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Management of rice and wheat crops under dual stress of soil and water salinity

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Abstract

Salt affected soils are increasing continuously due to the secondary salinization, especially irrigation with high electrical conductivity (EC) or residual sodium carbonate (RSC) waters. To feed the ever increasing population of Pakistan, management of brackish water is highly recommended. High saline or sodic waters can only be used on fertile soils after necessary management practices. Intensive cropping system needs sufficient irrigation water but the underground water that has been applied is mostly injurious to soil health. Continuous irrigation with brackish water not only damaged the soil health / quality but also affect the crop productivity. Series of field experiments were carried out at Jhugian Pir district Hafizabad to investigate the different management practices under rice-wheat cropping system following randomized complete block design (RCBD). Results revealed that the highest yield parameters of rice and wheat was obtained with canal water with 100% GR of soil followed by brackish water + 100 % GR of soil + GR of irrigation water on the basis of RSC. Results regarding post- harvest soil analysis (pH, EC and SAR of soil) at (0-15 and 15-30 cm) illustrated that soil conditions were improved with canal water + 100 %GR of soil followed by brackish water + 100 % GR of soil + GR on the basis of RSC of irrigation water and (Brackish water + 100 % GR of soil). The minimum reduction in pH, ECand SAR of soil was observed in the control treatment where no amendment. Results clearly demonstrated that salt affected soils can be successfully cultivated with proper management practices even irrigated with poor quality irrigation water.

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Introduction

To feed the ever increasing population of Pakistan, large amount of water is required for the cultivation of crops. Scarcity of irrigation water and increasing trend of soil and water salinity limited the growth and yield of crops. Pakistan is facing severe climatic changes where evapo-transpiration is many times higher than rainfall resultantly high accumulation of salts towards the productive layer of soil. Consequently, dual stress of soil and water salinity is the biggest threat to Pakistan's agriculture and reduces crop yields and cultivable area. It has been speculated that net addition of 0.98 to 2.47 tons salts per hectare resulted in decrease of 0.2 to 0.4% arable soils (Mahmood *et al.,* 2010).

The deficit in canal irrigation water requirement is 107MAF up to 2013 that can be compensated with groundwater. For this, number of tube wells are installed, out of which ~70–80% of pumped water accumulates soluble salts in the soil (Ghafoor *et al.,* 2002; Kahlown and Azam, 2003; Latif and Beg, 2004). Soil salinization is a major environmental, socio-economic hitch throughout the country. Irrigation with poor quality groundwater degrades the soil and extends the degraded soil to 3 m ha due to soil / water salinity without appropriate management. Use of saline / sodic groundwater without proper management practices results in adverse effect on crop growth (Rafiq, 1990; Murtaza *et al*., 2006).

Intensive cropping pattern with saline / sodic water result in deterioration of soil quality and salinity / sodicity. Ghafoor *et al.* (2008) and Murtaza *et al.* (2009) reported that use of high EC / RSC water with suitable amendments exerts positive impact on crops growth and soil physical properties. Combined application of organic amendments i.e. manures, compost, press mud etc. with inorganic amendments improved the biological properties and reduces the soil pH, EC and SAR (Wong *et al.,* 2009) and also improve the soil physical properties i.e. water-holding capacity and aggregate stability (Zeng *et al*., 2001; Saifullah *et al*., 2002; Tejada *et al.,* 2006; Wong *et al.,* 2008; Shahbaz *et al.,* 2012). Non-stop application of such waters deteriorates the soil physico-chemical properties i.e. EC, SAR, bulk density and hydraulic conductivity (Murtaza *et al*., 2006). Non–stop application of brackish water without care adds more salts in soil results in soil dispersion due to the presence of excessive Na^+ and specific ion toxicity and thus negatively affect the plant growth (Tyagi and Sharma, 2000; Grattan and Oster, 2003; Qadir and Oster, 2004; Ghafoor *et al.,* 2008; Shahbaz *et al.,* 2012). Application of brackish water not only accumulates salinity / sodicity in soil but also more Mg than Ca and high Mg content in brackish water results in more soil dispersion (Ghafoor *et al.,* 1992; Tyagi, 2001). Plant species respond variably to salinity / sodicity stresses to their tolerance potential and continuous addition of salts cross their threshold limits and affect the plant ontogeny and ultimately the yields (Hussain *et al.,* 2001; Murtaza *et al*., 2006; Ghafoor *et al.,* 2008; Murtaza *et al.,* 2009; Hussain *et al.,* 2016; Lamm, 2016).

Ameliorative approaches / strategies / practices should be opted to minimize the toxic effect of poor quality water by different organic and inorganic amendments viz. gypsum, FYM, poultry manure, press mud etc. (Yaduvanshi and Swarup, 2006). Studies were planned on farmer fields to cope the high EC / RSC water with different amendments in rice-wheat cropping system.

Materials and methods

Field Studies

Field experimentation on rice-wheat cropping system wascarried out at farmer fields 'Mouza' Jughian Pir district Hafizabad. Fields were selected after thorough sampling of soil, brackish and canal water. Gypsum requirement (GR) was calculated for the soil and for irrigation water on the basis of RSC. Fields were prepared properly and gypsum was applied in the respective treatments in permanent layout following rice-wheat rotation. Before transplantation of rice, gypsum was applied according to the GR of soil followed by leaching with canal and brackish water, respectively. Fertilizer to rice was 110-90-70 and to wheat 120-90-70 NPK kg $ha^{-1}$was applied following randomized complete block design (RCBD).

Treatments

Treatments details are as under,

T_1-Control

T_2-Canal water + 100 % G.R. of soil

T_3-Brackish water + 100 % G.R of soil

T_4-Brackish water + 100 % G.R of soil + GR of irrigation water on the basis of RSC

Soil and water analysis was carried out before start and after harvest of rice and wheat crop for pH_s, ECe, SAR and G.R. (U.S. Salinity Lab. Staff, 1954). Gypsum requirement of soil and irrigation water was determined on the basis of RSC (Eaton, 1950). Bulk density was determined by drawing undisturbed cores from 10-15 and 20-25 cm soil depths as reported by Blake and Hartge (1986) and soil texture using hydrometer method (Bouyoucos, 1962). Soil analysis before start of the experiment indicated that soils were moderately salt affected having pH_s (9.10), EC_e (7.05 dS m^{-1}), SAR (55.11 (mmol $L^{-1})^{1/2}$) while bulk density was 1.71 and 1.69 Mg m^{-3} (10-15 and 20-25 cm), respectively. The irrigation water used for growing of wheat and rice had RSC values (3.10 $mmol_c$ L^{-1}) and SAR (7.34 (mmol $L^{-1})^{1/2}$). Data regarding yield parameters of rice, wheat were recorded and analyzed statistically using analysis of variance test (ANOVA) (Steel *et al.,* 1997) by Statistix 8.1 and differences among the means were compared by the Duncan's multiple range tests (DMR) (Duncan, 1955).

Results

Field studies were conducted on farmer fields at 'Mouza' Jughian Pir district Hafizabad to assess the management of high EC / RSC water with different amendments in rice-wheat cropping system. Samples of soil and water were collected and analyzed for pHs, ECe, and SAR / RSC before start of experiment is given in Table 1.

Table 1. Initial Soil Status at Jhugian Pir.

Parameters	Units	Soil Depth (0-15 cm)	Soil Depth (15-30 cm)		
Soil Texture		Loam	Loam		
Bulk density	(Mg m^{-3})	1.71 (10-15 cm)	1.69 (20-25 cm)		
pH_s		9.10	8.87		
EC_e	(dS m^{-1})	7.05	5.93		
SAR	(mmol $L^{-1})^{1/2}$	55.11	47.75		
G.R.	(t $acre^{-1}$)	3.26	-		
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 $L^{-1})^{1/2}$
1.53	3.10	7.34	0.21	Nil	0.43

First Year

Data regarding biomass / paddy and grains yield of rice / wheat (1st year)and soil analysis at harvest are in Table 2. Results revealed that application of gypsum significantly affected the biomass / paddy and grain yield of rice and wheat. Maximum biomass in rice and wheat (1st year) was obtained (8.00 and 4.00 Mg ha^{-1}) with canal water +100 % GR of soil, respectively. The highest paddy yield was obtained i.e. 1.37 Mg ha^{-1} with brackish water + GR of soil and on the basis of RSC of irrigation water (T_4) while maximum grain yield of wheat 1.50 Mg ha^{-1} with canal water +100 % GR of soil. The paddy and grain yield with brackish water + GR of soil and on the basis of RSC of irrigation water) was statistically at par with the rest of treatments except control. Soil status (0-15 cm) with the usage of brackish water with 100% GR of soil + GR of irrigation water on the basis of RSC are statistically comparable to canal water +100% GR of soil. However, gypsum application either on the basis of 100% GR of soil or on the basis of soil + RSC of irrigation water reduced the harmful effects of brackish water. It was also noted that the reduction in soil EC_e was 22% for both rice and wheat with canal water+ 100% GR of soil, 36% and 24% with brackish water + GR of soil + GR of irrigation water on the basis of RSC in the upper soil layer, respectively. Similarly, the reduction in SAR after rice and wheat was 40% and 47% with canal water+ 100% GR of soil and 54% and 36% with brackish water + GR of soil and on the basis of RSC of irrigation water in the upper soil layer, respectively. However, brackish water + 100% GR of the soil (T_3) and brackish water + GR of soil+ irrigation water (T_4) not only helped in reclamation of saline sodic soil but also neutralized the hazardous effect of brackish water for crop production and remained at par with canal water +100% GR of soil (T_2).

The lower depth (15-30 cm) showed that increase in soil EC_e and SAR during reclamation process indicated the downward movement of salts.

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

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	*4.05 B	0.68 B	8.83 A	5.62 A	47.22 A	8.95 A	6.01 A	53.18 A
T_2-Canal water + 100 % G.R. of soil	8.00 A	1.27 A	8.68 B	4.59 C	33.71 B	8.74 B	4.93 C	37.94 C
T_3-Brackish water + 100 % G.R of soil	7.33 A	1.33 A	8.71 B	4.94 B	32.35 B	8.75 B	5.15 B	39.74 B
T_4-Brackish water + 100 % G.R of soil + GR of irrigation water on the basis of RSC	7.41 A	1.37 A	8.64 B	4.13 D	30.53 C	8.69 C	4.63 D	37.85 C
LSD	1.109	0.2278	0.0713	0.2251	1.6257	0.0251	0.1514	1.5457
Treatments	WHEAT- 1st Year							
	Biomass (Mg ha^{-1})	Grains (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	*1.92 B	0.70 C	8.77 A	5.30 A	34.15 A	8.88 A	5.60 A	32.16 A
T_2-Canal water + 100 % G.R. of soil	4.00 A	1.50 A	8.62 B	4.33 B	23.13 B	8.68 B	4.56 B	25.94 BC
T_3-Brackish water + 100 % G.R of soil	3.25 A	1.28 B	8.66 AB	4.60 B	24.17 B	8.65 B	4.90 B	27.73 B
T_4-Brackish water + 100 % G.R of soil + GR of irrigation water on the basis of RSC	3.75A	1.37 AB	8.55 B	4.27 B	25.15 B	8.60 B	4.40 B	24.30 C
LSD	0.7502	0.1548	0.1433	0.6544	2.6533	0.1980	0.6169	3.5305

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

Second Year

Data regarding biomass / paddy and grains yield of rice and wheat crops (2nd year) with soil analysis at harvest are in Table 3.The highest biomass in rice and wheat (2nd year) was obtained (12.76 and 5.07 Mg ha^{-1}) with canal water +100 % GR of soil, respectively. The highest paddy and wheat grain yield was obtained i.e. 2.15, 2.11 Mg ha^{-1} with canal water +100 % GR of soil followed by 1.95, 1.91 Mg ha^{-1} with brackish water + GR of soil and on the basis of RSC of irrigation water (T_4). Canal water +100 % GR of soil significantly enhanced the paddy and grain yield than the rest of treatments. Minimum paddy and biomass yield (0.98, 7.19 Mg ha^{-1}) were noted in the control treatment. Soil analysis at harvest (0-15 cm) showed that canal water +100% GR of soil improved the soil EC_e and SAR followed by brackish water with 100% GR of soil + GR of irrigation water on the basis of RSC. Similar to the first year, gypsum application improved the soil EC_e and SAR and improvement was much more when GR of brackish water kept into account. Soil EC_e was reduced after rice and wheat with canal water+ 100% GR of soil i.e. 21.67% and 21.84%, and with brackish water + GR of soil + GR of irrigation water on the basis of RSC i.e. 28.72%, 29.33%, respectively. As far as the reduction in SAR after rice and wheat was 34% and 26.5% with canal water+ 100% GR of soil and 32% and 24% with brackish water + GR of soil and on the basis of RSC of irrigation water, respectively. Similar trend was observed in the lower depth of soil as in first year, slight higher values of ECe and SAR than upper soil layer and gypsum application reduced the adverse effect of brackish water.

Table 3. Biomass and paddy /grain yield (Mg ha^{-1}) and soil analysis as affected by canal and brackish water irrigation with amendments at Jhugian Pir.

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	7.19 C	0.98 C	8.59	4.66 A	29.55 A	8.68	4.94 A	26.39 A
T_2-Canal water + 100 % G.R. of soil	12.76 A	2.15 A	8.52	3.83 B	22.04 C	8.58	4.04 BC	23.46 C
T_3-Brackish water + 100 % G.R of soil	10.83 B	1.86 B	8.56	4.10 AB	25.62 B	8.55	4.34 B	24.52 B
T_4-Brackish water + 100 % G.R of soil + GR of irrigation water on the basis of RSC	11.57 B	1.95 B	8.48	3.62 B	22.34 C	8.60	3.82 C	22.42 D
LSD	0.9885	0.2255	NS	0.6710	1.1599	NS	0.3560	0.7894
Treatments	WHEAT-2nd Year							
	Biomass (Mg ha^{-1})	Grains (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	2.06 C	0.74 C	8.57 A	4.63 A	27.78 A	8.63 A	4.77 A	28.11 A
T_2-Canal water + 100 % G.R. of soil	5.07 A	2.11 A	8.50 B	3.80 C	21.96 C	8.54 C	3.96 C	22.52 C
T_3-Brackish water + 100 % G.R of soil	4.09 B	1.69 B	8.54 A	4.08 B	23.56 B	8.53 C	4.30 B	24.27 B
T_4-Brackish water + 100 % G.R of soil + GR of irrigation water on the basis of RSC	4.78 A	1.91 AB	8.46 C	3.58 D	22.34 BC	8.58 B	3.64 D	23.23 C
LSD	0.6828	0.2559	0.0346	0.0939	1.3199	0.0326	0.1407	0.8680

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

Third Year

Data regarding biomass / paddy and grains yield of rice and wheat crops (3rd year) with soil analysis at harvest are in Table 4. Results showed that canal water + 100 % GR of soil (T_2) improved paddy and wheat grain yield (2.75, 2.46 Mg ha^{-1}) and biomass contents (14.65, 5.55 Mg ha^{-1}) of rice and wheat, respectively and it remained statistically significant with brackish water + 100 % GR of soil (T_3) and non-significant with brackish water + 100 % GR of soil + GR of irrigation water (T_4). Minimum paddy and grain yield (1.01, 0.76 Mg ha^{-1}) and biomass contents (5.70, 2.10 Mg ha^{-1}) were observed in the control treatment. Maximum reduction in EC_e, pH_s and SAR of soil at both soil depths (0-15) and (15-30 cm) found in T_2 (canal water + 100 % GR of soil) and it was followed by T_4 (Brackish water + 100 % GR of soil + GR on the basis of RSC of irrigation water. Soil EC_e was reduced to 24.86%, 26.48% after rice and wheat with canal water + 100 % GR of soil followed by 26.97%, 31.29% with brackish water with gypsum on the basis of soil 100% GR and GR of irrigation water on the base of RSC, respectively. Similarly, soil SAR was reduced by 36.96%, 44.41% after rice and wheat with canal water + 100 % GR of soil followed by 30%, 29.3% with brackish water with gypsum on the basis of soil 100% GR and GR of irrigation water on the base of RSC, respectively.

Discussion

Field experimentation for the consecutive three crops of rice and wheat exhibited the role of gypsum application for sustaining yield using sodic groundwater. Results clearly showed the effectiveness of canal water with gypsum in salt affected soils over brackish water. Results also expressed that brackish water can be used by applying gypsum on soil GR basis and GR of irrigation water on the basis of RSC. Results suggested that GR of irrigation water on the basis of RSC should be kept into account and thus presented comparable results to canal water and reduced the adverse effect on soil health. Results showed that dual stress of soil and water salinity can be mitigated with appropriate management and resultantly improved the crop yield.

Table 4. Biomass and paddy /grain yield (Mg ha^{-1}) and soil analysis as affected by canal and brackish water irrigation with amendments at Jhugian Pir.

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	5.70 C	1.01 C	8.55 A	4.52 A	25.42 A	8.58 A	4.63 A	26.79 A
T_2-Canal water + 100 % G.R. of soil	14.65 A	2.75 A	8.48 B	3.62 C	18.56 C	8.52 B	3.84 BC	19.84 B
T_3-Brackish water + 100 % G.R of soil	12.36 B	2.56 B	8.52 A	3.82 B	21.49 B	8.53 B	3.96 B	23.80 A
T_4-Brackish water + 100 % G.R of soil + GR of irrigation water on the basis of RSC	13.99 A	2.65 AB	8. 44 C	3.56 C	19.56 C	8.47 C	3.60 C	22.48 A
LSD	0.9064	0.1493	0.0331	0.1467	1.8044	0.0331	0.2781	3.4443
Treatments	WHEAT-3rd Year							
	Biomass (Mg ha^{-1})	Grains (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	2.10 C	0.76 C	8.53 A	4.49 A	24.29 A	8.56 A	4.57 A	25.80 A
T_2-Canal water + 100 % G.R. of soil	5.55 A	2.46 A	8.46 B	3.55 C	16.82 C	8.50 BC	3.72 C	18.47 C
T_3-Brackish water + 100 % G.R of soil	4.70 B	2.08 B	8.51 A	3.44 B	20.38 B	8.52 AB	3.88 B	19.32 C
T_4-Brackish water + 100 % G.R of soil + GR of irrigation water on the basis of RSC	5.26 AB	2.37 AB	8.44 B	3.42 D	18.79 B	8.46 C	3.58 C	22.48 B
LSD	0.6872	0.2777	0.0489	0.0822	1.8818	0.0529	0.1419	2.9341

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

It was also observed that brackish water with amendments can only be compared with canal water but not be better than canal water. Besides primary salinity, the tendency of soils towards salinization is mainly due to anthropogenic activities like use of brackish water without care. Literature revealed / presented the main management strategies are addition of inorganic and organic amendments, agronomic and engineering approaches etc. Amelioration with gypsum when combined with organic wastes and application of proper nutrition plan sustainably increased the rice and wheat yield on salt affected soils (Qadir *et al.,* 2001; Ghafoor *et al.,* 2002; Saifullah *et al.,* 2002; Zaka, 2007; Shahbaz *et al.,* 2012). Avoidance of poor quality groundwater must be carried out for the sake of soil health and if impossible then use it with proper care like application of amendments and introduction of agronomic / engineering approaches. Results showed that crop yield can be increased with brackish water with application of GR on soil basis and on soil / irrigation water's RSC basis. Improvement in soil parameters might be due to the amendments dissolution and root action in the soil during the crop growth (Murtaza *et al.,* 2009; Mehboob *et al.,* 2011; Shahbaz *et al.,* 2012; Hussain *et al.,* 2016).

Results of three years experimentation verified that gypsum application on soil GR basis with canal water (Haq *et al.,* 2007; Zaka *et al.,* 2003; Zaka, 2007). Our results confirmed the previous findings of many researchers (Ghafoor *et al.,* 2008; Murtaza *et al.,* 2009; Mehdi *et al.,* 2013). Treatment of high RSC water with gypsum application on soil GR basis and GR of irrigation water on RSC basis might help in sustaining yield. Gypsum application results in better crop yield and soil status due to replacement of Na^+ with Ca^{2+} and subsequent leaching from the upper soil layer (Tejada *et al.,* 2006; Yaduvanshi and Swarup, 2006; Murtaza *et al.,* 2009; Mehdi *et al.,* 2013; Hussain *et al.,* 2016). Appropriate management practices to ameliorate ill effect of high EC / RSC water owe to improvement in soil quality and rice-wheat yield (Sharma and Minhas, 2005; Murtaza *et al.,* 2006; Shahbaz *et al.,* 2012; Mehdi *et al.,* 2013; Bacilio *et al.,* 2016; Hussain *et al.,* 2016).

Conclusion

Studies concluded that application of gypsum on soil GR basis improved the rice-wheat crops and also improved the soil properties. Dual stress of salinity (soil and water) can be lessened or reduced by applying gypsum on soil need basis and RSC of irrigation water and resultantly yield of crops.

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