# REUSE OF DRAINAGE WATER FOR RICE AND WHEAT GROWTH DURING RECLAMATION OF SALINE-SODIC SOILS IN PAKISTAN UNDER THE NATIONAL DRAINAGE PROGRAM (NDP)[1]

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## ABSTRACT

Pakistan is facing scarcity of canal water for irrigated agriculture on 16 mha land. This problem is caused, among others, by the loss of surface storage capacity and by the current prolonged dry spell lasting over the several past years. Siltation of Mangla, Tarbela and Chashma Dams have caused a loss of . 5 $km^3$ which is 25 % of the design capacity. Since this problem is increasing, there may be a gradual decrease of food production for a population of 140 million, which is expected to have doubled by 2025. Water shortage is the most serious for the provinces of Punjab and Sindh, where ground water is of hazardous quality and about 75 % of pumped ground water is not safe for irrigation without amendments. In this scenario, it appears wise and timely to study the prospects of growing food grains during reclamation of salt-affected soils using ground water to save good quality canal water for irrigating good soils. Under arid and semi-arid conditions of Pakistan with scarce and irregular rainfall, limited leaching of salts promotes soil salination followed by sodication, induced by irrigation with ground water of high EC, SAR and RSC without amendments or other agronomic management practices. In this way, 6 mha of soils have become salt-affected, of which 60 % are saline-sodic and needs a source of calcium for amelioration. For initial reclamation of salt-affected soils, low quality irrigation waters are generally useful and some times even better than canal water, due to favorable effects of electrolytes on infiltration rate and hydraulic conductivity. For a variety of reasons, farmers are not properly applying the technologies for reclamation and management of saline-sodic soils. To improve this situation on sustainable basis, Univ. Agri., Faisalabad has launched a three-year research study on reclamation of saline-sodic soils by reusing drainage water, in which farmers are participating. The experiments were started in June 2001 in the Fourth Drainage Project Area located in the Central Punjab and are funded by the National Drainage Programme. The reclamation technologies include split application of gypsum @ soil or water GR alone and in combination with FYM or green manure, and on-farm wheat seed priming. This paper will present preliminary results and recommendations pertaining to economical as well as sustainable reuse of drainage water on saline-sodic soils, farmers' constraints and limitations for adapting the required technologies in this regard on the basis of the on-going experiments.

## 1 INTRODUCTION

Pakistan is facing scarcity of canal water for irrigated agriculture on 16 mha land. This problem is caused, among others, by the loss of surface storage capacity and by the current prolonged dry spell lasting over the several past years. Siltation of Mangla, Tarbela and Chashma Dams have caused a loss of . 5 $km^3$ which is 25 % of the designed capacity (Mohtadullah, 1993) . Since this problem is increasing, there may be a gradual decrease of food production for a population of 140 million, which is expected to have doubled by 2025. Water shortage is the most serious for the provinces of Punjab and Sindh, where ground water is of hazardous quality and about 75-80 % of pumped ground water is not safe for irrigation without amendments (Ahmad, 1993). In this scenario, it appears wise and timely to study the prospects of growing food grains during reclamation of salt-affected soils using ground water to save good quality canal water for irrigating good soils. Under arid and semi-arid conditions of Pakistan with scarce and irregular rainfall, limited leaching of salts promotes soil salinization followed by sodication, induced by irrigation with ground water of high EC, SAR and/or RSC without amendments or other agronomic management practices. In this way, 6.3 mha of soils have become salt-affected (Khan, 1993), of which 60 % are saline-sodic (Muhammed, 1983) and needs a source of calcium for amelioration (Qadir et al., 2000; Ghafoor et al., 1998; Shainberg et al, 1989).

Problem of salination and sodication is expected to increase at alarming rate in the days to come because of prevailing drought and voluminous input of brackish tube well waters for irrigation. The ground water with high EC, SAR and/or RSC is used by the Pakistani farmers without amendments which is inducing sodication of soils. For initial reclamation of salt-affected soils, low quality irrigation waters are generally useful and sometimes even better than canal water owing to favourable effect of their electrolytes on soil infiltration rate and hydraulic conductivity (Shainberg and Letey, 1984; Rhoades, 1988). Relatively higher ratios of EC : SAR in such drainage and ground waters have been found to improve water conducting properties of soils which resulted in better and rapid amelioration of saline-sodic soils (Ghafoor et al., 2000 and 2001).

It is generally agreed that farmers are not properly and effectively adapting the technologies regarding the reclamation and management of saline-sodic soils and waters. This is assumed, in general, because of (a) inability of the extension experts to contact and advise all the farmers of area assigned to him, (b) farmers' lack interest in such a stress land agriculture for want of financial resources, (c) farmers seldom approach the extension staff for advice, (d) technologies developed at farms of Agricultural Universities and Research Institutes are seldom available in time and space even to interested farmers, (e) lack of interaction between the farmers and research workers, (f) adulteration of agricultural inputs, (g) small farmers do not possess produce storing capacity which compel them for rapid disposal without realizing even the support prices and (h) lack of socio-political will of the society. Keeping the above in view, saline-sodic soils and water management investigations with the participation of farmers were initiated in June 2001 in the Fourth Drainage Project Area, Faisalabad, Punjab, Pakistan.

**Objectives**

1. Evaluation of different strategies for the reclamation of saline sodic soils using low quality ground water for irrigation following rice-wheat crop rotation.
2. Assesment of the production of rice and wheat crops during reclamation of saline-sodic soils using poor quality tube well water for irrigation.
3. Evaluation of the economics of rice-wheat crop rotation during reclamation of salt-affected soils using irrigation water of hazardous quality.

## 2 MATERIALS AND METHODS

### 2.1 Description of Project Area:

During the seventies, soils of the lower Rachna Doab were highly waterlogged and salt-affected and consequently the crop yields were dwindling rapidly. For controlling these problems, area of this Doab was divided into units named Khairwala, Gojra-Khewra, Shorkot-Kamalia etc. to launch development projects. Among the remedial measures, provision of surface and subsurface drainage systems was on the priority in the Remaining Rachna Doab and has been named as the Fourth Drainage Project Area (FDPA). It covers an area of 143437 ha but subsurface pipe drainage has been laid in badly affected area of 30364 ha. Construction of 79 sumps and pipe drains were completed by June 1994 while its commissioning was completed by December 1995. Soils are deep, poorly drained, moderately fine textured, calcareous, have structured B horizon (Typic Aquisalid subgroup) developed in alluvium derived from Himalayas and deposited during early Pleistocene.

#### 2.1.1 Rice (Oryza sativa):

The experiments have been permanently laid out following Randomized Complete Block Design with three replications at two sites in the FDPA. Each experiment was laid out on about 1.5 ha of land. Rice-wheat crop rotation is being followed. Transplanting of rice (2-3 seedlings per hill of about 40 days age with 22 cm row to row and plant to plant distance) was accomplished in July each year without puddling the soils. Puddling is commonly practiced to induce submergence which is the ecological requirement of rice. The NPK was applied at the rate of 100, 68 and 25 kg $ha^{-1}$, respectively as urea, single super-phosphate and potassium chloride. Crops were harvested (whole plot measuring 10 m by 31 m) and threshed manually during the month of November each year to record the paddy yield.

#### 2.1.2 Wheat (Triticum aestivum):

With the help of tractor driven drill, wheat was planted during the last week of November/first week of December each year after the harvest of rice in "Wattar" condition of soils using 100 kg $ha^{-1}$ seed rate. Row to row distance was kept as 22 cm. The NPK was applied at the rate of 100 and 68 kg $ha^{-1}$, respectively as urea, single super-phosphate and KCl. Crops were harvested manually and threshed mechanically during May each year to record grain yield.

#### 2.1.3 *Junter (Sesbania aculeata)*:

In the treatment (T6), junter was planted in mid-May 2002 by broadcast method using 30 kg seed per hectare. Crop was grown for about 45 days with 18 cm of tube well water irrigation. During this period plants thinly populated attained height of about 80 cm which were rotavated 10-15 days before transplanting rice. There was negligible rainfall during this period.

**Treatments:** The experiment was planned at two sites in the FDPA with the following treatments.

| Treatment | Description |
|---|---|
| T1 | Drainage water only. |
| T2 | Soil-applied of gypsum @ 25 % GR for 0-15 cm of soil to each of the first two crops. |
| T3 | Soil-applied FYM @ 25 ton $ha^{-1}$ annually 15 days before transplanting rice. |
| T4 | Combination of inorganic (50 %GR of 0-15 cm soil once) and FYM @10 ton $ha^{-1}$ annually 30 days before rice transplanting . |
| T5 | Soil-applied gypsum to reduce water SAR to 10 + junter green manuring every year. |
| T6 | One soil auger hole (7.5 cm dia.) up to 120 depth per 50 $m^2$ refilled with mixture of soil, rice husk and gypsum in 1:1:1 ratio once at the start of experiment, and soil received gypsum @ 50 % SGR for 0-15 cm once before the |

first rice crop in 2001.

T7 Wheat Seed soaked for three hours in 15 $mmol_c$ $L^{-1}$ gypsum solution before sowing in soil at ?Wattar? condition, and soil received gypsum @ 50 % SGR for 0-15 cm once before the first rice crop in 2001.

T8 Wheat Seed soaked for six hours in 15 $mmol_c$ $L^{-1}$ gypsum solution before sowing in soils at ?Wattar? condition, and soil received gypsum @ 50 % SGR for 0-15 cm once before the first rice crop in 2001.

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To grow each rice crop up to maturity, 70-75 cm and 20 cm of canal and tube well water (Table 1), respectively was applied. The corresponding amount of irrigation water was 40 cm and 10 cm for wheat. The studies were initiated in June 2001 and by June 2003, two crops each of rice and wheat have been harvested. Before laying out the experiments and after the harvest of each crop, composite soil samples were drawn from 0-15 cm and 15-30 cm soil depths and were analyzed for $pH_s$, $EC_e$, soluble ions, SAR etc. following the methods described by Page et al. (1982).

*Table 1 Quality of tube well waters used for irrigating rice-wheat crops during reclamation of soils*

| Location | Parameters of Water Quality | | | |
|---|---|---|---|---|
| | EC, dS/m | SAR | $SAR_{adj}$* | RSC, $mmol_c$/L |
| Site 1 | 4.1 | 20.1 | 22.4 | 8.9 |
| Site 2 | 2.6 | 7.6 | 8.4 | 0.4 |

*With the help of formula proposed by Sposito and Mattigod (1977).

## 3 RESULTS AND DISCUSSION

The present studies were initiated in July 2001 at two different sites in the FDPA and by now four crops (two wheat and two rice) have been harvested. The changes in $pH_s$, $EC_e$ and SAR of soils are presented as per cent decrease (-) or increase (+) over the initial values.

### 3.1 Soil Reaction ($pH_s$):

Response of $pH_s$ was mixed one (Tables 2 a & b) at both the sites to the tested treatments. In general, there was a small increase in $pH_s$ values after rice crops because of the rapid leaching of soluble salts but slow rate of $Na^+$ desorption as well as the irrigation with high SAR and/or RSC ground water. But there was a decrease in $pH_s$ after the harvest of wheat crops as this crop receives much smaller amount of irrigation water than rice and thus less leaching of soluble salts (Tables 3 a & b), i.e. an increase in $EC_e$ to SAR ratio. As a consequence of which, $EC_e$ to SAR ratio decreased after every crop compared to that of the initial soils in July 2001. It is known that increasing values of $EC_e$ tend to decrease while that of the SAR tend to increase the $pH_s$ (Quirk and Schofield, 1955; Ghafoor et al., 1997b; Quirk, 2001). However, mostly the $pH_s$ values are still around 8.4 which is the critical limit for sodic condition of soils (US Salinity Lab. Staff, 1954). Low rate of changes in the $pH_s$ also could be due to moderate calcareousness of soils since lime buffers the $pH_s$. Also there is no big difference in $pH_s$ values so far (after two years of the initiation of studies) among the two sites at both the soil depths.

### 3.2 Electrical Conductivity ($EC_e$):

There was a decrease in $EC_e$ during the study period at both the sites and both the soil depths except T8 at 0-15 cm after harvest of rice 2002 at site 1 (Tables 3 a & b). However, decrease in EC was more after rice than that after wheat crops mostly because of high input of irrigation water to rice which helped maintain leaching fraction (LF) more than that during wheat and high LF is necessary for reclamation and management of poor quality irrigation water.

At site 1 after the harvest of rice 2002, decrease in $EC_e$ was the highest with T2 followed by T3, T1, T5 and T4 at 0-15 cm soil depth while the treatment order was T3, T1, T5, T2 and T4 at 15-30 cm soil depth. At site 2 after the harvest of rice 2002, decrease in $EC_e$ was the highest with T2 followed by T1, T4, T7, T5 and T3 but increased with T8 at 0-15 cm soil depth while the treatment order was T1, T2, T4, T3, T5, T7 and T8 at 15-30 cm soil depth. In general, the gypsum application resulted in relatively less decrease in $EC_e$ because of its low solubility which is useful to sustain the electrolyte concentration in soil solution to favourably affect the hydraulic conducting (HC) soil properties (Ghafoor et al., 1997a; Rhoades, 1993) and better HC is an asset for the reclamation of saline and/or sodic soils. Overall, by the time of harvest of rice 2002 in November 2002, with almost all the treatments, $EC_e$ was still higher than 4 dS $m^{-1}$ which is mostly considered the critical limit for saline soils (US Salinity Lab. Staff, 1954).

The auger hole treatment (T6) caused less leaching of salts against expectation because visually it was observed that free water on the soil surface used to disappear much earlier in this treatment than the others. It is opined that applied irrigation water infiltrated better through these auger holes without interacting with soil to get enriched with salts. This phenomenon proved helpful for wheat (Table 5 a) which can not tolerate submergence but detrimental to rice which is a crop of submerged ecology.

**3.3 Sodium Adsorption Ratio (SAR):**

It is a measure of sodicity problem of soils and indirectly indicates gypsum requirement of soils and deterioration status of soil physical properties. The soils under this study at both the sites have SAR much higher than 13 (Tables 4 a & b), a limit for sodic soils prescribed by the US Salinity Lab. Staff (1954) and commonly is followed in several other countries. It was relatively higher at site 2 than that at site 1. It was higher in the surface 15 cm soil layer compared to that at 15-30 cm soil depth. Since soils were lying barren for the last many decades during which soils were salinated followed by sodication (Muhammed, 1983) due to formation of $CaCO_3$ (Ghafoor et al., 1990; 1997 a, b). The sodicity indicator natural plants like Nara (*Arundo donax*), Saji (*Sueda fruticosa*), Lani (*Salsola foetida*) and Sarkanda (*Saccharum manja*) were sparsely growing at both the sites.

The decrease in SAR remained much higher after rice compared to that after wheat crops at both the sites except post-rice 2002 at site 1. The rate of decrease in SAR was more in 0-15 cm than that at 15-30 cm soil depth because as the water/soil solution moves down into soil, its osmotic pressure decreases to affect a decrease in its salt carrying capacity. The decrease in SAR was generally higher at site 2 compared to site 1 most probably due to initially high SAR values at site 2. As the SAR decreases, there is a decreasing probability of Na - Ca exchange which has to slow down the rate of decrease in SAR as appears for site 1.

At site 1 after the harvest of rice 2002, decrease in SAR was the highest with T2 followed by T3, T1, T5 and T4 at 0-15 cm soil layer, while the treatment order was T5, T3, T1, T2 ant T4 at 15-30 cm soil depth. At site 2, after the harvest of rice 2002, the decrease in SAR was the highest with T7 followed by T5, T2, T4, T1, T2 and T8 at 0-15 cm soil layer, while the treatment order was T4, T1, T2, T7, T5, T3 ant T8 at 15-30 cm soil depth. The results indicate that application of commercial grade gypsum (75-80 % pure and passed through 30 mesh sieve) @ of 50 % in two equal splits to the first two crops with or without organic matter (FYM or GM) could successfully reclaim saline-sodic soils even when rice-wheat crops are irrigated with saline-sodic ground water as is the case with T4 and T5. Even the simple irrigation with brackish water has decreased SAR of calcareous soils considerably through valence dilution (Eaton and Sokoloff, 1935), dissolution of native lime which was promoted by the activities of the living roots of crops (Robbins, 1986), $Ca^{2+}$ supplied in irrigation water and in-situ mineral weathering (Rhoades et al., 1968).

It is reported (Ahmad and Riaz, 1986) that soils under investigation are dominated by the illite type (low CEC) clay minerals for which 6-10 $mmol_c\ L^{-1}\ Ca^{2+}$ in irrigation water or soil solution is the most efficient to promote Na-Ca exchange (Ghafoor, 1999; Ghafoor and Salam, 1993). As a result of brackish water irrigation with or without OM (T1, T3), the observed decease in SAR had been possible. However, since the soil amelioration is still in progress, treatment effectiveness and spatially variable soils 0responses to treatments are tentative and still changing and are likely continue to change by the time soils attain steady-state most probably by the end of third year of studies.

**3.4 Growth Response of Rice and Wheat Crops**

There is a gradual improvement in crop yields at both the sites (Tables 5 a & b). Growth performance of rice and wheat was better at site 1 than that at site 2 (Tables 5 a & b) because of initially low soil $EC_e$ and SAR (Tables 3 a & b, 4 a & b) as well as skillful management by the farmer at site 1. Yields of wheat were consistently better than that of rice at both the sites owing to high EC tolerance of wheat (Ayers and Westcot, 1985).

Grain yield of wheat 2002-03 was the highest with T6 followed by T4, T2, T5, T7, T3, T8 and T1 at site 1. At site 2, the treatment effectiveness to produce wheat 2002-03 grain yield was T8, T2, T7, T4, T1, T3, and T5. At site 1, auger hole treatment (T6) performed the best as the soil was dense and was in need of immediate drainage improvement that was provided by auger holes. However, wheat seed soaking (T7, T8) was less effective at this site as the soil was near to normal and germination was almost sufficient without seed treatment. But at site 2, wheat seed soaking (T7, T8) proved the best as the soil has SAR high enough to disturb germination that was countered by seed soaking. Overall, soil-applied gypsum @ 50 % soil GR in one (T7, T8) or two splits (T2, T4) proved better.

The effectiveness of T5 (gypsum @ water GR on the basis of SAR) proved better at site 1 than at site 2 because soil was less saline-sodic but received more sodic irrigation water than that of site 2 soil. Hence the applied quantity of gypsum proved enough to reclaim the saline--sodic soil at site 1 but remained small at site 2. As a result crop yields with T5 remained higher at site 1 than those at site 2. This indicates that treatment(s) has to be devised more specifically to exploit saline-sodic soils using brackish water for the irrigation of rice-wheat crops through soil characterization.

**3.5 Evaluation of Economics of Soil and Water Amelioration Treatments**

Economical gains are the ultimate objective of any industry including agriculture. The stress-land agriculture is generally discouraged because of initial cost of treatments of soils or irrigation waters. Although in the long run, stress-land agriculture is always in favour of farmers and country. Economics of the on-going experiments has been computed using the market cost of variable items and support prices of the paddy and wheat grains. The appreciation in the value of land and the cost of constant items have not been considered.

Expenditures are lower at site 2 than those at site 1 (Table 6). At site, net benefit was the highest with T2 followed by T4, T3, T1, T5, T7, T8 and T6. The treatment effectiveness was in the decreasing order of T8, T7, T5, T4, T2, T1 and T3 at site 2. The wheat seed soaking treatments (T8, T7) remained the best at site 2 because of high problem of soil salinity/sodicity where seed soaking helped better germination and subsequently better crop stand and growth to result high income because once plants are established, then can withstand hazards of salinity/sodicity in a better way (Ayers and Westcot, 1985). While this was not required at site 1 as the soil has become just normal. Gypsum application @ 50 soil GR in two equal splits with and without FYM (T2 and T4, respectively) have edge over the others, i.e. both treatments not only successfully reclaimed saline-sodic soil but also countered the adverse effects of high SAR and RSC tube well water used for the irrigation of rice and wheat crops.

In addition, there is great appreciation in the land value, e.g. at site 1 common value of one hectare salt-affected field was US$ 1450 to 2050 in 2000 which now has increased to US$ 6175 to 7500 per hectare. Secondly, there is considerable friendly effect of reclaimed soils on the environment through the sequestration of $CO_2$ from the atmosphere as well as through a better aesthetic value. Farm employment to help decrease migration from rural to urban areas is another added benefit of amelioration of salt-affected soils using poor quality water, otherwise disposal of brackish was is an environment risk.

Further, the salt balance in the Indus Basin is positive and area under salt-affected soils is increasing every year while canal water supplies are decreasing. In this scenario, amelioration of salt-affected soils even become more and more imperative and attractive. Because further loss in cultivated lands due to salination/sodication could not be tolerable since population is on the increase in most of the countries which will need food, fiber and shelter. These are the long term benefits those have not been included in the present economic evaluation.

### 3.6 Farmers motivation and their initiatives

Sign boards explaining treatments both in English and Urdu were permanently displayed at each site and for each experiment. Farmers are being encouraged as shown by their active participation and discussion with the project staff during meetings and their visits to the experimental sites. Because of good growth of crops, they are considerably motivated and encouraged to initiate reclamation of their salt-affected soils using tube well brackish waters. However, project staff has to approach them, and provided them only the facility of soil testing for gypsum requirement and tube well waters for irrigation quality along with technical advice. This fact has been realized further from the participation and quarries raised by farmers in our Farmer Focus Group meetings and Field Days convened at each site. Major constraint of farmers is the shortage of finances to purchase soil and/or water amendments. Secondly the availability of quality gypsum in time and space is the limitation to their initiative of reclaiming salt-affected soils. Overall, it is felt that Research cum Demonstration of technologies is the best to motivate the farmers for its adaption.

## 4 CONCLUSIONS

On the basis of 2-year results from soil reclamation studies using brackish water, it is concluded that:

- Low quality ground water could successfully reclaim saline-sodic soil provided agricultural grade gypsum passed through 30 mesh sieve is split applied (25 % and 25 % of the 0-15 cm soil GR each to the first and second crop). Addition of FYM did improved crop growth.
- The application of gypsum @ water SAR to reduce it to 10 with green manuring reclaimed saline-sodic soils to reasonable extent.
- For dense saline-sodic soils, in general, one auger hole per 50 sq. m. filled with rice husk, gypsum and soil proved better both for wheat which could not tolerate prolonged submergence and $O_2$ stress.
- Wheat seed priming, i.e. soaking in 15 $mmol_c\ L^{-1}$ gypsum solution for 3 or 6 hours soaking produced better crop on a saline-sodic soil receiving agricultural grade gypsum @ 50 % soil GR for 0-15 cm layer soil-applied once before the start of studies.
- Research-cum-demonstration, Focus Group Farmers meetings and on-site excursion proved very good and effective method of farmer as well as extension workers' education.
- Farmers' need technical and in-kind financial assistance.

- Visits and discussions with farmers by different Expert Missions proved helpful to build farmer confidence in the research project.

## 5 RECOMMENDATIONS

- Gypsum should be made available to farmer in time and space at subsidized rates.
- The activities of the on-going project need replication at more sites.
- In-service training of the Extension worker's in reclamation technologies is imperative.
- Reclamation of salt-affected soils using poor quality irrigation water is worth investment under agro-climatic and socio-economic conditions of arid regions.

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*Table 2 Percent decrease (-) or increase (+) in $pH_s$ of saline-sodic soil receiving poor quality ground water for irrigation of rice* *and wheat crops at site 1, FDPA*

| Treat-ment | 0-15 cm | | | | 15-30 cm | | | |
|---|---|---|---|---|---|---|---|---|
| | Initial | *P-rice 2001 | P-wheat 2001-02 | P-rice 2002 | Initial | P-rice 2001 | P-wheat 2001-02 | P-rice 2002 |
| T1 | 8.0 | +4.7 | -0.5 | +3.5 | 8.1 | +5.3 | + 2.2 | +0.7 |
| T2 | 8.3 | +4.0 | -5.0 | +3.3 | 8.2 | +4.8 | - 0.1 | +3.4 |
| T3 | 8.5 | +5.2 | -5.0 | +0.2 | 8.3 | +4.7 | -11.0 | +2.6 |
| T4 | 8.3 | -1.9 | -6.2 | +0.6 | 8.1 | +3.8 | + 7.7 | +2.6 |
| T5 | 8.4 | +1.1 | -5.6 | -2.7 | 8.2 | +6.6 | - 0.5 | +2.3 |
| T6 | 8.3 | -0.2 | -4.6 | Crop could not be planted | 8.4 | +3.1 | + 1.1 | Crop could not be planted |
| T7 | 8.4 | +0.2 | -6.6 | | 8.3 | +3.5 | + 0.6 | |
| T8 | 8.4 | -1.3 | -5.4 | | 8.3 | +3.9 | + 0.2 | |

* P stands for post.

*Table 3 Percent decrease (-) or increase (+) in $pH_s$ of saline-sodic soil receiving poor quality ground water for irrigation of rice and wheat crops at site 2, FDPA*

| Treat-ment | 0-15 cm | | | | 15-30 cm | | | |
|---|---|---|---|---|---|---|---|---|
| | Initial | P-rice 2001 | P-wheat 2001-02 | P-rice 2002 | Initial | P-rice 2001 | P-wheat 2001-02 | P-rice 2002 |
| T1 | 8.44 | +3.20 | -2.37 | +2.25 | 8.49 | +7.66 | -1.06 | +3.18 |
| T2 | 8.42 | +1.66 | -5.82 | +0.83 | 8.37 | +7.53 | -0.96 | +2.87 |
| T3 | 8.52 | +1.41 | -4.70 | +1.17 | 8.42 | +7.84 | -1.07 | +6.41 |
| T4 | 8.47 | -1.89 | -7.44 | -1.54 | 8.48 | +5.90 | -3.77 | +0.24 |
| T5 | 8.57 | +1.63 | -3.27 | +1.87 | 8.51 | +6.82 | -1.65 | +4.00 |
| T6 | Treatment not tested | | | | | | | |
| T7 | 8.66 | Crop not planted | -7.16 | -4.62 | 9.15 | Crop not planted | -9.07 | -6.99 |
| T3 | 8.70 | | -7.24 | -1.38 | 9.16 | | -9.39 | -4.04 |

*Table 4 Percent decrease (-) or increase (+) in $EC_e$ ($dS\ m^{-1}$) of saline-sodic soil receiving poor quality ground water for irrigation of rice and wheat crops at site 1, FDPA*

| Treat-ment | 0-15 cm | | | | 15-30 cm | | | |
|---|---|---|---|---|---|---|---|---|
| | Initial | P-rice 2001 | P-wheat 2001-02 | P-rice 2002 | Initial | P-ice 2001 | P-wheat 2001-02 | P-rice 2002 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| T1 | 8.07 | -50 | -11 | -73 | 12.10 | -59 | -58 | -75 |
| T2 | 8.81 | -57 | +01 | -81 | 9.86 | -48 | -35 | -70 |
| T3 | 7.52 | -40 | +34 | -77 | 8.98 | -31 | -16 | -79. |
| T4 | 5.68 | +05 | +75 | -52 | 9.05 | -33 | -14 | -59 |
| T5 | 6.73 | -31 | +46 | -54 | 9.31 | -35 | -18 | -70 |
| T6 | 7.21 | -47 | -11 | Crop could not be planted | 9.06 | -54 | -47 | Crop could not be planted |
| T7 | 5.01 | +04 | +84 | | 7.44 | -29 | -12 | |
| T8 | 6.55 | -14 | +46 | | 8.47 | -42 | -21 | |

*Table 5 Percent decrease (-) or increase (+) in $EC_e$ (dS $m^{-1}$) of saline-sodic soil receiving poor quality ground water for irrigation of rice and wheat crops at site 2, FDPA*

| Treat-ment | 0-15 cm | | | | 15-30 cm | | | |
|---|---|---|---|---|---|---|---|---|
| | Initial | P-rice 2001 | P-wheat 2001-02 | P-rice 2002 | Initial | P-rice 2001 | P-wheat 2001-02 | P-rice 2002 |
| T1 | 24.1 | -77 | -69 | -86 | 26.1 | -83 | -73 | -89 |
| T2 | 38.5 | -79 | -54 | -88 | 35.2 | -75 | -75 | -89 |
| T3 | 24.2 | -61 | -51 | -78 | 22.5 | -65 | -52 | -79 |
| T4 | 30.6 | -76 | -60 | -85 | 25.7 | -78 | -71 | -87 |
| T5 | 28.3 | -80 | -55 | -81 | 21.8 | -78 | -61 | -76 |
| T6 | Treatment not tested | | | | | | | |
| T7 | 18.2 | Crop not planted | -38 | -83 | 08.0 | Crop not planted | -02.13 | -74 |
| T8 | 04.5 | | +437 | -33 | 04.9 | | +143 | -36 |

*Table 6 Percent decrease (-) or increase (+) in SAR of saline-sodic soil receiving poor quality ground water for irrigation of rice and wheat crops at site 1, FDPA*

| Treat-ment | 0-15 cm | | | | 15-30 cm | | | |
|---|---|---|---|---|---|---|---|---|
| | Initial | P-rice 2001 | P-wheat 2001-02 | P-rice 2002 | Initial | P-rice 2001 | P-wheat 2001-02 | P-rice 2002 |
| T1 | 42.3 | -11 | -56 | -79 | 44.2 | -18 | +10 | -66 |
| T2 | 53.5 | -30 | -69 | -85 | 46.3 | -15 | -43 | -57 |
| T3 | 54.1 | -26 | -43 | -82 | 42.5 | +13 | +12 | -67 |
| T4 | 36.6 | -35 | -53 | -64 | 37.2 | -09 | -03 | -43 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| T5 | 32.0 | +17 | -35 | -77 | 54.5 | -24 | -08 | -71 |
| T6 | 45.7 | -37 | -62 | Crop could not be planted | 55.4 | -36 | -49 | Crop could not be planted |
| T7 | 29.0 | +72 | +03 | | 48.2 | -05 | -35 | |
| T8 | 38.0 | -24 | -05 | | 57.2 | -32 | -25 | |

*Table 7 Percent decrease (-) or increase (+) in SAR of saline-sodic soil receiving poor quality ground water for irrigation of rice and wheat crops at site 2, FDPA*

| Treat-ment | 0-15 cm | | | | 15-30 cm | | | |
|---|---|---|---|---|---|---|---|---|
| | Initial | P-rice 2001 | P- wheat 2001-02 | P-rice 2002 | Initial | P-rice 2001 | P-wheat 2001-02 | P-rice 2002 |
| T1 | 92.7 | -56 | -68 | -80 | 103.5 | -62 | -82 | -82 |
| T2 | 145.0 | -75 | -86 | -87 | 109.8 | -57 | -76 | -79 |
| T3 | 96.0 | -55 | -67 | -66 | 86.2 | -36 | -63 | -64 |
| T4 | 109.2 | -76 | -86 | -86 | 97.3 | -57 | -84 | -83 |
| T5 | 213.3 | -79 | -87 | -88 | 87.8 | -60 | -71 | -71 |
| T6 | Treatment not tested | | | | | | | |
| T7 | 143.7 | Crop not planted | -78 | -92 | 44.2 | Crop not planted | -51 | -79 |
| T8 | 36.0 | | +75 | -55 | 29.7 | | +06 | -39 |

*Table 8 Crop yields (kg $ha^{-1}$) at sites 1 during reclamation of saline-sodic soils using poor quality ground water for the irrigation of rice and wheat crops, FDPA*

| Treatment | Rice 2001 | Wheat 2001-02 | Rice 2001 | Wheat 2002-03 |
|---|---|---|---|---|
| T1 | 3532 | 2569 | 1141 | 3900 |
| T2 | 3730 | 3433 | 1761 | 4518 |
| T3 | 2692 | 2618 | 1566 | 4182 |
| T4 | 3409 | 3211 | 1013 | 4562 |
| T5 | 3656 | 2668 | 1176 | 4419 |
| T6 | 1062 | 3705 | Crop could not be planted | 4629 |
| T7 | 2890 | 3884 | | 4306 |
| T8 | 1951 | 2766 | | 4113 |

*Table 9 Crop yields (kg $ha^{-1}$) at sites 2 during reclamation of saline-sodic soils using poor quality ground water for the irrigation*

*of rice and wheat crops, FDPA*

| Treatment | Rice 2001 | Wheat 2001-02 | Rice 2001 | Wheat 2002-03 |
|---|---|---|---|---|
| T1 | 148 | 1507 | 1393 | 2835 |
| T2 | 445 | 2248 | 1472 | 3214 |
| T3 | 198 | 1877 | 1265 | 2732 |
| T4 | 222 | 2445 | 1899 | 2860 |
| T5 | 395 | 1433 | 1376 | 2714 |
| T6 | Treatment not tested | | | |
| T7 | Crop could not be planted | 2766 | 2720 | 3776 |
| T8 | | 2717 | 2497 | 3846 |

*Table 10 Economics (US$ ha$^{-1}$) of treatments for the reclamation of saline-sodic soils receiving poor quality ground water for irrigation of rice and wheat crops (data from 4 crops, i.e. 2 years), FDPA*

| Treat-ment | Site 1 | | | Site 2 | | |
|---|---|---|---|---|---|---|
| | Expendi-ture | Benefit | | Expendi-ture. | Benefit | |
| | | Gross | Net | | Gross | Net |
| T1 | 192 | 1705 | 1513 | 137 | 909 | 772 |
| T2 | 317 | 1980 | 1663 | 272 | 1014 | 742 |
| T3 | 268 | 1762 | 1494 | 174 | 865 | 691 |
| T4 | 367 | 1871 | 1504 | 302 | 733 | 431 |
| T5 | 357 | 1821 | 1464 | 223 | 1040 | 817 |
| T6* | 332 | 1145 | 0813 | Treatment not tested | | |
| T7* | 298 | 1600 | 1302 | 244 | 1563 | 1319 |
| T8* | 327 | 1367 | 1040 | 252 | 1696 | 1444 |

*Prices: Actual variable costs and support prices of the produce.** Data from 3 crops.

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