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Full Length Article

Amelioration of Saline-sodic Soil using Gypsum and Low Quality Water in Following Sorghum-berseem Crop Rotation

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Abstract

A field study was conducted on a Lyallpur saline-sodic variant soil at Proka Farm II, University of Agriculture, Faisalabad, Pakistan. The study aims to evaluate the effectiveness and economic viability of using low quality water with or without gypsum for reclamation of sandy clay loam saline-sodic soil (pH_s = 8.35-8.53, EC_e = 6.23-6.79 dS m^{-1}, SAR = 47.67-51.24, CEC = 3.61-5.15 $cmol_c$ kg^{-1}, organic matter = 0.23-0.28% and lime =6.25-6.87%). Tube well (EC = 3.94 dS m^{-1}, SAR =19.73, RSC = Nil) and canal (EC = 2.86 dS m^{-1}, SAR = 11.81, RSC = Nil) waters were used for irrigation as per treatment plan. The treatments were: Tube well water (TW) alone, TW–Canal water (CW) alone, TW–CW + Gypsum @ 50% soil gypsum requirement (SGR) and TW–CW + Gypsum @ 100% SGR. Treatments were replicated thrice. After harvesting sorghum and berseem crops, significantly the greatest decrease in pH_s, EC_e and SAR occurred with TW–CW + G_{100}. The highest net benefit (Rs.) from sorghum and berseem in rotation for two years was obtained with TW–CW + G_{100} (268293), while lowest with TW (82452) during 2009-2010 and 2010-2011. The results obtained from the two year study show that TW–CW + G_{100} could be used to reclaim saline-sodic soils by following sorghum-berseem rotation. © 2013 Friends Science Publishers

Keywords: Net benefit; Reclamation; Saline-Sodic soil; Brackish water

Introduction

Soil salinity and/sodicity is a global problem posing major threat to sustainable agriculture in the world. Globally, > 8 × 10^8 ha of land are affected, either by salinity (3.97 × 10^8 ha) or sodicity (4.34 × 10^8 ha) (FAO, 2000), both constitutes about 6% of the world's total land area. Salinity or sodicity in profile layers are major abiotic environmental stresses to crop production (Grewal, 2010). In Pakistan, approximately 26% of total irrigated land is salt-affected (Anonymous, 2010). The problem of salt-affected soils is not new but its intensity has been increasing because of poor management practices and inappropriate amelioration procedures.

Pakistan lies between Latitudes 24º to 37º North and Longitudes 61º to 76º East in the northern hemisphere. High temperature and scarce rainfall promote upward movement of salts from the soil solution causing salinization (Manchanda and Garg, 2008). Out of total (79.61 mha) geographic area of Pakistan, 6.67 mha is salt-affected (Khan, 1998) and 23.04 mha is cropped land (GOP, 2010). About 56% of the salt-affected soils of Pakistan are saline-sodic (Mirbahar and Sipraw, 2000) and need external calcium source for amelioration (Ghafoor *et al*., 2012).

In arid and semi-arid regions, agriculture depends on irrigation water, which is under control with respect to time and amount of application. The volume of canal irrigation water is however, insufficient to support agriculture in the Indus Plains. Hence, a supplemental source of water has to be made available from the ground water reservoir and agriculture drainage water for horizontal or vertical expansion of agriculture. In Pakistan, about 9.05 × 10^6 ha-m ground water is pumped (Anonymous, 2011-2012) and is brackish due to higher levels of EC, SAR and RSC, which are harmfully affecting soil quality as well as crop yields (Latif and Beg, 2004; Murtaza *et al*., 2009). However, such waters can be used effectively and productively for irrigation during early phase of reclamation of saline-sodic soils, if proper management practices are followed (Qadir *et al.*, 2001; Murtaza *et al.*, 2009).

The population of Pakistan is increasing at a rate of 1.87% (Anonymous, 2009), which is exerting enormous pressure on land and water resources to produce more food and fodder. In this scenario, it appears wise and timely to study the prospects of growing fodder crops during reclamation of salt-affected soils along with chemical amendments.

Gypsum is the most extensively used amendment for the reclamation of saline-sodic soils because of its low cost, general availability, and rich supply of Ca^{2+} followed by leaching can ameliorate saline-sodic soils (Oster, 1993; Tuna *et al.*, 2007; Ghafoor *et al*., 2008; Murtaza *et al*., 2009). Plant growth in saline/saline-sodic soils decreases soil salinity/sodicity with the passage of time, roots increased soil permeability and influence nutrient availability (Ilyas, 1990). Fodder crops also act as bioremediator for salt-affected soils. The sorghum is more

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salt tolerant crop with good fodder yields as compared to maize and Sudan grass (Chang and Leghari, 1995). Previously, lot of work has been conducted on reclamation of salt-affected soils by following different crop rotations but limited literature is available on fodder crops. In Pakistan, small/poor farmers prefer to grow fodder crops and grasses on salt-affected soils. Considering these aspects of fodder crops during reclamation of salt-affected soils, the study was planned to study the effect of brackish ground water along with chemical amendment (gypsum) on growth of sorghum and berseem in rotation during reclamation of saline-sodic soils.

Materials and Methods

This field study was conducted on a fine silty, hyperthermic, moderately permeable, friable, typic camborthids soil at Proka Farm II, University of Agriculture, Faisalabad, Pakistan. Four treatments were replicated thrice in a randomized complete block design (RCBD) on a permanent layout having plot size of 17 m × 30 m following sorghum-berseem crop rotation. The treatments employed were (1) Tube well water (TW) alone, (2) TW–Canal water (CW) alone, (3) TW–CW + Gypsum @ 50% soil gypsum requirement (TW–CW + G_{50}) and (4) TW–CW + Gypsum @ 100% SGR (50–50% i.e., 50% to each of the first two crops (TW–CW + G_{100}).

After lay out of the experiment, composite soil samples were collected from each experimental plot at 0-15 and 15-30 cm soil depths for determining various chemical characteristics (pH_s, EC_e, SAR, gypsum requirement and soluble cations and anions). Determinations were done for saturation paste extract EC (EC_e), saturated soil paste pH (pH_s), $CaCO_3$ (Puri, 1931), organic matter (Nelson and Sommers, 1982), cation exchange capacity (Gillman and Sumpter, 1986), CO_3^{2-} and HCO_3^- (titration with standard H_2SO_4), soluble Ca^{2+} + Mg^{2+} (titration with standard versinate solution), Cl^- (titration with standard $AgNO_3$) and Na^+ (flame photometrically) using methods described by the US Salinity Laboratory Staff (1954) and Page *et al.* (1982). Sodium adsorption ratio (SAR) was determined by Equation 1 using concentrations of Na^+, Ca^{2+} and Mg^{2+} in $mmol_c\ L^{-1}$.

$$SAR = Na^+/[(Ca^{2+} + Mg^{2+})/2)]^{1/2} \qquad (1)$$

Hydrometer method was used for particle-size analysis of soil (Bouyoucos, 1962). Gypsum requirement was determined from each treatment plot following Schoonover (Schoonover, 1952) method and was applied as per treatment plan. The amount of gypsum @ SGR for TW–CW + G_{50} was 2 tons ha^{-1}, while it was 4 tons ha^{-1} for TW–CW + G_{100} treatment. In case of TW–CW + G_{100} treatment, half amount of gypsum was applied before sowing the first sorghum (*Sorghum bicolor* L.) crop in June 2009 and remaining half to second berseem (*Trifolium alexandrium* L.) crop in October 2009. The gypsum was mixed in the top layer (8-10 cm) by cultivator. The analytical methods used for water analysis were the same as for the analysis of soil saturation extract. The following relationship was used to compute RSC using concentrations of ions in $mmol_c\ L^{-1}$:

$$RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+}) \qquad (2)$$

Fertilizers N, P and K @ 100, 75 and 50 kg ha^{-1} as urea, diammonium phosphate (DAP) and sulphate of potash (SOP), respectively were applied uniformly in all the treatments. Sorghum was sown using seed rate 75 kg ha^{-1}. All the P and K were applied at the time of sowing, while half of N as urea was applied at the time of sowing. The remaining N as urea was applied in two equal splits at tillering {28 days after germination (DAG)} and booting stages (54 DAG). All the experimental plots were irrigated as per requirements of crops. Crop was harvested at maturity. Crop growth parameters viz. plants (No. m^{-2}), plant height (cm) and yield (kg ha^{-1}) were recorded. After sorghum harvest, the soil samples were collected from experimental sites and were analyzed for pH_s, EC_e, SAR and soluble cations and anions (US Salinity Lab. Staff, 1954).

After the harvest of sorghum crop, sowing of berseem crop was done by using 20 kg ha^{-1} seed rate. Fertilizer P @ 75 kg ha^{-1} as DAP was applied at the time of sowing. Berseem was harvested at maturity each time and biomass was recorded and a total of three cuttings were taken. After the harvest of berseem, soil samples were collected from each experimental plot and were analyzed for EC_e, pH_s, SAR and soluble cations and anions. Data regarding rainfall, temperature, relative humidity and evapo-transpiration are presented in Table 1b. Economics of treatments was calculated using the common market prices and variable inputs. The data collected was subjected to statistical analysis and LSD test was applied to evaluate treatment differences (Steel *et al*., 1997). The same experimental procedure was adopted during 2^{nd} year as explained for the first year.

Results

Since the quality of tube well water at Proka Farm II is hazardous (Table 1a). Due to very high EC of tube well water, conjunctive use of canal and tube well waters was planned to maintain appropriate salt balance low for sustainable crop production. The experiment site is located at the tail end of the Sir Wala Distributary, taking off from the Rakh Branch canal, Faisalabad. The water at farm gate was analyzed many times and has high EC mainly due to sewage water disposal into this distributary either directly or through lift pumps.

Physical Properties of Soil

The physical properties were determined before the application of treatments and after the final harvest of berseem 2010-2011.

Table 1a: Quality of tube well and canal waters used for growing sorghum and berseem crops (Average of 9 observations)

Characteristic	Unit	Canal Water	Tube well water
EC	dS m^{-1}	2.86	3.94
SAR	$(mmol\ L^{-1})^{1/2}$	11.81	18.2
RSC	$mmol_c\ L^{-1}$	Nil	Nil

Table 1b: Average range of rainfall, temperature, relative humidity and evapo-transpiration received during growing season

Crop	Rainfall (mm)	Temperature (°C)	Relative Humidity (%)	ET_O (mm)
Soghum 2009	207.2	24.9-33.8	33.6-65.8	3.1-8.2
Berseem 2009-2010	23.5	11.1-29.9	36.8-82.3	0.8-6.0
Soghum 2010	591.9	26.3-33.9	40-74.6	3.0-6.3
Berseem 2010-2011	48.3	10.1-24.8	47-73.4	0.9-4.2

In general the values of BD at lower soil depth were high than those at upper 15 cm depth. Mostly BD values are high due to saline-sodic nature of soil which has induced dispersion. After the final harvest of berseem in May 2010, BD decreased with all the treatments, although decrease was only 1.14% to 3.11% over the corresponding initial values at both the soil depths and highest decrease (3.11%) was recorded with TW–CW + G_{100} at 15-20 cm soil depth. After the final harvest of berseem in May 2010, BD decreased significantly with all the treatments and decrease was 3.51% to 12.80% over the corresponding initial values at both the soil depths. The greatest decrease of 12.80% was noted with TW–CW + G_{100} at 5-10 cm soil depth. There was small decrease in BD, which was the lowest with TW–CW (3.51%) followed by TW (4.19%), TW–CW + G_{50} (10.24%) and TW–CW + G_{100} (12.80%) treatments at 5-10 cm soil depth (Table 2). The lowest decrease in soil BD was observed at 15-20 cm soil depth with TW–CW + G_{50} (7.69%) followed by TW–CW (5.68%), TW–CW + G_{100} (4.91) and TW (3.98%). The improvement in BD at lower soil surface could also be attributed to improvement in flocculation by high EC water applied as well as physical manipulation of soil through ploughing.

After the final harvest of berseem in May 2010, infiltration rate (IR) increased with all the treatments (Table 2). The highest increase in IR over the initial value was recorded with TW–CW + G_{100} (42.8%) followed by TW–CW (40.8%), TW–CW + G_{50} (33.3%) and TW (33.3%) in a period of one year.

After the final cutting of berseem in May 2011, IR increased with all the treatments (Table 2). The increase was the highest with TW–CW + G_{100} (0.24%) followed by TW–CW + G_{50} (0.31%), TW–CW (0.21%) and TW (0.10%). The highest increase in IR (60%) over the initial value was recorded with TW–CW + G_{100} followed by TW–CW + G_{50} (47.6%), TW –CW (38.2%) and TW (25%) in a period of two years (Table 2). The addition of gypsum exerted ameliorative effect on infiltration rate of soil.

Chemical Properties of Soils

Soil reaction (pH_s): The pH_s is generally $\geq$ 8.0 even in normal calcareous arid region irrigated soils while pH_s of sodic soils may approach 10.0 as a result of Na_2CO_3 formation. In the present studies, pH_s for lower soil depth remained higher compared to that for the upper depth after the harvest of berseem (Table 3). Since the experimental field was lying barren for the past many years during which precipitation of Ca^{2+} and Mg^{2+} as $CaCO_3$, $CaSO_4$ and $Mg(SiO_3)_2$ occurred to affect an increase in exchangeable Na^+ and thus ESP. After the harvest of sorghum in October 2009, treatment differences in pH_s were statistically non-significant for both the soil depths. After the final harvest of berseem in May 2010, treatments again differed non-significantly at 0-15 and 15-30 cm soil depths.

After the harvest of sorghum in October 2010, treatments differed statistically for both the soil depths (Table 3). The pH_s at 0-15 cm soil depth was the highest (8.55) for TW–CW followed by TW (8.49), TW–CW + G_{50} (8.30) and TW–CW + G_{100} (8.08). For 15-30 cm soil depth, highest increase (0.95%) in pH_s was observed with TW followed by TW–CW (0.43%) and TW–CW+ G_{50} (0.36%). After the final harvest of berseem in May 2011, treatments differed significantly at both the soil depths. For 0-15 cm soil depth, maximum decrease (6.25%) was recorded with TW–CW + G_{100} followed by TW–CW + G_{50} (3.80%) and TW (0.04%) (Table 3). For 15-30 cm soil depth, the highest pH_s of 8.44 was recorded with TW–CW=TW followed by TW–CW + G_{50} (8.31) and TW–CW + G_{100} (8.01).

Electrical Conductivity (EC_e)

After the harvest of sorghum in October 2009, treatment differences remained significant at 0-15 cm soil depth (Table 4). The highest decrease in EC_e (46.86%) was recorded for TW–CW + G_{100} over the initial value. At 15-30 cm soil depth, treatment differed statistically. Maximum decrease in EC_e (28.79%) was observed with TW–CW + G_{100} followed by TW–CW + G_{50} (26.45%), TW–CW (13.98%) and TW (12.77%) over the initial values (Table 4). After the final harvest of berseem in May 2010, treatment differed significantly at both the soil depths. Maximum EC_e (dS m^{-1}) was recorded with TW (5.88) followed by TW–CW (5.61), TW–CW + G_{50} (4.55) and TW–CW + G_{100} (4.41) at 0-15 cm soil depth (Table 4). The treatments also showed significant effect at 15-30 cm soil depth where maximum EC_e (dS m^{-1}) was recorded with TW–CW (5.97) followed by TW (5.91), TW–CW + G_{50} (5.17) and TW–CW + G_{100} (4.77) (Table 4).

After sorghum harvest in October 2010, treatments differed significantly at 0-15 cm soil depth where maximum decrease in EC_e (38.05%) was recorded for TW–CW + G_{100} over the initial value. At 15-30 cm soil depth, treatments differed statistically with the lowest EC_e (4.50 dS m^{-1}) for TW–CW + G_{100} = TW–CW + G_{50} and was the highest with

Table 2: Physical properties of saline-sodic soil receiving brackish water

Treatment	[a]IR (cm h^{-1})	[a]Bulk density (Mg m^{-3})		[b]IR (cm h^{-1})	[b]Bulk density (Mg m^{-3})	
		05-10 cm	15-20 cm		05-10 cm	15-20 cm
2009-2010						
TW	0.08	1.67	1.76	0.10(33.3)	1.64(-1.80)	1.74 a (-1.14)
TW–CW	0.14	1.71	1.76	0.20(40.8)	1.68(-1.75)	1.72 ab (-2.27)
TW–CW + G_{50}	0.15	1.66	1.69	0.20(33.3)	1.62(-2.41)	1.65)ab (-2.36
TW–CW + G_{100}	0.20	1.64	1.63	0.30(42.8)	1.61(-1.83)	1.58 b (-3.11)
LSD				LSD	0.082[NS]	0.153[NS]
2010-2011						
TW	0.08	1.67	1.76	0.10(25.0)	1.60 a(-4.19)	1.69 a(-3.98)
TW–CW	0.14	1.71	1.76	0.21(38.2)	1.65 a(-3.51)	1.66 ab(-5.68)
TW–CW + G_{50}	0.15	1.66	1.69	0.31(47.6)	1.49 b(-10.24)	1.56 ab(-7.69)
TW–CW + G_{100}	0.20	1.64	1.63	0.24(60.0)	1.43 b(-12.80)	1.55 b(-4.91)
LSD					0.0972*	0.1245*

[a]Initial soil characteristics before start of the experiment; [b]Post berseem; *Treatments differed significantly at P<0.05. Means followed by same letter(s) within a column do not differ significantly according to LSD test (P≤0.05); [NS]Non-significant

TW: Tube well water alone, TW– CW: Tube well water–canal water, TW–CW + G_{50}: Tube well water–canal water + Gypsum @ 50% soil gypsum requirement and TW–CW + G_{100}: Tube well water–canal water + Gypsum @ 100% soil gypsum requirement

Table 3: Effect of brackish water management practices on pH_s during reclamation of saline-sodic soil

Treatment	0–15 cm soil depth			15–30 cm soil depth		
	Initial[a]	Post-sorghum	Post-berseem	Initial[a]	Post-sorghum	Post-berseem
2009-2010						
TW	8.35	8.38(0.40)	8.52(2.03)	8.44	8.31(-1.61)	8.58(1.59)
TW–CW	8.45	8.43(-0.28)	8.65(2.27)	8.51	8.39(-1.43)	8.64(1.50)
TW–CW + G_{50}	8.50	8.60(1.16)	8.44(-0.71)	8.35	8.61(2.98)	8.51(1.88)
TW–CW + G_{100}	8.53	8.39(-1.71)	8.25(-3.39)	8.67	8.26(-4.96)	8.25(-5.09)
LSD		0.70 [NS]	0.19 [NS]		0.40 [NS]	0.25 [NS]
2010-2011						
TW	8.35	8.49 a(+1.72)	8.35 a(-0.04)	8.44	8.52 a(+0.95)	8.44 a(0.00)
TW–CW	8.45	8.55 a(+1.18)	8.49 a(+0.51)	8.51	8.55 a(+0.43)	8.44 a(-0.86)
TW–CW + G_{50}	8.50	8.30 b(-2.39)	8.18 b(-3.80)	8.35	8.38 a(+0.36)	8.31 a(-0.52)
TW–CW + G_{100}	8.53	8.08 c(-5.24)	8.00 c(-6.25)	8.67	8.07 b(-6.88)	8.01 b(-7.65)
LSD		0.165*	0.151*		0.302*	0.176*

Table 4: Effect of brackish water management practices on EC_e (dS m^{-1}) during reclamation of saline-sodic soil

Treatment	0–15 cm soil depth			15–30 cm soil depth		
	Initial[a]	Post-sorghum	Post-berseem	Initial[a]	Post-sorghum	Post-berseem
2009-2010						
TW	6.23	5.93a(-5.12)	5.88a(-5.95)	6.74	5.98a(-12.77)	5.91a(-14.04)
TW–CW	6.45	5.92a(-9.01)	5.61b(-14.97)	6.85	6.01a(-13.98)	5.97a(-14.74)
TW–CW + G_{50}	6.78	4.95b(-37.06)	4.55c(-49.07)	6.47	5.12b(-26.45)	4.77b(-35.55)
TW–CW + G_{100}	6.79	4.62c(-46.86)	4.41d(-54.08)	6.71	5.21c(-28.79)	5.17c(-29.79)
LSD		0.16*	0.15*		0.13 *	0.13*
2010-2011						
TW	6.23	6.01a(-3.58)	6.64a(+6.53)	6.74	5.92 a(-12.12)	5.85a(-13.20)
TW–CW	6.45	5.34b(-17.16)	5.29b(-18.04)	6.85	5.78 a(-15.67)	5.70a(-16.74)
TW–CW + G_{50}	6.78	4.49c(-33.82)	4.18c(-38.35)	6.47	4.50 b(-30.40)	4.32b(-33.18)
TW–CW + G_{100}	6.79	4.21d(-38.05)	4.06c(-40.21)	6.71	4.50 b(-32.94)	4.01c(-40.19)
LSD		0.106*	0.228*		0.192*	LSD:0.197*

[a]Initial before the start of experiment; *Treatments differed significantly at P<0.05. Values in parentheses indicate % increase (+) or decrease (-) over the initial values

TW: Tube well water alone, TW– CW: Tube well water–canal water, TW–CW + G_{50}: Tube well water–canal water + Gypsum @ 50% soil gypsum requirement and TW–CW + G_{100}: Tube well water–canal water + Gypsum @ 100% soil gypsum requirement

TW (5.98 dS m^{-1}).

After the final harvest of berseem in May 2010, treatments differed significantly at both soil depths (Table 4). Maximum EC_e was recorded with TW (6.64 dS m^{-1}) followed by TW–CW (5.29 dS m^{-1}), TW–CW+ G_{50} (4.18 dS m^{-1}) and TW–CW + G_{100} (4.06 dS m^{-1}) at 0-15 cm soil depth. The treatments also differed significantly at 15-30 cm soil depth. The EC_e remained highest (5.85 dS m^{-1}) with TW followed by TW–CW (5.70 dS m^{-1}), TW–CW + G_{50} (4.32 dS m^{-1}) and TW–CW + G_{100} (4.01 dS m^{-1}). The decrease in EC_e was greater at upper compared to lower soil depth suggesting fast leaching of salts from the surface layers because soil water got loaded with salts while passing through the upper layers and hence its capacity to pick and carry more salts from the lower depth decreased.

Table 5: Effect of brackish water management practices on SAR during reclamation of saline-sodic soil

Treatment	0–15 cm soil depth			15–30 cm soil depth		
	Initial[a]	Post-sorghum	Post-berseem	Initial[a]	Post-sorghum	Post-berseem
2009-2010						
TW	49.58	42.63a(-16.30)	45.13a(-9.85)	48.99	45.43a(-7.83)	42.63a(-14.92)
TW–CW	47.67	41.24b(-15.58)	40.42b(-17.94)	49.17	43.61b(-12.74)	41.19b(-19.38)
TW–CW + G_{50}	50.54	35.33c(-43.04)	25.31c(-99.66)	52.54	38.51c(-36.11)	31.14c(-68.32)
TW–CW + G_{100}	51.24	33.13d(-54.66)	21.33d(-140.26)	50.91	32.12d(-58.52)	27.16d(-87.44)
LSD		0.16 *	0.16*		0.17 *	0.13*
2010-2011						
TW	49.58	42.63 a(-14.02)	40.33 a(-18.66)	48.99	40.14 a(-18.06)	37.35a (-23.77)
TW–CW	47.67	38.34 b(-19.57)	37.18 b(-22.01)	47.17	38.29 b(-22.13)	36.13b (-26.51)
TW–CW + G_{50}	50.54	21.45 c(-57.56)	20.34 c(-59.75)	52.41	22.31 c(-57.43)	20.14c (-61.58)
TW–CW + G_{100}	51.24	18.33 d(-64.23)	15.31 d(-70.13)	50.91	18.91 d(-62.86)	15.17d (-70.21)
LSD		0.072*	0.099 *		0.116*	0.128 *

[a]Initial before the start of experiment; Values in parentheses indicate % increase (+) or decrease (-) over the initial values. *Treatments differed significantly at P<0.05

TW: Tube well water alone, TW– CW: Tube well water–canal water, TW–CW + G_{50}: Tube well water–canal water + Gypsum @ 50% soil gypsum requirement and TW–CW + G_{100}: Tube well water–canal water + Gypsum @ 100% soil gypsum requirement

Table 6: Economics of applied treatments for two Sorghum and two Berseem crops

Treatment	Expenditure (Rs./ha)		Total Expenditure (Rs./ha)	Gross Income (Rs./ha)		Total Gross Income (Rs./ha)	Net Benefit (Rs./ha)
	Sorghum 2009–2010	Berseem 2009–2011		Sorghum 2009–2010	Berseem 2009–2011		
TW	47625	61583	109209	55754	135907	191661	82452
TW–CW	47625	61583	109209	67712	184347	252059	142850
TW–CW + G_{50}	52513	61583	114097	80101	268987	349088	234991
TW–CW + G_{100}	52513	71548	124061	86221	306133	392354	268293

During 2009–2010: The market price of sorghum was @ Rs. 70/40 kg and berseem @ Rs. 80/40 kg. The cost of sorghum sowing including ploughing, planking and other cultural operations was Rs. 4650 ha^{-1}; urea @ Rs. 750 /bag, DAP @ Rs 2310/bag, SOP @ Rs. 1310/bag. The cost of gypsum was Rs. 50/bag and gypsum broadcasting was Rs. 240/ha. The price (Rs. kg^{-1}) of sorghum and berseem seed was 28 and 200, respectively

During 2010-11: The market price of sorghum was @ Rs. 70/40 kg and berseem @ Rs. 80/40 kg. The cost of sorghum sowing including ploughing, planking and other cultural operations was Rs. 7830 ha^{-1}; urea @ Rs. 827 /bag, DAP @ Rs 2934/bag, SOP @ Rs. 2375/bag. The price (Rs kg^{-1}) of sorghum and berseem seed was Rs. 60 and Rs. 200, respectively

TW: Tube well water alone, TW– CW: Tube well water–canal water, TW–CW + G_{50}: Tube well water–canal water + Gypsum @ 50% soil gypsum requirement and TW–CW + G_{100}: Tube well water–canal water + Gypsum @ 100% soil gypsum requirement

Sodium Adsorption Ratio (SAR)

Soils under study had higher SAR than 13. After the harvest of sorghum in October 2009, SAR decreased significantly with all the treatments (Table 5), decrease being the higher with TW–CW + G_{100} (58.52%) followed by TW–CW + G_{50} (36.11%), TW–CW (12.74%) and TW (7.83%). After the final harvest of berseem in May 2010, treatments significantly differed at both the soil depths. The treatment TW–CW + G_{100} lowered the SAR to the greater extent at both the soil depths. After the harvest of sorghum in October 2010, SAR decreased significantly with all the treatments at 0-15 cm soil depth (Table 5). The treatments effectiveness was in the decreasing order of TW–CW + G_{100} (64.23%) followed by TW–CW + G_{50} (57.56%), TW–CW (19.57%) and TW (14.02%). For 15-30 cm soil depth, treatments significantly decreased SAR where treatment effectiveness was in the decreasing order of TW (40.14%), TW–CW (38.29%), TW–CW + G_{50} (22.31%), and TW–CW + G_{100} (18.91%). Maximum decrease in SAR was observed with TW–CW + G_{100} (62.86%) followed by TW–CW + G_{50} (57.43%), TW–CW (22.13%) and TW (18.06%). The SAR values for the TW (control) also decreased at both the soil depths due to Ca^{2+} in irrigation water and valence dilution effect.

After the harvest of berseem in May 2011, treatments significantly lowered the SAR at both 0-15 and 15-30 cm soil depths. Greatest SAR was recorded with TW (40.33) followed by TW–CW (37.18), TW–CW + G_{50} (20.34) and TW–CW + G_{100} (15.31) at 0-15 cm soil depth (Table 5). The treatment effectiveness was in the decreasing order of TW–CW + G_{100} (70.13%) followed by TW–CW + G_{50} (59.75%), TW–CW (22.01%) and TW (18.66%) at 0-15 cm soil depth (Table 5). Post-berseem higher SAR values might be due to highest salt accumulation which enhanced $CaCO_3$ and $CaSO_4$ precipitation leading to high Na^+ concentration and thus SAR. At 15-30 cm soil depth, SAR was the highest with TW followed by TW–CW + $G_{50,}$ TW–CW, and TW–CW + G_{100} (Table 5). At 15-30 cm soil depth the treatment order for decrease in SAR was TW–CW + G_{100} (70.21%) followed by TW–CW + G_{50} (61.58%), TW–CW (26.51%) and TW (23.77%). The decrease in SAR was more at lower soil depth compared to upper depth due to better Na^+ desorption followed by leaching of desorbed Na^+ from the surface layers. The most effective treatment for lowering SAR was the combination of TW–CW + G_{100}.

The EC_e, pH_s and SAR values at the termination of experiment in May 2011 indicated that agricultural operations initiated the amelioration of saline-sodic soils, but to accelerate the Na^+-Ca^{2+} exchange, some external calcium source is useful. It could be recommended that gypsum application @ 100% SGR in two equal splits (i.e., 50% to the first crop and 50% to second crop) ameliorated the soil even using brackish water.

Crop Growth

Sorghum (*Sorghum bicolor*): Sorghum is a very common fodder crop in the Indus Basin of Pakistan and animals love to eat it as green fodder. It is favored in crop rotation with berseem during reclamation of saline-sodic soils. As soil was saline-sodic and irrigation water was also of low quality, good yield of any crop could not be expected during early phase of soil reclamation. The sorghum yield, the ultimate goal of farming was affected significantly with all the treatments (Fig. 1). Maximum fodder yield (t ha^{-1}) of sorghum 2009 was recorded with TW–CW + G_{100} and TW–CW + G_{50} (18.27), followed by TW–CW (16.13) and TW (14.13). The highest fodder yield in 2010 (t ha^{-1}) was recorded for TW–CW + G_{100} (31.0) followed by TW–CW + G_{50} (27.56), TW–CW (22.56) and TW (17.73).

Berseem (*Trifolium alexandrium*): Berseem is a leguminous fodder crop. It is grown for the most part of the areas below 1700 m altitude with irrigation facilities. At flowering, it remains soft and tender with 18 to 20% crude protein on dry matter basis. Growth response of berseem remained significant with all the treatments (Fig. 2). For the first cutting, maximum yield was obtained with TW–CW + G_{100} (10.01 t ha^{-1}) followed by TW–CW + G_{50} (9.72 t ha^{-1}), TW–CW (8.60 t ha^{-1}) and lowest (6.70 t ha^{-1}). For the 2nd cutting, lowest yield was obtained with treatment TW (6.09 t ha^{-1}) that increased to a maximum of 13.19 t ha^{-1} with TW–CW + G_{100} closely followed by TW–CW + G_{50} (12.22) and TW–CW (8.58). During 3rd cutting, TW–CW + G_{100} emerged as the most yielding treatment with a value of 10.38 t ha^{-1} and the lowest with TW (4.97).

Green fodder yield of berseem (2010-11) was significantly affected with the treatments (Fig. 2). For the 1st cutting, highest yield (t ha^{-1}) was obtained with TW–CW + G_{100} (12.96) followed by TW–CW + G_{50} (10.97), TW–CW (8.69) and TW (7.18). For the 2nd cutting, maximum yield (t ha^{-1}) was obtained with TW–CW + G_{100} (14.22) followed by TW–CW + G_{50} (12.83), TW–CW (9.91) and TW (7.33). For the 3rd cutting, TW–CW + G_{100} emerged as the high yielding (13.95 t ha^{-1}) treatment and TW yielded the lowest (6.45 t ha^{-1}).

Under the conditions of this experiment, soil was ameliorated to a great extent regarding EC_e, pH_s, SAR, BD and IR with gypsum based treatment. As expected, the same treatment gave better yields of sorghum and berseem rendering the crop husbandry useful and viable.

Discussion

Gypsum is an important amendment for the reclamation of saline-sodic/sodic soils. Chaudhry (2001) reported maximum increase in IR with the application of gypsum

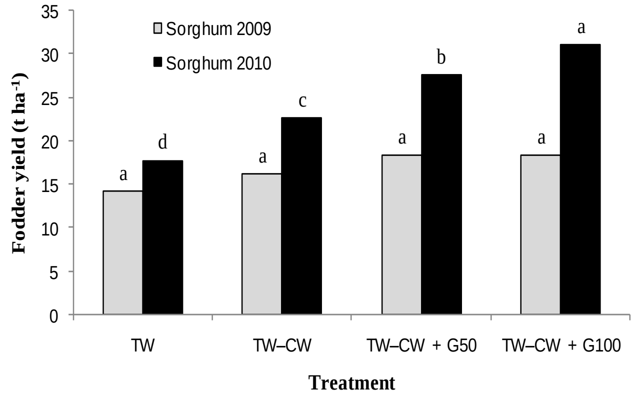

Fig. 1: Growth response of sorghum to water management strategies during reclamation of saline-sodic soil

TW: Tube well water alone, TW– CW: Tube well water–canal water, TW–CW + G_{50}: Tube well water–canal water + Gypsum @ 50% soil gypsum requirement and TW–CW + G_{100}: Tube well water–canal water + Gypsum @ 100% soil gypsum requirement

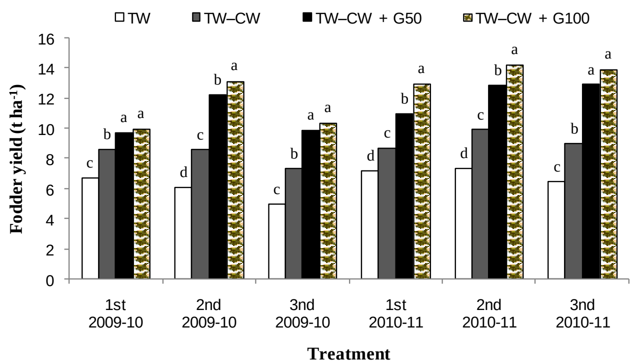

Fig. 2: Growth response of berseem to water management strategies during reclamation of saline-sodic soil

TW: Tube well water alone, TW– CW: Tube well water-canal water, TW–CW + G_{50}: Tube well water-canal water + Gypsum @ 50% soil gypsum requirement and TW–CW + G_{100}: Tube well water-canal water + Gypsum @ 100% SGR

during the reclamation of salt-affected soils. It was observed that BD decreased from 1.36 to 1.30 Mg m^{-3} but it was not statistically significant. Murtaza *et al.* (2006) also reported an increase in IR and a decrease in BD with saline-sodic water irrigation along with organic and inorganic amendments after a period of three years following a cotton-wheat crop rotation.

As regards chemical properties of soil, the overall decrease in pH_s was more at upper depth compared to lower soil depth. The highest decrease in pH_s could be endorsed at upper soil depth due to the greater removal of Na^+ than from the lower one. In the same way a reduction in pH_s and SAR was observed by Zaka *et al*. (2003) with the application of organic amendments and gypsum. A further decrease in pH_s may be deduced from the work of Robbins (1986), who found a greatest increase in CO_2 partial pressure during amelioration of calcareous saline-sodic soil by growing Sordan grass. It reflects that gypsum along with FM caused maximum leaching of Na^+ to affect a decrease in soil SAR which in turn decreased pH_s (Murtaza *et al*., 2006). The availability of Ca^{2+} in soil solution increased and Ca^{2+} ions accompanied with H^+ ions released from the decomposition of organic matter replaced Na^+ ions from exchange sites. Joachim *et al*. (2007) reported that FM decreased pH_s by 9.5%, gypsum by 3.9% and pH_s decreased by 14.7% during the first year when the two amendments were combined. During 2nd year, FM decreased pH_s by 26.9%, gypsum by 14.2% and 29.8% with combined application of FM and gypsum. The observed decrease in soil pH_s could be due to beneficial effects of FM and gypsum, which leads to de-sodification of saline-sodic soil.

The increase in soil EC_e with TW during post-berseem 2010-2011 might be due to high EC of the irrigation water and poor physical properties. The higher concentration of Na^+ in soils lead to dispersal of clay particles ensuing crusting, low hydraulic conductivity (HC) and hardening of the soil surface upon drying as a result soil water impeded. This was strengthen with Isabelo and Jack (1993), who reported that highest accumulation of salts in upper soil profile in semi-arid zones particularly when it is coupled with insufficient leaching and upward movement of salts instead of downward. The increase in soil EC_e with saline water irrigation is not uncommon (Qadir and Oster, 2002; Qadir and Schubert, 2002; Murtaza *et al.,* 2006) however, the extent and type of induced salinity varies with soil type, amount and chemical composition of irrigation water applied to crop during the growing season and the amount of salts leached from the roots zone.

Chaudhary *et al.* (2004) reported an increase in soil pH_s, EC_e and ESP with saline water despite some increase in post experiment soil, where the harmful effects were more severe under saline-sodic water irrigations. Gypsum @ 50% of SGR applied in two splits reclaimed soil even with the use of brackish water within a short time. However, these soils had lowest cation exchange capacity (CEC 6-10 $cmol_c\ kg^{-1}$), for which the optimal Ca^{2+}concentration of 8 $mmol_c\ L^{-1}$ has been found (Hassan, 2004). It is reported that considerable Ca^{2+} generally leaches down without affecting Na^+ desorption from the amendment application zone.

Overall, the significant decrease in EC_e after sorghum harvest appears most probably through increased IR with gypsum application (Zia *et al.,* 2007) and partially due to monsoon rains during its growth period. Comparatively lowest decrease in EC_e after sorghum harvest appears mainly due to irrigation with high EC water (Armstrong *et al.,* 1996). Similar results have been indicated by Niazi *et al.* (2000), Mahmood *et al.* (2001) during reclamation of salt-affected soils.

Qadir *et al.* (2001) reported a decrease in SAR from 30 to 15 in 1.2 m profile with the use of gypsum and FM. Niazi *et al.* (2000) also observed maximum decrease in SAR when soil was amended with gypsum @ 100% SGR. But in case of gypsum application at 50% SGR, the rate of decrease in SAR was lower, however, gradual decrease in SAR was observed after harvesting each crop. Murtaza *et al.* (2006) found that relatively higher SAR values after second crop could be elaborated on the basis of more accumulation of salts which caused precipitation of $CaSO_4$ and $CaCO_3$ due to low solubility resulting into high Na^+ concentration and thus SAR.

The maximum rate of decrease in SAR was observed during the initial phases of amelioration. The salts removal from the root zone to lower soil depth acts as a sink, resulting in endorsement of Na^+- Ca^{2+} exchange reaction. The Ca^{2+} occupied on exchange sites also acts as a sink to enhance the dissolution of applied $CaSO_4$ and native $CaCO_3$. At lower SAR, highest decrease in statistical probability of exchange between adsorbed Na^+ and soluble Ca^{2+} was observed which affect the efficiency of Na^+-Ca^{2+} exchange (Shainberg *et al.,* 1980). The incorporated effect of these factors leads to rapid reduction in SAR. The decrease in SAR was greater at upper soil depth compared to lower with all the treatments. This could be due to lowest ratio of soluble Ca^{2+}: Na^+ in soil solution as it moved downward. The maximum concentration of Na^+ displaced from surface soil increasing the SAR of downward moving soil water, this could result in less Na^+ desorption from the lower soil depth.

Although crop yields are lower compared to the province and country average but reasonably high from poor quality soil and water resources. The country is facing shortage of canal water and good lands are being urbanized at alarming rate. This scenario is compelling to exploit low quality soil and water resources for the production of fodder crops to feed the large number of animals.

Maximum fodder yield with gypsum could be due to favorable Ca^{2+}: Na^+ ratio in soil solution with improved soil permeability, growth and better yield of sorghum fodder. Yadav *et al.* (2007) recorded 26% reduction in sorghum fodder yield with the use of brackish water compared with good quality irrigation water. Conjunctive use of saline and canal water affected the production of different crops having different tolerance mechanism and yield potential to saline environment as indicated earlier by Maas and Hoffman (1977). Singh *et al.* (2008) reported that sorghum-berseem fodder-based crop rotation gave the greatest sorghum fodder yield of 29.62 t ha^{-1}. The efficacy of gypsum in ameliorating the adverse effects of brackish water and increasing crop yields has been reported by Chaudhry *et al.* (2004) and Sharma and Minhas (2004).

Better production with gypsum seems through some additional and improved nutrients availability along with better physical characteristics of soil, like IR. The better IR will enhance leaching of salts and decrease their accumulation in root zone (Ahmad *et al*., 2006; Zia *et al.*, 2007). As a result of chemical reactions in soil pertaining to Na desorption and it's leaching from surface layer, fodder yield would be improved.

Overall, gypsum treatment (TW–CW + G_{100}) out yielded the biomass compared with TW. Lange *et al.* (2005)

also reported highest yields of fodder crop (alfalfa) for 3 years constantly but acid and gypsum treatments differed non-significantly during reclamation of a calcareous saline-sodic soil. The highest berseem fodder yield of 36.85 t ha^{-1} was observed during sorghum-berseem fodder-based crop rotation (Singh *et al*., 2008). During winter season, maximum fodder yield (berseem) was obtained for a long time. The highest land-use efficiency (78.35%) was achieved by sorghum-berseem cropping system followed by rice-wheat (65.75%) and sweet basil-matricaria (63.56%) systems. This is mainly due to the longer winter crops duration. However, it was noticed from the yield trend and crop stand that sorghum was better salt tolerant and produced good crop yield (Chang and Sipio, 2002).

Economic gains are the ultimate objective of an industry including agriculture. Due to high initial cost of soil or water treatments, stress-land agriculture is usually discouraged. Economics of treatments has been calculated using common market prices and variable inputs while toll prices of sorghum and berseem (Table 6). The gross income was greatest with TW–CW + G_{100} followed by TW–CW + G_{50}, TW–CW and TW. The highest net benefit (Rs.) was obtained with TW–CW + G100 (268293) followed by TW–CW + G50 (234991), TW–CW (142850) and TW (82452) up to berseem (2010-2011). It is encouraging to note that the cost of treatments has been realized from the first crop. Highest income was realized from berseem than that from sorghum since sorghum yield was low due to higher EC_e and SAR to begin with. The indirect benefits of such studies, like farm employment, environment-friendly enterprise and appreciation in land value, make the job even more attractive and a viable option for agriculture.

In conclusion, application of gypsum as per 100 % SGR with alternate irrigation of tubewell and canal water proved to be the best treatment combination for reclamation of saline-sodic soils. It was further concluded that sorghum is better crop during the reclamation, which provide fodder for livestock in adverse summer conditions when there is common fodder scarcity. Whereas berseem being legume crop improved soil physico-chemical properties thereby providing good growth conditions for next crop. This treatment also provided maximum economic benefit to the farmer in comparison to other treatments.

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