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USE OF LOW QUALITY GROUNDWATER FOR RECLAMATION OF SALINE-SODIC SOIL BY GROWING RICE AND WHEAT CROPS

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Abstract

A field experiment was conducted at Qaim Bharwana, district Jhang, Pakistan on a saline-sodic soil (EC_e = 12.7-20.1 dS m^{-1}, pH_s = 10.3-10.4, SAR = 157.0-273.9 at 0-15 cm soil depth and EC_e = 5.4-12.1 dS m^{-1}, pH_s = 9.5-10.0, SAR = 70.1-171.4 at 15-30 cm soil depth) following rice-wheat rotation using tube well water (EC = 1.32 dS m^{-1}, SAR = 4.8, RSC = Nil, Ca:Mg = 0.74) for irrigation. The treatments tested were: TW) Tube well water alone, FYM-20) FYM @ 20 Mg ha^{-1}, Gyp-100) gypsum @ 100% soil gypsum requirement (SGR) and FYM+Gyp) FYM @ 10 Mg ha^{-1} + gypsum @ 50% SGR. After rice 2005 harvest, soil analysis showed that pH_s for both the soil depths decreased non-significantly, per cent decrease over initial being maximum with Gyp-100 followed by FYM+Gyp, TW and FYM-20 at 0-15 cm, while treatment effectiveness order for pH (per cent) decrease was FYM+Gyp>TW>FYM-20 at 15-30 cm soil depth but slightly increased with Gyp-100. The EC_e decreased non-significantly with treatments, per cent decrease over initial being maximum with FYM+Gyp followed by Gyp-100, FYM-20 and TW at 0-15 cm. Decrease in pH_s was significant at 15-30 cm soil depth and the treatment order was FYM+Gyp>TW>Gyp-100>FYM-20. Treatments differed non-significantly to lower SAR for both the soil depths, per cent decrease being maximum with FYM+Gyp followed by Gyp-100, FYM-20 and TW at 0-15 cm, while the order was FYM+Gyp>Gyp-100>FYM-20>TW at 15-30 cm soil depth. Soil analysis after harvest of wheat 2005-06 depicted a decrease in pH_s with all the treatments, order being Gyp-100>FYM+Gyp>FYM-20>TW at 0-15 cm soil depth. At 15-30 cm depth, the treatment order to decrease pH_s was Gyp-100>FYM+Gyp>TW>FYM-20. Maximum decrease in EC_e was observed with FYM+Gyp followed by TW, FYM-20 and Gyp-100 at both the 0-15 cm and 15-30 cm soil depths. Maximum reduction in soil SAR was observed with FYM+Gyp followed by Gyp-100, FYM-20 and TW at both the soil depths. The paddy yield of rice 2005 was maximum with FYM+Gyp followed by Gyp-100, FYM-20 and TW. The highest grain yield of wheat during 2005-06 was obtained with FYM+Gyp followed by FYM-20, Gyp-100 and TW. Maximum net profit was obtained with FYM+Gyp followed by FYM-20, Gyp-100 and TW.

Introduction

Pakistan has the largest irrigation system in the world but the availability of canal water does not commensurate to grow crops on the cultivable land, rather scarcity of good quality water is becoming severe day by day due to increased cropping intensity and non-agricultural demands. To overcome this shortage, 0.77 million tube wells have been installed (Anon., 2005), and 70-80% of pumped water is of hazardous quality owing to high electrical conductivity (EC), sodium adsorption ratio (SAR) and/or residual sodium carbonate (RSC) and thus needs site-specific scientific management.

In many arid and semi-arid regions of the world including those of Pakistan, inadequate availability of good quality water compels farmers to use ground water for irrigation. However, majority of the ground water sources contain high concentrations of $NaHCO_3$ (Minhas & Bajwa, 2001). Long-term use of such water for irrigation can lead to deterioration in soil physical and chemical properties and adversely affect yields of crops (Minhas & Bajwa, 2001; Choudhary *et al*., 2002). Excess of cations such as sodium and anions like carbonate and, bicarbonate in water could increase soil pH, EC and SAR.

In order to offset harmful effects associated with the use of brackish water for irrigation, application of gypsum is a common recommendation as a source of calcium to replace adsorbed sodium and improve physical and chemical properties of soils (Ayers & Westcot, 1985). Incorporation of organic materials for reducing deleterious effects of poor quality water irrigation through mobilization of native soil $CaCO_3$ and other Ca-bearing minerals (Minhas *et al*., 1995; Choudhary *et al*., 2002) could be another option. Compared to gypsum, application of FYM proves more useful when irrigation water has relatively low EC than high residual sodium carbonate (Yadav & Kumar, 1994). This indicates that for economical utilization and reclamation of salt-affected soils, a combination of different management practices and soil amendment need to be exploited on site-specific basis, particularly when brackish water is applied for irrigation.

Keeping all the above facts in view, the present study was designed with the objectives: (1) To evaluate the effectiveness of organic and inorganic amendments alone and in combination to reclaim a salt-affected soil, (2) To evaluate the response of rice and wheat crops to soil applied treatments and (3) To evaluate the economics of soil reclamation treatments.

Materials and Methods

A field experiment was conducted on a saline-sodic soil during June 2005 (Table 1). Four treatments were applied in a Randomized Complete Block Design with 3 replications, growing rice-wheat crops in rotation. The treatments employed were: TW) Tube well water only, FYM-20) FYM @ 20 Mg ha^{-1} 30 days before rice transplanting during the year 2005, Gyp-100) gypsum @ 100% SGR (applied at the start of studies and FYM+Gyp) gypsum @ 50% SGR once + FYM @ 10 Mg ha^{-1} before rice crop. After laying out the experiment, composite soil samples were collected from each treatment plot at 0-15 and 15-30 cm soil depths and analyzed for soil chemical properties like pH_s, EC_e, soluble cations and anions and the SAR was computed. Physical characteristics (infiltration rate, IR and bulk density, BD) were measured at the start of experiment.

The seedbed was prepared and calculated amount of gypsum on the basis of soil gypsum requirement (SGR) and FYM were broadcasted and mixed into soil with cultivator. For all the treatments, low quality groundwater was used for irrigation (EC= 1.32, SAR= 4.8, RSC = nil, Ca:Mg = 0.74). Two to three (45-50 days old) rice seedlings hill^{-1} of cv. KS-282 were transplanted on 25 July 2005. Fertilizer N, P and K @ 100-67-25 kg ha^{-1}, respectively were applied. Half of the N and full doses of P and K were applied at the time of rice transplanting without puddling the soil. The remaining of N was applied in two equal splits 25 and 40 days after transplanting. The crop growth parameters viz. tillers, plant height, hills m^{-2}, 1000-grain weight, paddy and straw yields were recorded at harvest upon attaining the physiological crop maturity. After rice harvest, composite soil samples were collected from each plot and analyzed for pH_s, EC_e and soluble cations and anions following the method described by the U.S. Salinity Lab. Staff (Anon., 1954).

Table 1. Soil analysis before the start of studies.

Treatment	pH_s		EC_e (dS m^{-1})		SAR	
	0-15 cm	15-30cm	0-15 cm	15-30cm	0-15 cm	15-30cm
TW	10.3	10.0	18.4	12.1	234.0	161.0
FYM-20	10.3	9.5	12.7	5.7	157.0	70.0
Gypsum-100	10.3	9.7	16.4	5.4	207.0	79.0
FYM + Gyp	10.4	9.9	20.1	11.5	272.9	171.0

After the harvest of rice, the field was prepared and wheat was sown at field capacity condition using a seed rate of 100 kg ha^{-1}. Fertilizers, N and P were applied @ 100-67 kg ha^{-1}. Half of N and full dose of P were applied at the time of sowing and remaining N was applied in two equal splits with the second and third irrigations. Crop growth parameters like tillers, plant height, 1000-grain weight, grain and straw yields were recorded at harvest during May 2006. The physical characteristics of soil (bulk density and infiltration rate) were determined after wheat 2005-06. Composite soil samples were collected from each plot at 0-15 and 15-30 cm soil depths. The samples were processed and analyzed for pH_s, EC_e, soluble cations and anions following the methods of the U.S. Salinity Lab. Staff (Anon., 1954). The data regarding soil properties and crops growth parameters collected during one year experiment were subjected to statistical analysis following ANOVA technique. The treatment economics was computed on the basis of variable costs only and support prices of produce were considered. The treatment differences regarding crop yields and soil pH_s, EC_e, and SAR were evaluated using LSD test (Steel & Torrie, 1993).

Results

At the start of studies, bulk density ranged from 1.50 to 1.55 Mg m^{-3} at 10-15 cm soil depth while it ranged from 1.52 to 1.62 Mg m^{-3} at 20-25 cm soil depth (Table 2). After the harvest of wheat in May 2006, bulk density decreased with all treatments but decrease was only 2-5% over the respective initial values at both the soil depths except with TW at 20-25 cm depth, where it remained unchanged (Table 3). The infiltration rate before the start of experiment ranged from 0.45 to 0.75 cm h^{-1} (Table 2) which is higher than the critical value of 0.25 cm h^{-1} for productive soils (Anon., 1954). After wheat 2005-06 harvest, the IR increased with all the treatments, being maximum with FYM+Gyp followed by Gyp-100, FYM-20 and TW (Table 3).

Table 2. Effect of treatments on physical properties of soil after wheat.

Treatment	Bulk density				Infiltration rate (cm h^{-1})	
	0-15 cm		0-25 cm		Initial[a]	PW[b]
	Initial[a]	PW[b]	Initial[a]	PW[b]		
TW	1.55	1.52 (-2.0)	1.73	1.54 (-1.3)	0.45	0.60 (+33.0)
FYM-20	1.51	1.47 (-2.6)	1.77	1.57 (-3.0)	0.50	0.70 (+40.0)
Gypsum-100	1.55	1.50 (-3.2)	1.83	1.55 (-3.0)	0.60	0.80 (+33.3)
FYM + Gyp	1.50	1.47 (-3.0)	1.78	1.51 (-5.6)	0.75	1.10 (+47.0)

In parentheses values are % increase (+) or % decrease (-) over the respective initial values. * Treatments differed significantly at p=0.05. NS, Treatments differed non-significantly at p=0.05. Values in a column sharing same letter(s) are not statistically different at p=0.05. (a) Initial soil bulk density and infiltration rate before the start of experiment. (b) PW represents post-wheat (2005-06) bulk density and infiltration rate.

Table 3. Chemical properties of soil after harvest of rice.

Treatment	pH_s		EC_e (dS m^{-1})		SAR	
	0-15 cm	15-30cm	0-15 cm	15-30cm	0-15 cm	15-30cm
TW	9.72(-6.2)	9.75 (-2.5)	7.37 (-60.0)	6.35a (-47.6)	58 (-75.2)	52a (-67.6)
FYM-20	9.66(-5.8)	9.78 (-2.3)	4.45 (-65.0)	3.53b (-38.6)	31 (-80.5)	22b (-68.6)
Gyp-100	9.30(-10.2)	9.76 (+2.0)	4.62 (-71.8)	3.02b (-44.4)	30 (-85.5)	18a (-77.3)
FYM + Gyp	9.60(-8.1)	9.64 (-2.5)	4.95 (-75.4)	3.60b (-68.7)	34 (87.4)	23b (86.5)
LSD	0.49^{NS}	0.39^{NS}	3.81^{NS}	1.86*	35.63	23.38

In parentheses, values are % increase (+) or % decrease (-) over the respective initial values. * Treatments differed significantly at p=0.05. NS, Treatments differed non-significantly at p=0.05. Values in a column sharing same letter(s) are not statistically different at p=0.05.

After the harvest of rice in November 2005, the treatment FYM+Gyp performed better in lowering the pH_s, EC_e and SAR of soil compared to that with control (Table 4). Maximum reduction (%) in pH_s was observed with GYP-100 followed by FYM+Gyp, TW and FYM-20 over the respective initial values at 0-15 cm soil depth. At 15-30 cm soil depth, pH_s decreased with all the treatments except Gyp-100. Maximum decrease (%) was observed with FYM+GYP followed by TW and FYM-20. Maximum per cent reduction in EC_e was with FYM+GYP followed by Gyp-100, FYM-20 and TW at 0-15 cm and at 15-30 cm soil depth, treatment order to decrease EC_e was FYM+GYP>TW>GYP-100>FYM-20. The treatment order for per cent decrease in SAR was FYM+Gyp>Gyp-100>FYM-20>TW at 0-15 and 15-30 cm soil depths.

Table 4. Chemical properties of soil after harvest of wheat.

Treatment	pH_s		EC_e (dS m^{-1})		SAR	
	0-15 cm	15-30cm	0-15 cm	15-30cm	0-15 cm	15-30cm
TW	9.16 (-11.6)	9.49 (-5.1)	4.70 (-74.4)	4.30 (-64.5)	33 (-85.8)	31 (-81.0)
FYM-20	8.94 (-12.9)	9.29 (-2.0)	4.60 (-63.8)	3.20 (-44.8)	32 (-79.8)	20 (-70.7)
Gyp-100	8.51 (-17.7)	8.95 (-8.1)	6.20 (-62.2)	5.20 (-3.7)	24 (-88.4)	24 (-69.5)
FYM + Gyp	8.97 (-14.2)	9.29 (-6.1)	4.50 (-77.7)	3.00 (-74.0)	25 (90.6)	16 (90.6)
LSD	0.73^{NS}	0.76^{NS}	3.09^{NS}	2.83^{NS}	19.93^{NS}	10.71^{*}

In parentheses, values are % increase (+) or % decrease (-) over the respective initial values. * Treatments differed significantly at *p*=0.05. NS, Treatments differed non-significantly at *p*=0.05. Values in a column sharing same letter(s) are not statistically different at *p*=0.05.

After the harvest of wheat 2005-06, treatments effects were non-significant on pH_s at 0-15 and 15-30 cm soil depths. Maximum per cent decrease in pH_s was observed with Gyp-100, followed by FYM+Gyp, FYM-20 and TW at 0-15 cm depth, while at 15-30 cm soil depth, the treatment order to decrease pH_s was Gyp-100 followed by FYM+Gyp, TW and FYM-20. However, gypsum with or without FYM affected more decrease in pH_s which favours crops under the calcareous alkaline conditions of experiment soil. The EC_e was maximum with Gyp-100 followed by TW, FYM-20 and FYM+Gyp at both the soil depths. The per cent decrease in EC_e was maximum with FYM+Gyp followed by TW, FYM-20 and Gyp-100 at the 0-15 and 15-30 cm soil depths.

Maximum SAR was noted with TW followed by FYM-20, FYM + Gyp and Gyp-100 for the upper soil depth, while the treatment order to decrease SAR at the lower soil depth was TW>Gyp-100>FYM-20>FYM + Gyp. The treatment order to affect per cent decrease in SAR was FYM+Gyp>Gyp-100>TW>FYM-20 at 0-15 cm soil depth and at 15-30 cm depth, this order was FYM+Gyp>TW>FYM-20>Gyp-100. There was a little increase in EC_e in some of the plots but generally the pH_s, EC_e and SAR decreased during wheat growth period. Overall, FYM with or without gypsum (FYM+Gyp or FYM-20) proved better for improving soil compared to TW alone.

Crop growth: Productive tillers, plant height and paddy yield (Table 5) showed significant treatment differences for rice. Maximum paddy yield was noted with FYM+Gyp followed by Gyp-100, FYM-20, TW. Straw yield was maximum with Gyp-100 followed by FYM+Gyp, FYM-20 and TW which also indicates better growth with gypsum.

Table 5. Growth response of rice during reclamation of saline-sodic soil.

Treatment	Paddy (kg ha^{-1})	Straw (kg ha^{-1})	Prod. tillers (No. m^{-2})	Non-prod tillers (No m^{-2})	Plant height (cm)	1000-grain wt. (g)
TW	381b	1464	87b	28	66.7b	20.77
FYM-20	740b	1793	112ab	18	72.2ab	21.97
Gyp-100	812ab	2496	134ab	25	66.0b	21.20
FYM + Gyp	1303ab	2366	172a	15	76.5a	21.76
LSD	224.6^{*}	422.5^{NS}	82.69^{*}	18.68^{NS}	6.18^{*}	5.57^{N}

*Treatments differed significantly at *p*=0.05. NS, Treatments differed non-significantly at *p*=0.05. Values in a column sharing same letter(s) are not statistically different at *p*=0.05.

For wheat, plant height, non-productive tillers, straw and grain yields were significantly affected by the treatments (Table 6). Straw and grain yields were maximum with FYM+Gyp followed by FYM-20, Gyp-100 and TW. The gross income was maximum with FYM+Gyp followed by FYM-20, Gyp-100 and TW, while treatment order for net benefit was FYM+Gyp, FYM-20, Gyp-100, TW up to the wheat 2005-06 (Table 7).

Table 6. Growth response of wheat during reclamation of saline-sodic soil.

Treatment	Grain (kg ha^{-1})	Straw (kg ha^{-1})	Prod. tillers (No. m^{-2})	Non-Prod tillers (No m^{-2})	Plant height (cm)	1000-grain wt. (g)
TW	654b	980b	64	10b	62.8b	41.12
FYM-20	1549a	2324a	85	14a	90.3a	42.52
Gyp-100	1283ab	1925ab	77	11b	83.8a	41.38
FYM + Gyp	1852a	2779a	98	11b	84.0a	42.97
LSD	360.8^{*}	541.2^{*}	42.26^{NS}	2.81^{*}	12.19^{*}	3.31^{NS}

*Treatments differed significantly at *p*=0.05. NS, Treatments differed non-significantly at *p*=0.05. Values in a column sharing same letter(s) are not statistically different at *p*=0.05.

Table 7. Economics (Rs. ha^{-1}) evaluation of treatments for rice 2005 and wheat 2005-06.

Treatment cost	Variable cost			Income			Net benefit	Benefit cost ratio
	Gypsum	FYM	Total	Rice	Wheat	Total		
TW	-	-	-	5609	9174	14783		
FYM-20	-	4940	4940	9757	22163	31920	26980	6.46
Gypsum-100	6867	-	6867	10552	18340	28892	22025	4.20
FYM + Gyp	6177	2470	8647	16232	26651	42884	34237	4.96

Discussion

Small decrease of only 2.5% in the bulk density over the initial values with all the treatments is probably due to small period of only one year among the two measurements, while improvement in physical properties of soils needs a longer time even if the soils have been chemically ameliorated (Murtaza *et al*., 2006). There was considerable increase in IR with gypsum alone or in combination with FYM. The effectiveness of gypsum in preventing the breakdown of aggregates and resultantly an increase in soil porosity has been reported by Lebron *et al*. (2002). Similar increase in infiltration rate was reported by Chaudhry (2001) with the application of gypsum and FYM. More (1994) reported an increase in infiltration rate upon the addition of different organic materials to sodic soils, being highest with application of FYM. Although bulk density decreased from 1.36 to 1.30 Mg m^{-3}, it was statistically similar.

Reduction in pH_s with FYM+Gyp and FYM-20 treatment could be attributed to the removal of carbonates and bicarbonates of sodium to a greater extent during reclamation. Similar results were obtained by Muhammed & Khaliq (1975) and Sharma *et al.* (2001). Percent decrease in EC_e was higher at upper than that at lower soil depths suggesting a rapid leaching of salts from surface layers because soil water got loaded with salts while passing through the upper layers and hence its capacity to dissolve more salts from the lower depth decreased (van Schilfgaarde & Rhoades, 1979). Similar trend of decrease in EC_e was observed by Murtaza *et al*., (1996) during reclamation of a saline-sodic soil by using agricultural drainage water. The decrease in EC_e with gypsum with or without FYM appears most probably through increasing infiltration rate with gypsum application (Chaudhry *et al*., 1982; Zia *et al*., 2006) as well as Ca^{2+} released from soil lime as a result of CO_2 released during FYM bio-chemical oxidation. Relatively less decrease in EC_e after wheat than that after rice crop appears because of the time laps between the last irrigation and time of soil sample collection during the hot months of April and May (Armstrong *et al*., 1996). Similar results have been reported by Mahmood *et al*. (2001) and Qadir *et al*. (2001) in Pakistan and by Rao *et al*. (1994) in India. The decrease in SAR at both the soil depths with the gypsum treatments is natural since external source of Ca^{2+} was applied in addition to Ca^{2+} added in TW, released through in-situ mineral weathering and/or from the dissolution of native lime in soil. Qadir *et al*. (2001) noticed a decrease in SAR from 30.0 to 15.0 in 1.2 m profile with the use of gypsum and FYM. Mahmood *et al.* (2001) reported gypsum in combination with FYM as the best option to decrease pH_s, EC_e and SAR below permissible limits while using brackish water for irrigation.

Maximum paddy yield with gypsum could be due to favorable Ca^{2+}/Na^{+} ratio in soil solution which improved soil permeability, which helped better paddy yield through favourable effect of Ca^{2+} probably on maintaining cell membrane integrity and plant metabolism (Ashraf, 2004). The results are in confirmatory with those reported by Hussain *et al*. (1986). Chaudhray *et al*. (1990) reported that maximum paddy yield was obtained with gypsum @ 50% soil GR along with FYM @ 50 Mg ha^{-1}, which was 66.2% higher than that from the control plots. Better paddy yield with FYM also seems through some additional nutrient availability along with improvement in physical characteristics of soil like infiltration, which in turn enhanced leaching of salts, leaving low concentration (EC_e) in root zone (Manchanda *et al*., 1989; Agarwal *et al*., 1964 and Chand *et al*., 1977).

The grain and straw yields of wheat were the best with combined application of gypsum and FYM. It appears that during the preceding rice crop, there was considerable reclamation of soils which helped wheat to yield better. Even the higher EC tolerance of wheat than rice (Ayers & Westcot, 1985) was added benefit to wheat to yield better. However, application of calcium might also have induced better EC and SAR tolerance in wheat through maintaining cell membrane integrity for sustaining their selectivity in ion absorption from soils (Staples & Toenniessen, 1984).

Economic evaluation of treatments: Cumulative expenditure was maximum for FYM+Gyp followed by GYP-100, FYM-20 and TW. The gross income was maximum with FYM+Gyp followed by FYM-20, Gyp-100 and TW, while treatment order for net benefit was FYM+Gyp, FYM-20, Gyp-100, TW up to the wheat 2005-06 (Table 7). From two crops treatment FYM+Gyp gave the highest net benefit followed by FYM-20, Gyp-100 and TW. The cost of amendments was recovered from the very first crop of rice 2005.

Conclusions: On the basis of results obtained from this reclamation study, it is concluded that low quality ground water could successfully reclaim saline-sodic soils provided agricultural grade gypsum @ 50% SGR with FYM is applied. Addition of FYM along with gypsum proved better for the economic yields of both the rice and wheat crops. 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 rehabilitation of barren salt-affected soils, preferably in the canal commanded areas particularly when productive class-I soils are being urbanized.

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