, poor soil physical/chemical properties and nutritional imbalance. The cyclic irrigation of canal and tube well waters along with auger hole 30 m^{-2} refilled with gypsum and rice husk (1:1 ratio) remained better in lowering EC_e, pH_s and SAR and produced maximum grain and straw yields of wheat. Economic analysis of the applied treatments showed that maximum benefit cost ratio was 3.47, 3.38 and 2.95 with cyclic irrigation of CW and TW along with one auger hole per 30 m^2 refilled with gypsum and rice husk (1:1 ratio by volume) at sites 3, 1 and 2, respectively.

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