ECONOMICAL USE OF BRACKISH TUBE WELL WATERS FOR RICE-WHEAT PRODUCTION AND RECLAMATION OF SALINE-SODIC SOILS

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A series of field experiments in the Fourth Drainage Project Area (Site 1 at Chak 140/R.B., Site 2 at Chak 147/R.B., Site 3 at Chak 123/G.B.), Faisalabad were carried out on saline-sodic soils (EC_e 5.7-38.5 dS m^{-1}, pH_s 8.07-8.52, SAR 36.6-145.0, and 9.0-35.2 dS m^{-1}, 8.10-8.52, 37.2-109.8 at 0-15 and 15-30 cm soil depths, respectively) following rice-wheat crop rotation using tube well water for irrigation (EC 2.2-4.3 dS m^{-1}, SAR 7.8-28.0, RSC 0.4-14.6 mmol$_c$ L^{-1}). The treatments employed were; T1) Tube well water alone, T2) Soil-applied gypsum @ 50 % gypsum requirement of soil (25 % SGR to each of the first two crops), T3) Soil-applied FYM @ 10 t acre^{-1} annually before rice, T4) Combination of treatments 2 and 3. Up-till-now, three crops of rice and two that of wheat have been harvested. After rice harvest in Nov. 2003, soil EC_e, SAR and pH_s for both the soil depths at all the three sites decreased. Overall percent decrease being maximum with T2 followed by T4, T3 and T1. There was considerable differences in the effectiveness of treatments to improve these saline-sodic soils at different sites indicating a site-specific approach, based on soil and irrigation water characterization for their amelioration. Since these soils were highly saline-sodic and lying barren for the last > 30 years, first crop of rice 2001 was poor but the yields of the following crops gradually improved. Overall, rice and wheat yields were the highest with T2 followed by T4, T3 and T1. The cost of reclamation treatments was recovered from the first two crops at sites 2 and 3 but from three crops at site 1. Overall, the net benefit was maximum with T2 followed by T4, T3 and T1. Net income was the highest at site 2 followed by sites 3 and 1. The farmer's skill and management in agronomic operations during reclamation appeared a key factor to realize economic yields and soil amelioration. It is recommended that farmer education and supply of quality inputs in time and space must be insured and soil amelioration projects are worth investment under the existing agro-ecological and socio-economical conditions of Pakistan for food security, rural poverty alleviation and cleaning of the environment through the decreased effect of green house gases.

Keywords: Brackish water, reclamation, saline-sodic soils, net income

INTRODUCTION

Agriculture is the main stay of Pakistan economy, employing 66% of the labour force, accounting for 26% of GDP (Anonymous, 2002) and contributing significantly to the export earnings. Pakistan has the largest irrigation system in the world but the availability of canal water does not commensurate to grow crops on all the culturable land. Rather scarcity of quality water is becoming severe due to increased cropping intensity and non-agricultural demands and/or ambient drought. To overcome this shortage, ≈0.6 million tube wells has been installed which pump 55 MAF water, of which 70-80 % water is of hazardous quality owing to high EC, SAR and/or RSC (Personal communication from the Directorate of Rapid Soil Fertility Survey and Soil Testing Institute, Lahore) and needs site-specific scientific management. The salt-affected area is about 6.67 mha in the Indus valley of Pakistan (Khan, 1998) which expectedly is increasing owing to the use of low quality ground water for irrigation under the prevailing drought conditions of the country.

Reuse of saline-sodic water and amelioration of salt-affected soils are becoming important tool to improve the crop production as well as to decrease the disposal problem of such waters. This could help to bring more land into cultivation, environment friendly through the sequestration of CO_2 (Lal, 2001), source of employment and thus rural poverty alleviation, and to decrease the rural to urban migration. Poor quality water can be used for crop production on a variety of salt-affected soils provided proper agronomic practices coupled with chemical techniques are followed like the use of gypsum, FYM and salt tolerant crops (Ghafoor et al., 1997; Qadir et al., 2001). The use of high electrolyte waters often prove useful during the initial phase of soil amelioration (Ghafoor et al., 2004). This paper reports results of field experiments in the Fourth Drainage Project Area, Faisalabad with the following objectives:

1) Productive use of poor quality tube well waters on salt-affected soils.

2) Effectiveness of gypsum with and without FYM for reclaiming salt-affected soils.

3) Growth response of rice and wheat to soil amelioration treatments.

4) Economics evaluation of soil reclamation treatments.

MATERIALS AND METHODS

A series of field experiments was laid out on sandy clay loam (Gajiana soil series, Typic Aquisalids sub-group; site 1 at Chak 140/R.B. Muthianwala and site 2 at Chak 147/R.B. Churi) and clay loam (Khurrianwala soil series, Salic Aquic Natrargids subgroup) at Chak No. 123/G.B, Awagat (site 3), Faisalabad in the Fourth Drainage Project Area, FDPA (Fig 1-3). Four treatments were replicated thrice in the Randomized Complete Block Design with a plot size of 13.4 m × 29.23 m following rice-wheat crop rotation. The treatments were: T1, Brackish tube well water only, T2, Soil-applied gypsum @ 50 % SGR (25 % to rice 2001 + 25 % to wheat 2001-02), T3, FYM @ 10 tons acre^{-1} annually before transplanting rice and T4, Combination of T2 and T3 treatments. After laying out the experiments, composite soil samples were collected from each plot at 0-15 and 15-30 cm depths. Agricultural grade gypsum (passed through 30 mesh sieve having 70% purity) and FYM (as available with farmers) were mixed into the surface soil of the respective treatments with cultivator. Two to three seedlings of rice, 45-50 days old, were transplanted without puddling the soils during July each year. Fertilizer NPK @ 100-68-38 kg ha^{-1} were applied as urea, SSP and MOP, respectively. Half of N, all the P and K were applied at the time of transplanting. Remaining N was applied in two equal splits 30 and 45 days after transplanting. Tube well waters were used for irrigation those had EC 2.2-4.3 dS m^{-1}, SAR 7.8-28.0, RSC 0.4-14.6 mmol$_c$ L^{-1}

The wheat crop was drill-sown using seed rate of 100 kg ha^{-1} after rice harvest in December each year. Fertilizer NP @ 100-68 kg ha^{-1} were applied as urea and SSP, respectively. Half of N and all the P were applied at the time of sowing. The rest of the N was applied in two equal splits with the first and third irrigations. The experimental plots at sites 1 and 2 received 42 irrigations of tube well water and 10 irrigations of canal water, while 50 of tube well and 7 of canal water at site 3, each irrigation of about 7.5 cm depth. Whole of the plots were harvested at maturity. The rice was threshed manually and wheat was mechanically threshed to record economic yields.

After the harvest of each crop, composite soil samples were collected from each plot at 0-15 and 15-30 cm soil depths. All the soil samples were analyzed for pH$_s$, EC$_e$ and soluble cations and anions (Page et al., 1982). During the first and second years of study, there was no rainfall while 135 mm rainfall was recorded during the third year. The data collected were subjected to statistical analysis following ANOVA technique and treatment differences were evaluated using LSD test (Steel and Torrie, 1980). For economic analysis, market prices of variable inputs and support prices those of the produce were used.

RESULTS AND DISCUSSION

Soil Characteristics: Analyses of soil samples, taken from 0-15 and 15-30 cm soil depths before the start of experiment, indicate that the experimental soils were strongly saline-sodic (Fig. 1-3). The highly variable levels of EC$_e$ and SAR in different parts of the same experiment plots were encountered which is not an exception rather is a rule for natural saline-sodic field conditions. The natural flora in these fields included Saji (*Sueda fruticosa*), Lani (*Salsola foetida*), Naru *(Arundo donax)*, Pahari Keeker (*Prosopis juliflora*) and Desi Keeker (*Acacia arabica*) but plants were sparsely growing.

The pH$_s$, in general, increased over the initial values by a small fraction of 0.1-5.0 % (Fig. 1) but there was also a small deceases at places. After the harvest of rice 2003, the pH$_s$ was almost similar to the initial levels. At this time, the treatment effectiveness to increase the pH$_s$ was in the decreasing order of T1 > T3 > T2 while decreased with T4 for both the depths at site 1. At site 2, the treatment sequence to decrease pH$_s$ was T4 > T3 > T2 but increased with T1 for the 0-15 cm, while the order to increase pH$_s$ was T3 > T4 > T1 > T2 for the 15-30 cm soil depth. At site 3, the pH$_s$ increased with T3 but decreased with other treatments in the order T4 > T2 > T1 for the 0-15 cm, but it increased with T2 and T3 while decreased with T4 and T1 for the 15-30 cm soil depth.

The pH$_s$ is not considered a valid criteria for saline-sodic soils since 1977 as it is the result of interactive effect of EC and SAR (Bresler et al., 1982; Bohn et al., 1985). An increase in pH$_s$ at 0-15 cm could be attributed to high SAR and RSC of irrigation waters while at 15-30 cm, the increase was further elevated by the incoming desorbed sodium from the overlying soil layers. The changes in pH$_s$ remained minimum at site 3 followed by sites 2 and 1, and the pattern of changes correlated well with the quality of irrigation waters. Such minor increases/decreases in pH$_s$ during reclamation of saline-sodic soils were also observed by Qadir et al. (1996, 2001) and Hussain et al. (1986, 2000).
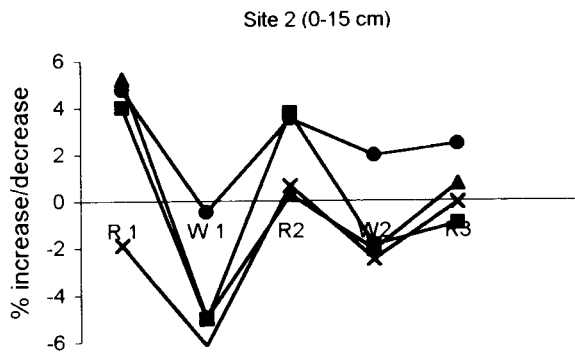
The EC is a measure of total soluble salts present in a system. The initial EC$_e$ was very high and ranged from 6 to 31 dS m^{-1} (Fig. 2). After the harvest of rice 2001 (first crop in sequence), there was ≥ 50 % decrease over the initial values at both the soil depths at all three sites, particularly where EC$_e$ ≥ 8 dS m^{-1}. After the harvest of rice 2003 (fifth crop in sequence), treatments decreased EC$_e$ by ≥ 70% over the initial values at all the sites. At site 1, treatment effectiveness was in decreasing order of T2 > T1 > T3 > T4 > for 0-15 cm and T3 > T1 > T2 > T4 for 15-30 cm. At site 2, this order was T2 > T1 > T3 > T4 for 0-15 cm and T1 > T2 > T4 > T3 for 15-30 cm. At site 3, the treatments ranking was T2 > T4 > T1 > T3 for 0-15 cm and T2 > T1 > T4 > T3 for 15-30 cm soil depths. In general, gypsum application alone (T2) or with FYM

Site 1 (0-15 cm)

R = Rice , W = Wheat
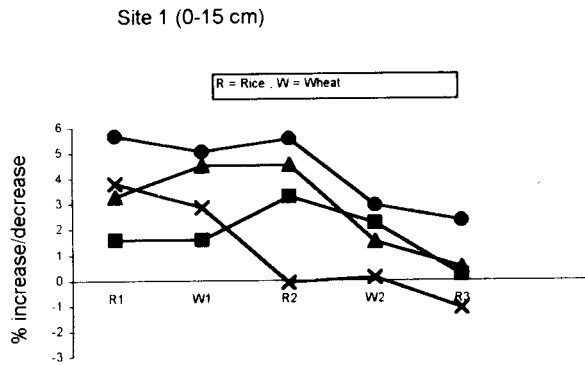
Original pHs: T1 = 8.33, T 2=8.29, T3=8.25, T4=8.48

Site 1 (15-30 cm)

──●── T1   ──■── T2   ──▲── T3   ──✕── T4
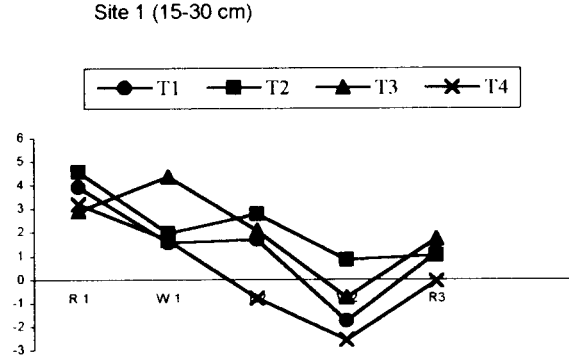
Original pHs: T1=8.47, T2=8.36, T3=8.32, T4

Site 2 (0-15 cm)

Original pHs=T1=8.05, T2=8.32, T3=8.48, T4=8.3

Site 2 (15-30 cm)
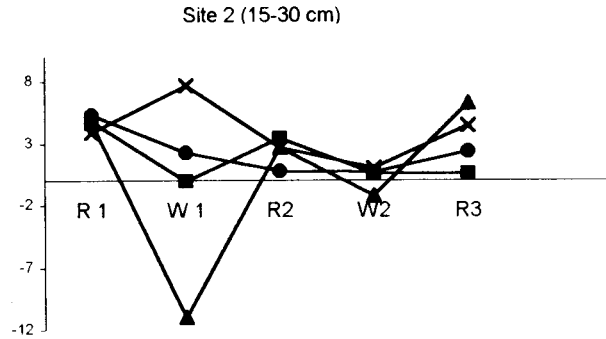
Original pHs= T1=8.14, T2=8.20, T3=8.34,T4

Site 3 (0-15 cm)
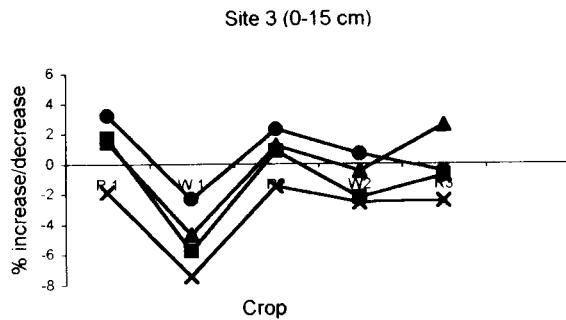
Original pH$_s$=T1=8.44, T2=8.42, T3=8.52, T4=8.47

Site 3 (15-30 cm)
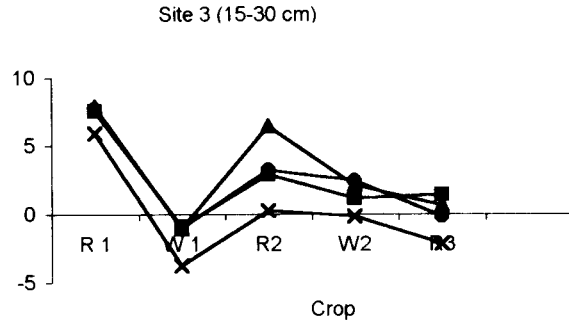
Original pH$_s$=T1=8.49, T2=8.37, T3=8.42, T4=8.48

Fig. 1. Changes in pH$_s$ during reclamation of saline-sodic soils.

3

Site 1 (00-15 cm)

Original ECe=T1=27.36, T2=25.33, T3=20.94, T4=24.17 dS/m)

Site 1 (15-30 cm)

Original ECe: T1=16.41, T2=17.66, T3=20.03, T4=13.7 dS/m)

Site 2 (00-15cm)

Original EC$_e$: T1=8.07 T2=8.81, T3=7.52, T4=5.68 dS/m

Site 2 (15-30 cm)

Original EC$_e$: T1=12.1, T2=9.86, T3=8.98, T4=9.05 dS/m

Site 3 (00-15 cm)

(Original EC$_e$: T1=24.07 T2=38.49, T3=24.22, T4=30.59 dS/m)

Site 3 (15-30 cm)

(Original EC$_e$: T1=26.1, T2=35.2, T3=22.5, T4=25.7 dS/m)

Fig. 2. Changes in EC$_e$ during reclamation of saline-sodic soils.

Site 1 (00-15 cm)

| —●—T1 | —■—T2 | —▲—T3 | —✕—T4 |

R1   W1   R2   W2   R3

Original SAR: T1=124.3, T2=112.2, T3=73.0, T4=124.9

Site 1 (15-30 cm)

R = Rice , W = Wheat

R1   W1   R2   W2   R3

Original SAR: T1=73.5, T2=69.1, T3=78.9, T4=78.1

Site 2 (00-15 cm)

R1   W1   R2   W2   R3

Original SAR: T1=42.3, T2=53.5, T3=54.1, T4=36.6

Site 2 (15-30 cm)

R1   W1   R2   W2   R3

Original SAR: T1=44.2, T2=46.3, T3=42.5, T4=37.2

Site 3 (00-15 cm)

R1   W1   R2   W2   R3

Crop

Original SAR: T1=92.7, T2=145, T3=96, T4=109.2

Site 3 (15-30 cm)

R1   W1   R2   W2   R3

Crop

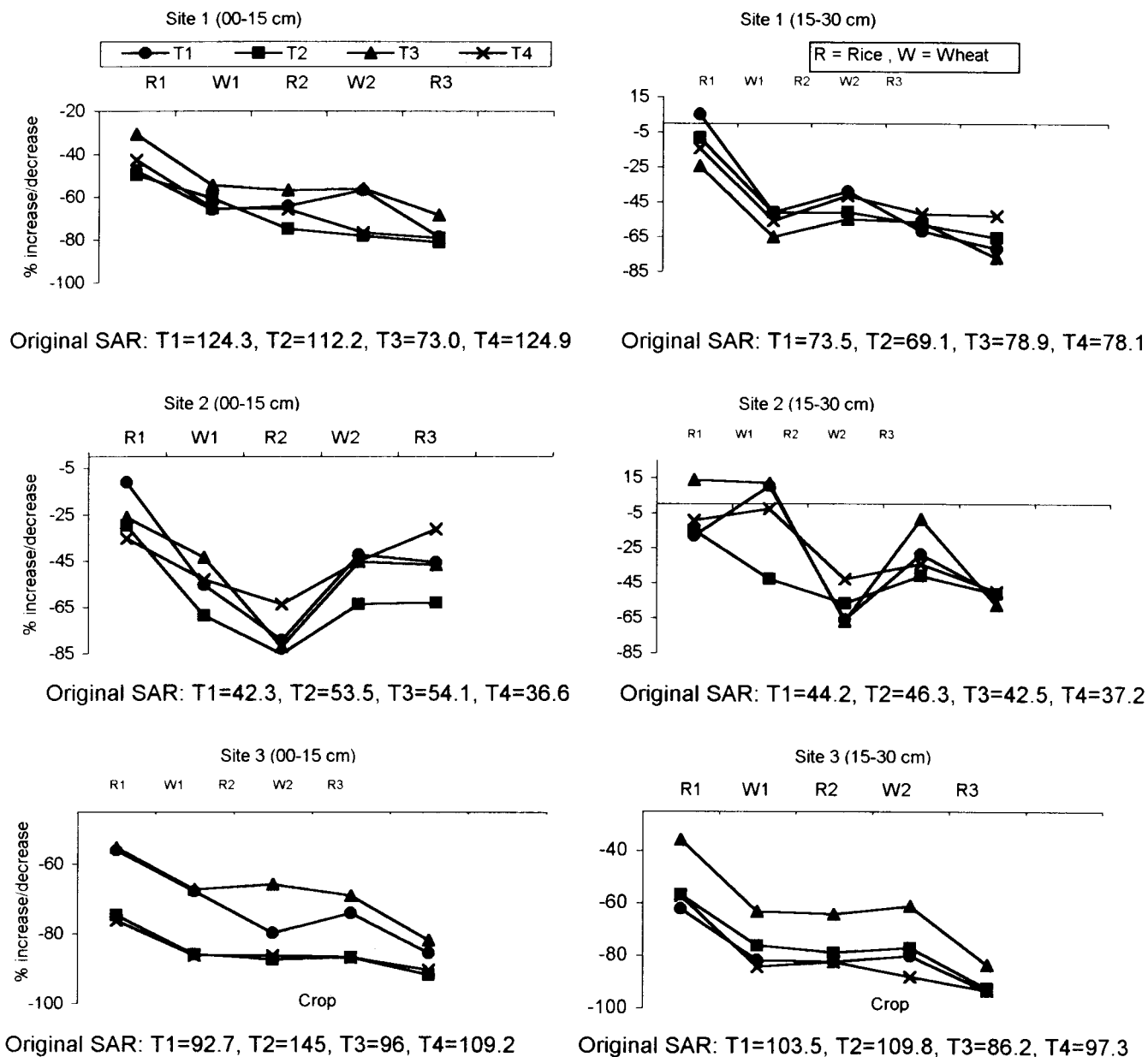Original SAR: T1=103.5, T2=109.8, T3=86.2, T4=97.3

Fig. 3. Changes in SAR during reclamation of saline-sodic soils.

(T4) proved better to lower the EC_e indicating better infiltration through sustaining electrolyte concentration in soil solution, i.e. better infiltration will affect high leaching fraction (LF) and more decrease in EC_e. Relatively less decrease in EC_e after wheat than that after rice crops appears mainly because of the time laps between the last irrigation and time of soil sample collection during the hot months of April and May each year (Armstrong et al., 1996). Similar experiences have been reported by Niazi et al. (2000), Mahmood et al. (2001) and Qadir et al. (2001) in Pakistan and by Rao et al. (1994) in India. Decrease in EC_e was the highest at site 3 followed by sites 2 and 1 and treatment differences leveled off with time, i.e. spacially variable soil improvement responses to the same treatments, and reflects the significance of soil characterization to formulate/suggest the technology for the soil reclamation instead of general recommend-ation even for the easily manageable soil parameters like EC_e.

The soil SAR was the highest at site 1 followed by sites 3 and 2 at the start of studies (Fig. 3). After the harvest of rice 2001, the SAR decreased by about 50% at all the three sites, i.e. higher the initial SAR, greater and faster was the decrease in SAR due to statistical probability of Na-Ca exchange (Ghafoor, 1999 ; Bresler et al., 1982). By the harvest of rice 2003, treatment effectiveness to lower SAR was in the decreasing order T2 > T4 > T1 > T3 for 0-15 cm and T3 > T1 > T2 > T4 for 15-30 cm at site 1; T2 > T3 ≈ T1 >T4 for 0-15 cm and T3 > T2 ≈ T1 ≈ T4 for 15-30 cm at site 2; T2 > T4 > T1 > T3 for 0-15 cm and T2 ≈ T1 ≈ T4 > T3 for 15-30 cm soil depths at site 3. Overall, the soil reclamation with respect to pH_s, EC_e and SAR remained considerably better and faster/earlier with

the application of gypsum (T2). Greater soil improvement at site 3 could be assumed to relatively better quality of irrigation water compared to that at other two sites. It could be concluded that split application of gypsum @ 50% SGR could affect soil reclamation even using high brackish water within a reasonably short time.

Crop Growth

The grain yield of the first rice crop was very low at site 2 and 3 while grain formation failed at site 1 (Table 1) mostly because of high EC_e which was much higher than the limits (6-7 dS m^{-1}) to cause 50 % reduction in paddy yield. The economic yields of the following wheat and rice crops were improved gradually owing to the advancement in soil reclamation (Fig.1-3). Although, rice proved a better crop for soil reclamation but wheat produced better grain yield than that of rice which could be attributed to differential genetic make up of these crops. Rice is better tolerant to SAR than wheat while wheat is better tolerant to EC than rice (Ghafoor et al., 2004; Gupta et al., 1986). In general, T2 produced better yields of rice and wheat but T4 was found much better for wheat than that for rice. Perhaps with T4, the soil infiltration was better which is useful for wheat but not for rice as rice was transplanted without puddling the soils. Rice love to grow under submerged soils conditions. An improved infiltration limited the soil submergence and induced alternate wetting- drying conditions. Limited soil submergence promoted the growth of weeds as well as leaching of nutrients and both these factors helped suppress the yields of rice crops. Earlier such observations were recorded by Ghafoor et al. (1996), Niazi et al. (2000) and

Table 1. Economic yields of rice and wheat (kg acre^{-1}) at different sites in the FDPA during 2001-03

Location	Crop	T1, Control		T2, G25+25%		T3, FYM 10t/ha		T4, T2+T3	
		Straw	RP/WG*	Straw	RP/WG	Straw	RP/WG	Straw	RP/WG
Site 1	Rice 2001	1140	00	1240	00	1020	00	1100	00
	Wheat 2001-02	180	110	1130	850	540	450	540	380
	Rice 2002	3	00	361	157	150	30	120	21
	Wheat 2002-03	772	549	1813	1411	1341	1016	1159	955
	Rice 2003	712	322	1379	342	1025	342	871	481
Site 2	Rice 2001	3150	1430	3320	1510	2410	1090	3030	1380
	Wheat 2001-02	1690	1040	2060	1390	1600	1060	1880	1300
	Rice 2002	792	462	1452	713	1491	634	937	410
	Wheat 2002-03	2049	1579	2542	1829	2286	1693	2379	1847
	Rice 2003	827	282	1006	370	1122	480	828	440
Site 3	Rice 2001	140	60	390	180	180	80	210	90
	Wheat 2001-02	1230	610	1400	910	880	760	1660	990
	Rice 2002	1194	564	1176	596	1117	512	1576	769
	Wheat 2002-03	1345	1148	1870	1301	1429	1106	1359	1158
	Rice 2003	484	401	592	533	557	450	425	338

*RP=Rice paddy, WG=Wheat grain

Mahmood et al. (2001). It was observed that grain size of both the crops remained smaller and sterility percentage in rice (data not reported here) went up, particularly in the control plots at all the three sites. Overall, the treatment effectiveness was in the decreasing order of T2 > T4 > T3 > T1 for rice and wheat when sites were averaged.
In addition, better crop growth gave the added benefit of cleaning the environment through sequestration of atmospheric CO_2 (Lal, 2001) as one mole of CO_2 consumption yields 1.4 g of biomass and the consumption of 70 moles of CO_2 in photosynthesis affects simultaneously a net release of 100 moles of O_2 (Monteith, 1981). Consideration of this aspect makes the soil reclamation programmes even more attractive, environment friendly and cost-effective.

farm employment, and impact of environment cleaning are considered, the reclamation of salt-affected soils becomes much more attractive.

CONCLUSIONS

On the basis of results from these reclamation studies, it is concluded that low quality ground water could successfully reclaim saline-sodic soils provided agricultural grade gypsum (- 30 mesh, 70 % pure) @ 50 % of the SGR is soil-applied even in two splits. Addition of FYM along with gypsum proved much better for wheat than that for rice yield. Rice proved better crop for soil reclamation while wheat yielded better and thus contributed more for net benefit than rice.

Table 2. Economics (Rs. acre^{-1}) of various soil treatments up to rice 2003

Treatment	Site 1			Site 2			Site 3		
	Exp.	Benefit		Exp.	Benefit		Exp.	Benefit	
		Gross	Net		Gross	Net		Gross	Net
T1	1913	10519	8606	4878	44593	39715	3739	29795	26056
T2	6267	30528	24261	7987	55226	47240	7151	37001	29850
T3	5185	19055	13870	7651	48047	40396	4897	30072	25175
T4	6950	18989	12039	9951	50320	40369	7912	29399	21487

Prices: Gypsum @ Rs. 28.50 per bag at sites 1 & 2 while Rs. 29.50 per bag at sites 3 and 4; FYM @ Rs. 400.00 per trolley of 4 tons at all sites; 1 DPL for broadcasting @ Rs. 100.00 per day per 20 bags of gypsum and Rs. 100.00 per trolley of FYM; Paddy KS282 @ Rs. 240.00 per 40 kg and Basmati Supper @ Rs.460 per 40 kg; rice straw @ Rs. 300.00 per acre and wheat straw @ Rs.60.00 per 40 kg.

Economic Evaluation of Treatments

The expenditure and income were calculated for the quantities of amendments at actual cost but produce at support prices (Table 2). Other costs on cultural operations, is common to all the treatments (fertilizers, ploughing, weeding, irrigation costs) were not considered. On the basis of five crops (Table 2), gypsum @ 50% SGR (T2) gave maximum net benefit of Rs. 24261 followed by T3 (Rs. 13870), T4 (Rs. 12039) and T1 (Rs. 8606) at site 1. Net benefit was maximum with T2 (Rs. 47240) followed by T3 (Rs. 40396), T4 (Rs. 40369) and T1 (Rs. 39715) at site 2, while net income remained the highest with T2 (Rs. 9850) followed by T1 (Rs. 26056), T3 (Rs. 25175) and T4 (Rs. 21487). Ghafoor et al. (1997) arrived at similar results from their field studies.
The cost of reclamation treatments was recovered from the first two crops at sites 2 and 3 while from the first three crops at site 1. More income was received from wheat than that from rice as paddy yield was low due to very high EC_e and SAR at the time of rice transplanting (Fig. 1-3) which decreased considerably during the first crop of rice 2001 to favour better yields of following wheat and rice crops. If appreciation in land value, provision of

RECOMMENDATIONS

Gypsum (70 % pure) should be made available to farmers in time and space at subsidized rates. Reclamation of salt-affected soils using brackish water is worth investment under the agro-socio-environmental conditions of Pakistan for food security and poverty alleviation.

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