Research Article

Strategies for the Management of Saline Water for Rice-Wheat Crops in Saline-Sodic Soil

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Abstract | Amelioration of salt prone areas and reuse of saline/ sodic water is becoming important tool to improve the crop production as well as to decrease the disposal of such water. More land can be brought into cultivation by using poor quality ground water. Poor quality water can be used for cultivation of crops with appropriate management viz. chemicals like gypsum, H_2SO_4, calcium chloride, sulfur or organic additions like manures, muds, biogas slurry, composts etc. The marginal soils irrigated with saline water have deteriorated physical properties were improved with inorganic and organic amendments. Field studies were conducted at Kot Murad (district Hafizabad) to evaluate the different management practices for saline water in salt affected soils. Results suggested that the canal water with soil GR produced the maximum yields of rice and wheat trailed by the application of saline water with GR of soil and irrigation water. Soil analysis at harvest showed that soil was improved with canal water with GR of soil trailed by saline water with GR of soil and irrigation water. The least variations in soil pH, EC and SAR were observed in control where nothing was applied. Comprehensive studies in different ecological zones with salt affected soils with variety of saline water may be grown to confer these approaches.

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Introduction

Crop productivity on marginal soils can be sustained substantially by altering the environment or plants. The both options can be combined for the productive utilization of adverse degraded land with poor quality groundwater by managing the dual salinity of soil and water with suitable interventions. Crop production is directly correlated with the water availability and quality and is constrained by soil/ water salinity. Water salinization is more prevalent than soil salinization resultantly enhanced the soil salinity/ sodicity and reduced the crop productivity. The main approaches to combat the salinity/ sodicity are the establishment of clean root-zone environment for proper plant growth or the plants that suit the prevailing adverse environment. The best fit and widely used approach is that enables the plants to respond in the changed environment (Tyagi and Sharma, 2000; Feizi *et al*., 2010). Research regarding water salinity is focused on salinity management either by retaining salts using different amendments or to screen the salinity tolerant species or to induce salinity tolerance in plants to sustain the yields resultantly better crop yields (Tyagi, 2001; Sharma and Minhas, 2005; Maskooni and Afzali, 2015). The saline water can be

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used for raising crops by applying suitable strategies like application of amendments, blending/ mixing of high RSC/ substandard water with canal water or cyclic application and irrigation scheduling at less sensitive stages of crops. Application of saline water is directly correlated with crop sensitive stages (Zeng *et al*., 2001; Sharma and Minhas, 2005).

It was reported that ~ 6.79×10^{10} m^3 groundwater used for irrigation and out of which 70-75% is hazardous (Latif and Beg, 2004; Qadir and Oster, 2004). Increasing trend of saline water application without the amendments increased the extent of soil salinity. Saline water irrigation with proper amendments to salt affected soils has positive impact on crops and soil physical properties (Murtaza *et al*., 2009; Haider and Hossain, 2013; Maskooni and Afzali, 2015). Application of organic and inorganic amendments enhances the soil microflora and reduces the soil pH (Wong *et al*., 2009). Application of organic content (composted materials and manures) to salt stress fields irrigated with saline water enhanced the soil physical conditions like porosity, water-retention capacity, soil aggregation indices and reduce the soil sodium content (Tejada *et al*., 2006; Wong *et al*., 2008; Feizi *et al*., 2010; Haider and Hossain, 2013).

The continuous irrigation with substandard water damages the soil physico-chemical properties viz. pH, EC_e, SAR, porosity, bulk density, infiltration rate and hydraulic conductivity (Murtaza *et al*., 2006). Accumulation of salts due to saline water with high EC/ RSC results in soil dispersion and affect plant growth adversely (Qadir *et al*., 2001; Grattan and Oster, 2003; Ghafoor *et al*., 2008; Al-Rawahy *et al*., 2010). Crops respond to saline water with variable EC/ RSC according to their tolerance potential or threshold limits but the continuous application of such waters affect the crop yields negatively (Hussain *et al*., 2001; Murtaza *et al*., 2006; Murtaza *et al*., 2009; Maskooni and Afzali, 2015). Sound strategies and practices should be planned to lessen ill effects of high EC/ RSC water. Ameliorative approaches should be followed to reduce the soil / water salinity by different interventions like gypsum, FYM, poultry manure, press mud etc. (Saifullah *et al*., 2002; Yaduvanshi and Swarup, 2006; Al-Rawahy *et al*., 2010; Haider and Hossain, 2013). Present studies were planned to manage the high RSC irrigation water with diverse strategies in areas having rice-wheat cropping schemes on farmer fields.

Materials and Methods

Studies were conducted at farmer fields at Kot Murad district Hafizabad following rice-wheat cropping system. The experimentation site was decided due to availability of canal and saline tube well water. Site/ field were properly prepared and as per treatment, gypsum was applied in permanent layout. The calculation of gypsum requirement for soil and for irrigation water based on RSC was carried out. The required gypsum was applied before transplantation of rice subsequent leaching with canal and saline water. The fertilizer applied @ 110-90-70 for rice and 120-90-70 NPK kg ha^{-1} for wheat. The treatment plan laid out in RCBD (randomized complete block design) as under:
T_1: Control; T_2: Canal water + GR of soil (100%); T_3: Saline water + GR of soil (100%); T_4: Saline water + GR of soil (100%) + GR of irrigation water based on RSC.

Samples were collected (soil and water) before and after harvest of each crop and analyzed for pH_s, EC_e, SAR and GR while soil texture was determined with hydrometer (U.S. Salinity Lab Staff, 1954; Bouyoucos, 1962). Soil bulk density (BD) was determined by drawing undisturbed cores at different soil depths i.e. 0-15, 20-25 cm (Blake and Hartge, 1986). Gypsum requirement (GR) of irrigation water was determined on RSC basis as reported by Eaton (1950). The recorded data were analyzed statistically using ANOVA (analysis of variance) and computed the Least Significance Difference (LSD) by the Duncan's multiple range tests (Duncan, 1955).

Results and Discussions

To evaluate the saline water management for crop production and on soil properties, farmer field trials at Kot Murad district Hafizabad were conducted. The soil and water analyses for different parameters (pH_s, EC_e, and SAR / RSC) before initiation of experiment (Table 1). Soil was sandy loam (0-15 and 15-30 cm) having pH_s 9.20, 9.33, EC_e 6.98, 5.91 dS m^{-1}, SAR 50.27, 42.59 $(mmol\ L^{-1})^{1/2}$ and GR 3.44 t $acre^{-1}$ while BD was 1.67-1.64 Mg m^{-3} (10-15, 20-25 cm), respectively.

Results presented in Table 2 exposed that gypsum significantly influenced the rice and wheat yield attributes positively. During 1st year of rice and wheat, the canal water with GR of soil (T_2) produced the highest biomass i.e. 9.82 and 3.58 Mg ha^{-1}, respectively. The saline water + GR of soil and irrigation water (T_4) produced the maximum paddy yield i.e. 1.45 trailed by 1.33 with saline water +GR of soil (T_3) and 1.12 Mg ha^{-1} with canal water with GR of soil (T_2). The statistically non-significant impact on paddy yield with saline water with GR of soil and irrigation water (T_4) was observed to T_2 and T_3. The canal water with GR of soil produced the maximum wheat grain yield i.e. 1.47 Mg ha^{-1} followed by saline water with GR of soil and irrigation water (T_4) i.e. 1.33 Mg ha^{-1}. Soil analyses (0-15 cm) after harvesting of rice and wheat demonstrated that soil salinity / sodicity decreased due to the application gypsum and increased at 15-30 cm due to leaching of salts. However, applying gypsum either based on GR of soil or of irrigation water reduced the ruinous tendency of saline water. Results suggested that canal water with GR of soil was at par with use of saline water with GR of soil and irrigation water. It was also observed that the soil EC_e was reduced to 24-23% with canal water with GR of soil and 30-24% with saline water with GR of soil and water in the upper soil layer after rice and wheat, respectively. Likewise, the SAR was reduced to 11-29% after rice and wheat with canal water with GR of soil and 33-30% with saline water with GR of soil and of water in the upper soil layer, respectively. In this regard, applying gypsum reduced the soil and water salinization and had healthy effect on soil properties.

Table 1: *Initial Soil Status at Kot Murad.*

Parameters		**Units**	**Soil depth (0-15 cm)**		**Soil depth (15-30 cm)**
Soil Texture			Sandy Loam		Sandy Loam
Bulk density		(Mg m^{-3})	1.67 (10-15 cm)		1.64 (20-25 cm)
pH_s			9.20		9.33
EC_e		(dS m^{-1})	6.98		5.91
SAR		(mmol L^{-1})$^{1/2}$	50.27		42.59
G.R.		(t acre^{-1})	3.44		-
Irrigation sources					
Tube well water			Canal water		
EC (dS m^{-1})	RSC (mmol$_c$ L^{-1})	SAR (mmol L^{-1})$^{1/2}$	EC (dS m^{-1})	RSC (mmol$_c$ L^{-1})	SAR (mmol L^{-1})$^{1/2}$
1.51	4.00	4.77	0.14	Nil	0.12

Table 2: *Biomass and paddy /grain yield (Mg ha^{-1}) and soil analysis as affected by canal and brackish water irrigation with amendments at Kot Murad.*

Treatments	**RICE-1st Year**							
	Biomass (Mg ha^{-1})	**Paddy (Mg ha^{-1})**	**Soil analysis at harvest (0-15 cm)**			**Soil analysis at harvest (15-30 cm)**		
			pH_s	**EC_e (dS m^{-1})**	**SAR (mmol L^{-1})$^{1/2}$**	**pH_s**	**EC_e (dS m^{-1})**	**SAR (mmol L^{-1})$^{1/2}$**
T_1-Control	3.90 B*	0.51B	8.91 A	5.49 A	42.27 A	9.11 A	5.90	48.54
T_2-Canal water + 100 % G.R. of soil	9.82 A	1.12A	8.75BC	4.42 B	38.09 B	8.83 B	4.88	40.00
T_3-Brackish water + 100 % G.R of soil	8.89 A	1.33A	8.77B	4.58 B	37.38 B	8.78BC	4.95	43.19
T_4-Brackish water + 100 % G.R of soil + GR of irrigation water on the basis of RSC	9.51 A	1.45A	8.71C	4.23 C	32.78 C	8.74 C	4.68	38.34
LSD	1.330	0.2754	0.0503	0.1624	2.1670	0.0713	2.8075	1.609
	WHEAT- 1st Year							
T_1-Control	1.58 C	0.72 B	8.89 A	5.30 A	32.12 A	8.92 A	5.32 A	33.35 A
T_2-Canal water + 100 % G.R. of soil	3.58 A	1.47 A	8.70 B	4.30 B	24.09 C	8.75 AB	4.68 AB	26.93 B
T_3-Brackish water + 100 % G.R of soil	3.08 B	1.23 B	8.69 B	4.28 B	26.19 B	8.70 AB	4.39 B	29.12 AB
T_4-Brackish water + 100 % G.R of soil + GR of irrigation water on the basis of RSC	3.42 AB	1.33 AB	8.65 B	4.28 B	24.73 BC	8.63 B	4.50 B	25.60 B
LSD	0.4770	0.1895	0.1597	0.4704	1.8471	0.2483	0.7328	5.5013

**Means sharing the same letter(s) in a column do not differ significantly at $p<0.05$ according to Duncan's Multiple Range Test.*

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Results presented in Table 3 proved that gypsum significantly influenced the rice and wheat yield attributes positively and improved the soil parameters. During 2nd year of rice and wheat, the canal water with GR of soil (T_2) produced the maximum biomass (12.46) and paddy (2.23) following saline water and GR of soil and water (10.63 and 1.96 Mg ha^{-1}), respectively. The maximum biomass (4.66) and wheat grains (2.02) in 2nd year was obtained with canal water with GR of soil (T_2) following saline water with GR of soil and water i.e. 4.38 and 1.90 Mg ha^{-1}, respectively. The effect of biomass, paddy yield / grain yield of wheat with canal water with GR of soil was non-significant statistically to saline water with GR of soil and water. Post-harvest soil analysis (0-15 cm) showed that gypsum application reduced the soil parameters i.e. pH, EC_e and SAR. Soil EC_e and SAR at rice harvest were almost at par with canal water with GR of soil and saline water with GR of soil and water i.e. 3.63 and 3.62 dS m^{-1};19.74 and 20.08 (mmol L^{-1}) $^{1/2}$. The same trend was observed with the post harvest soil analysis of wheat in the 2nd year. Slight lower values of EC_e and SAR were observed at 0-15 cm than the 15-30 cm depth predicting clearing of rhizosphere zone from salts. The soil EC_e and SAR was reduced due to gypsum application with saline water or canal water and improved the soil health. The canal water with gypsum proved to be better by reducing the EC_e and SAR than saline water with gypsum application.

Results presented in Table 4 proved that gypsum significantly influenced the rice and wheat yield attributes positively and improved the soil parameters. During 3rd year of rice and wheat, the highest biomass of rice (13.97) and wheat (5.32 Mg ha^{-1}) with canal water with GR of soil (T_2) followed by 13.21 and 5.14 Mg ha^{-1} with saline water and GR of soil and water, respectively. Similarly, the maximum paddy (2.72) and wheat grains (2.53 Mg ha^{-1}) with canal water with GR of soil (T_2) following with saline water with GR of soil and water (2.59 and 2.47 Mg ha^{-1}) in comparison with control i.e. 0.95 and 0. 78 Mg ha^{-1}, respectively. Soil EC_e and SAR were lessened with canal water and GR of soil i.e. 3.46 and 16.91 and with saline water with GR of soil and water i.e. 3.55 dS m^{-1}; 18.73 (mmol L^{-1})$^{1/2}$ at rice harvest. The post harvest soil analysis after wheat showed that soil EC_e and SAR were also reduced to 3.42 and 16.10 with canal water and GR of soil and saline water with GR of soil and water i.e. 3.52 and 17.58. Increase in soil EC_e and SAR were observed at the 15-30 cm depth due the leaching of salts than the 0-15 cm soil depth. Application of saline water with gypsum on the basis of soil and irrigation water based proved to be an efficient strategy to sustain the yields for the areas where soil and water salinity are problems.

Field studies carried out for three years following rice-wheat cropping pattern demonstrated that saline water can be managed for sustainable yield of rice wheat crops and results are comparable to canal water with gypsum application. Results showed that canal water with gypsum application by compensating the soil salinity proved better than saline water. However, application of saline water with GR of soil and irrigation water provided quite equivalent consequence to canal water and improve the soil characteristics. Management of soil and water with gypsum improved the crop yield and soil analysis. Irrigation with canal water surpassed saline water with amendments. Saline water should be used only after proper management practices to avoid the secondary salinization. Proper management strategies include introduction of chemical amendments i.e. gypsum, H_2SO_4 etc., organic sources like FYM, poultry manure, press mud and salt tolerant crops (Qadir *et al*., 2001; Feizi *et al*., 2010; Haider and Hossain, 2013).

Literature revealed that application of gypsum with or with organic sources with balance plant nutrition in rice-wheat system should be opted to sustain the productivity of such areas having high RSC water (Ghafoor *et al*., 2002; Saifullah *et al*., 2002; Zaka, 2007; Haider and Hossain, 2013). Soil health can be maintained vigilantly by avoiding the irrigation with poor quality ground water or if it is obligation to use such water then proper management like land leveling, chiseling, flushing and irrigation scheduling with application of amendments (Murtaza *et al*., 2009; Mehboob *et al*., 2011). Literature proposed the management practices of water, amendments and agronomic measures for sustainable crop yields (Sharma and Minhas, 2005; Feizi *et al*., 2010). Our results are corroborated the evidence that application of gypsum on soil GR basis proved efficient with canal water or irrigation source is not saline (Haq *et al*., 2007; Zaka, 2007; Al-Rawahy *et al*., 2010).

Soils having sodic ground water should be treated with the $CaSO_4.2H_2O$ (Gypsum) on soil and irrigation water and might lead to sustainable agriculture (Mehdi *et al*., 2013). Application of gypsum improved the soil properties owed to gypsum dissolution and leaching of salts from the root zone (Tejada *et al*., 2006; Yaduvanshi and Swarup, 2006; Murtaza *et al*., 2009; Maskooni and Afzali, 2015). Amelioration of poor quality ground water having higher EC, SAR, RSC by proper management practices might promote the soil health and resultantly crop yields (Murtaza *et al*., 2006; Al-Rawahy *et al*., 2010; Mehdi *et al*., 2013; Haider and Hossain, 2013).

Table 3: *Biomass and paddy /grain yield ($Mg\ ha^{-1}$) and soil analysis as affected by canal and brackish water irrigation with amendments at Kot Murad.*

Treatments	RICE-2nd Year							
	Biomass ($Mg\ ha^{-1}$)	Paddy ($Mg\ ha^{-1}$)	Soil analysis at harvest (0-15 cm)			Soil analysis at harvest (15-30 cm)		
			pH_s	EC_e ($dS\ m^{-1}$)	SAR ($mmol\ L^{-1})^{1/2}$	pH_s	EC_e ($dS\ m^{-1}$)	SAR ($mmol\ L^{-1})^{1/2}$
T_1-Control	6.67 D*	0.92 D	8.69 A	4.72 A	27.65 A	8.73 A	4.75 A	28.27 A
T_2-Canal water + 100 % G.R. of soil	12.46 A	2.23 A	8.50 B	3.63 B	19.74 B	8.65 A	3.66 B	21.73 C
T_3-Brackish water + 100 % G.R of soil	9.26 C	1.81 C	8.49 B	3.60 B	21.16 B	8.50 B	3.72 B	23.97 B
T_4-Brackish water + 100 % G.R of soil + GR of irrigation water on the basis of RSC	10.63 B	1.96 B	8.45 B	3.62 B	20.08 B	8.43 B	3.68 B	21.43 C
LSD	0.7602	0.1212	0.1599	0.3296	3.3120	0.1186	0.5833	1.1128
	WHEAT-2nd Year							
T_1-Control	1.64 C	0.75 C	8.67 A	4.69 A	26.51 A	8.72 A	4.73 A	27.55 A
T_2-Canal water + 100 % G.R. of soil	4.66 A	2.02 A	8.48 B	3.58 B	18.14 C	8.63 B	3.64 C	20.50 C
T_3-Brackish water + 100 % G.R of soil	4.13 B	1.76 B	8.46 C	2.55 B	20.81 B	8.47 C	3.67 B	22.69 B
T_4-Brackish water + 100 % G.R of soil + GR of irrigation water on the basis of RSC	4.38 AB	1.90 AB	8.44 D	3.60 B	19.79 B	8.42 D	3.65 B	21.89 B
LSD	0.4744	0.2203	0.0173	0.1688	1.5859	0.0300	0.0277	1.2404

**Means sharing the same letter(s) in a column do not differ significantly at $p<0.05$ according to Duncan's Multiple Range Test.*

Table 4: *Biomass and paddy /grain yield ($Mg\ ha^{-1}$) and soil analysis as affected by canal and brackish water irrigation with amendments at Kot Murad.*

Treatments	RICE-3rd Year							
	Biomass ($Mg\ ha^{-1}$)	Paddy ($Mg\ ha^{-1}$)	Soil analysis at harvest (0-15 cm)			Soil analysis at harvest (15-30 cm)		
			pH_s	EC_e ($dS\ m^{-1}$)	SAR ($mmol\ L^{-1})^{1/2}$	pH_s	EC_e ($dS\ m^{-1}$)	SAR ($mmol\ L^{-1})^{1/2}$
T_1-Control	5.54 D*	0.95 C	8.65 A	4.62 A	25.40 A	8.68 A	4.65 A	26.09 A
T_2-Canal water + 100 % G.R. of soil	13.97 A	2.72 A	8.46 B	3.46 C	16.91 C	8.50 B	3.54 B	19.79 B
T_3-Brackish water + 100 % G.R of soil	11.43 C	2.40 B	8.47 B	3.52BC	19.23 B	8.46 C	3.60 B	21.49 B
T_4-Brackish water + 100 % G.R of soil + GR of irrigation water on the basis of RSC	13.21 B	2.59 A	8.42 C	3.55 B	18.73 BC	8.44 C	3.58 B	20.71 B
LSD	0.6531	0.1661	0.0238	0.0685	1.9444	0.0326	0.0928	1.9340
	WHEAT-3rd Year							
T_1-Control	1.69 C	0.78 C	8.64 A	4.58 A	23.89 A	8.66 A	4.62 A	24.69 A
T_2-Canal water + 100 % G.R. of soil	5.32 A	2.53 A	8.44 B	3.42 B	16.10 C	8.45 BC	3.50 B	18.47 B
T_3-Brackish water + 100 % G.R of soil	4.83 B	2.29 B	8.44 B	3.48 B	18.47 B	8.46 B	3.55 B	19.77 B
T_4-Brackish water + 100 % G.R of soil + GR of irrigation water on the basis of RSC	5.14 AB	2.47 AB	8.40 C	3.52 B	17.58 BC	8.43 C	3.53 B	18.64 B
LSD	0.3545	0.2011	0.0238	0.1258	1.7097	0.0238	0.0914	3.0902

**Means sharing the same letter(s) in a column do not differ significantly at $p<0.05$ according to Duncan's Multiple Range Test.*

Conclusions and Recommendations

Studies clearly demonstrated that gypsum application enhanced the rice and wheat yields of and improved the soil properties either with canal water or saline water. The salinization due to soil and water can be mitigated or lowered by amendments like gypsum on soil and water basis to sustain the crop productivity of rice-wheat cropping pattern. The saline water should be used after complete analyses and if RSC is high, amendments should be applied n the basis of RSC to avoid the secondary salinization due to substandard water.

Novelty Statement

The soil and water salinity can be mitigated or lowered by amendments like gypsum. Saline water irrigation with proper amendments to salt affected soils has positive impact on crops and soil physical properties.

Author's Contribution

M. Sarfraz: Conducted experiments and collected data.
M. Amjad Qureshi: Drafted the manuscript.
M. Arshad Ullah: Reviewed the manuscript.
Shahzada Munawar Mehdi: Supervised the trials.
Abdul Rasool Naseem and M. Qaisar Nawaz: Collected the references.
Sarfraz Hussain: Reviewed the manuscript.
M. Rizwan: Analyzed data statistically.

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