# MANAGING SALINE-SODIC GROUNDWATER IN THE INDUS BASIN

*M.A. Kahlown* and*
*Mushtaq A. Gill***

## ABSTRACT

*The quality of groundwater in the Indus Basin varies from fresh to hazardous. In many areas it has high carbonates, bicarbonates and pH, which creates sodicity when applied to the soil. The groundwater abstraction from the public and private tubewells is about 6.05 Mham, of which 1.23 Mham is from public tubewells and 4.81 MAF is contributed by the private tubewells. The present area of the Indus Basin with groundwater having salts less than 1500, 1500-3000 and more than 3000 ppm is 8.13, 1.94 and 6.4 mha, respectively. The situation of groundwater-quality is deteriorating fast due to rapid growth of tubewells in the private sector. According to an estimate, there are 5,65,000 tubewells pumping groundwater in the Indus Basin. Alone in Punjab, there are about 5,00,000 tubewells operating, 70 percent of which are producing water of saline-sodic quality. A large part of salt- affected soils of the country are sodic. Generally gypsum is applied to reclaim sodic soils, for which ample amount of fresh water is needed for leaching of salts. At present, non-availability of fresh water is making the soil-reclamation by this method a difficult proposition.*

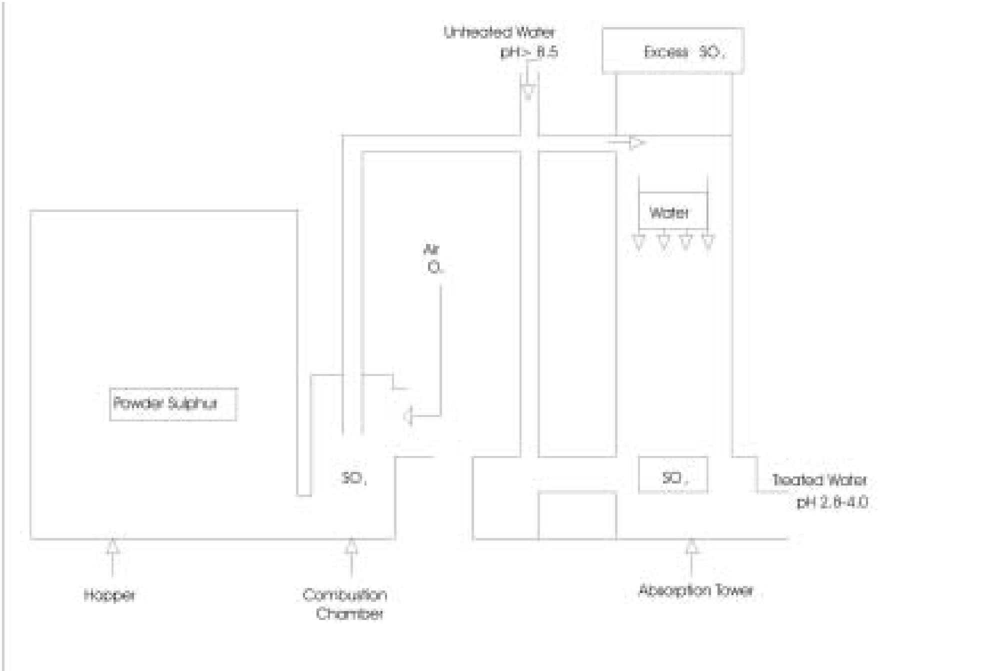
*On the other hand, the application of sulphuric acid as an amendment could not get popularity among the farmers, as acid is extremely dangerous to handle. To address these issues, the Sulphurous Acid Generator, an innovative device has been introduced. This equipment uses sulfur to produce the sulphuric acid to treat the brackish water. The sulphurous acid, generator was used to conduct field-trials on abandoned saline-sodic soil with sodic water from Rabi 1997-98 to Kharif 1999 in the Mona project area. The specific objective of the study was to evaluate the effectiveness of sulphurous acid generator in treating the sodic water and application of treated and untreated water in various combinations for reclaiming the abandoned soil. Five irrigation-combinations of treated and untreated water were evaluated. In order to bring the pH and RSC of irrigation-water at desired level, the ratio of 1:4 of treated and untreated water was used. The mixed irrigation-water with this ratio had TDS, SAR, RSC and pH of 1200 ppm, 11.5, 0.6 and 7.0, respectively. This paper describes the positive impact of treated water on soil permeability, pH, salinity, sodicity and crop-yield of abandoned soil and concludes with some recommendations.*

## BACKGROUND

To meet the food demand of ever-increasing population of the country and to earn foreign exchange from the agriculture sector, it is essential to enhance agricultural productivity, both through the increase in cropped areas as well as in crop-yields. But limited availability of fresh water and soil salinity/sodicity are the major bottlenecks in the sustainable development of agricultural sector in the country. To increase the productivity of agricultural sector, abandoned land and marginal-quality groundwater will have to be managed. To augment the inadequate supplies of good-quality water, the use of groundwater of variable qualities has tremendously increased in the recent past. The groundwater abstraction from the public and private tubewells is about 6.05 MAF, of which 1.23 MAF is from public tubewells and 4.8 is contributed by the private tubewells. The situation of groundwater-quality is deteriorating fast, due to rapid growth of tubewells in the private sector. According to an estimate there are 5,65,000 tubewells pumping groundwater in the Indus Basin. In Punjab alone, the number of private tubewells has increased from about ten thousand in 1960 to about five hundred thousand in 2000. These groundwaters have different types of salts, which deteriorate the soil accordingly (Masood and Gohar, 2000). The present area of the Indus Basin, with groundwater having salts less than 1500, 1500-3000 and more than 3000 ppm is 8.13, 1.94 and 6.4 Mha, respectively.

The sodic groundwater containing high amount of sodium, carbonates and bicarbonates enhances sodicity in soil, deteriorates the soil- permeability and hydraulic conductivity of soil (Haider *et al*. 1976, Ghafoor *et al*. 1997). Soon after the installation of Salinity Control and Reclamation Projects (SCARPs), the farmers pointed out that tubewell irrigation had made their soils hard. This deterioration of soil was due to high SAR and RSC in irrigation water. More

* Chairman, PCRWR, H.# 3, St.# 17, F-6/2, Islamabad, Pakistan. ** Director General, On Farm Water Management, Lahore, Pakistan.




**Source:** *Saeed Mirza, PCRWR, 2003*

**Figure - 1: Schematic Diagram of Sulphurous-Acid Generator**

than 70 percent tubewells pump unfit water, and indiscriminate use of such water has made large irrigated areas unproductive (Javaid et al., 1997). The analysis of 41134 water samples from tubewell of different SCARPs in Punjab indicated that more than fifty percent unfit water-samples were due to high Sodium Adsorption Ratio (SAR) and Residual Sodium Carbonate (RSC) (Table-1). But on the other hand, farmers do not have any option other than using groundwater due to the shortage of fresh water. Therefore, for the adequate use of huge groundwater resources, innovative and sustainable technologies need to be introduced.

Another major constraint of agriculture in Pakistan is the huge area affected by soil-salinity and sodicity. The salt-affected soils exist on about 25 percent of canal command areas. WAPDA carried out extensive salinity-survey, covering 16.42 mha area in the Indus Basin during 1977- 79, which indicated that 11 percent of abandoned soil-profiles were saline and 27 percent were saline-sodic and sodic. The Soil Survey of Pakistan also conducted a detailed survey of about 6 mha salt-affected soils. Saline, saline-sodic and sodic soils were recorded on 10.7, 86.5 and 0.2 percent area, respectively. Both these surveys indicated that saline-sodic soils shared the major proportion of salt-

**Table-1: Quality of Tubewell-Water Samples**

| Status | No. of Samples | Percentage |
|---|---|---|
| **Fit** | 18605 | 45 |
| **Unfit** | 22529 | 55 |
| **Unfit due to:** | | |
| EC | 10547 | 47 |
| SAR | 2479 | 11 |
| RSC | 9503 | 42 |

**Source:** *Soil Fertility Research Institute, Punjab, 1981-96* affected soils. To reclaim and bring these lands under cultivation, one of the basic essential inputs is good-quality water that is already short in the country. With the existing canal-supply, the reclamation of huge salt-affected area is nearly impossible. Moreover, for the reclamation of these sodic soils, the application of a suitable amendment with excessive leaching is needed. Gypsum is generally applied for the reclamation of sodic soils, but it needs ample quantity of freshwater for leaching of salts (Haq, 1966 Waheed, 1971, Muhammad and Khaliq, 1975). Sulphuric acid has also been tried as a soil-amendment, but it could not get popularity among farmers due to the problems associated in its handling and application (Overstreet *et al*. 1951, Hussain and Mian, 1983). These bottlenecks discourage the farming community, in general, to take up reclamation of saline sodic and sodic soils when the application of a soil-amendment is involved.

This study was conducted to overcome the shortage of freshwater for soil-reclamation and to apply amendment for the reclamation of sodic soils. In this study, an innovative device known as Sulphurous Acid Generator was used, which treated brackish groundwater and provided irrigation-water containing amendment for soil-reclamation (Sweet Water Farming, USA, 1995). The major objective of this study was to test the effectiveness of sulphurous acid generator for treating brackish water and using various combinations of treated and untreated water for reclamation of abandoned saline-sodic soil.

## APPLICABILITY OF SULPHUROUS ACID GENERATOR

### Working of Sulphurous-Acid Generator

The Sulphurous Acid Generator Plant consists of a hopper, combustion chamber, counter-current absorption tower, inlets for air, brackish water and outlet for treated water (Figure-1). Powdered elemental sulfur is stored in the hopper, from where it is released to combustion chamber by gravity. About 1.5-2 kg of sulfur is burnt through the inlet provided for entering of air/oxygen. The oxygen of air reacts with burning sulfur and makes sulfur dioxide. Sulfur dioxide is highly soluble in water. During the operation, the plant sucks brackish water from the source. This water is mixed with sulfur dioxide and sulphurous acid is formed. The chemical changes in the plant continue, oxygen is mixed with sulphurous acid and sulphuric acid is formed. The sulphuric acid is mixed with brackish water and lowers the pH, bicarbonate and carbonate contents of water. Finally, the water treated with acid is discharged by the generator plant, with average flow of 3.4 lps. When the treated water is applied for soil reclamation, sulphuric acid reacts with calcium carbonate ($CaCO_3$) in the soil and calcium sulphate ($CaSO_4$) is produced. Then calcium of $CaSO_4$ replaces the sodium from the soil-matrix through cation-exchange phenomena and finally soil is reclaimed from the sodium hazards. Sulphuric acid also reacts with the sodium carbonate and bicarbonate in the soil and produces sodium sulphate ($Na_2SO_4$), which is leached with moved water. The chemical reactions in the plants and later in the soil due to the application of treated generator water, are given as under:

$S + O_2 \text{ (HEAT)} \rightarrow SO_2$

$SO_2 + H_2O \rightarrow H_2SO_3$

$H_2SO_3 + O_2 \rightarrow H_2SO_4 + 1/2O_2$

$H_2SO_4 + 2NaHCO_3 \rightarrow Na_2SO_4 + 2H_2O + CO_2$

$H_2SO_4 + Na_2CO_3 \rightarrow Na_2SO_4 + H_2O + CO_2$

$H_2SO_4 + CaCO_3 \rightarrow CaSO_4 + H_2O + CO_2$

$CaSO_4 + 2Na.X \rightarrow Ca.X + Na_2SO_4$ (for calcareous soil)

$H_2SO_4 + 2Na.X \rightarrow H.X + Na_2SO_4$ (for non-calcareous soil)

## METHODOLOGY

The study was carried out on abandoned, saline-sodic, silty clay loam field in the command of tubewell MN-91 in the Mona project-area from *Rabi* 1997-98 to *Kharif* 1999. In planning various treatments to be evaluated, it emphasis was to test different

**Table - 2: Quality of Irrigation Water**

| Water source | TDS (ppm) | ECe (ds $m^{-1}$) | pH | SAR | RSC |
|---|---|---|---|---|---|
| Untreated tubewell water | 1209 | 1.9 | 8.5 | 14.2 | 2.7 |
| Generator treated water | 1440 | 2.3 | 2.8-4.0 | 10.1 | Nil |
| Mixed water (one part treated and four parts untreated water) | 1261 | 2 | 7 | 11.5 | 0.6 |

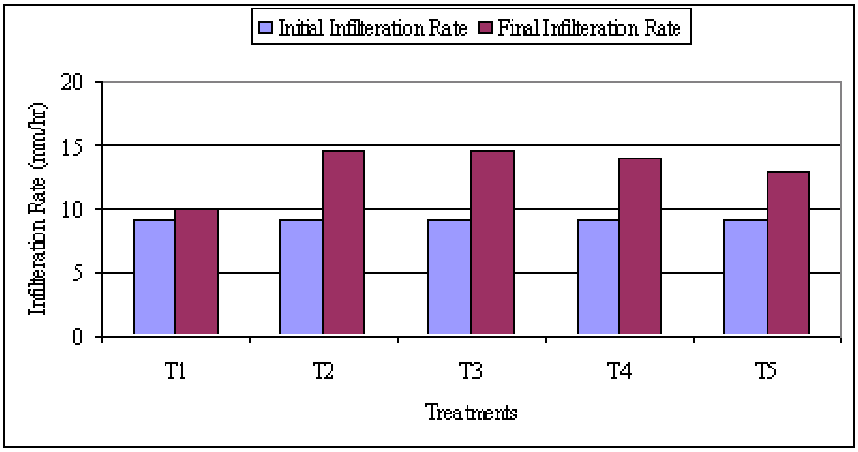



Figure - 2: Changes in Infiltration Rate of Soil

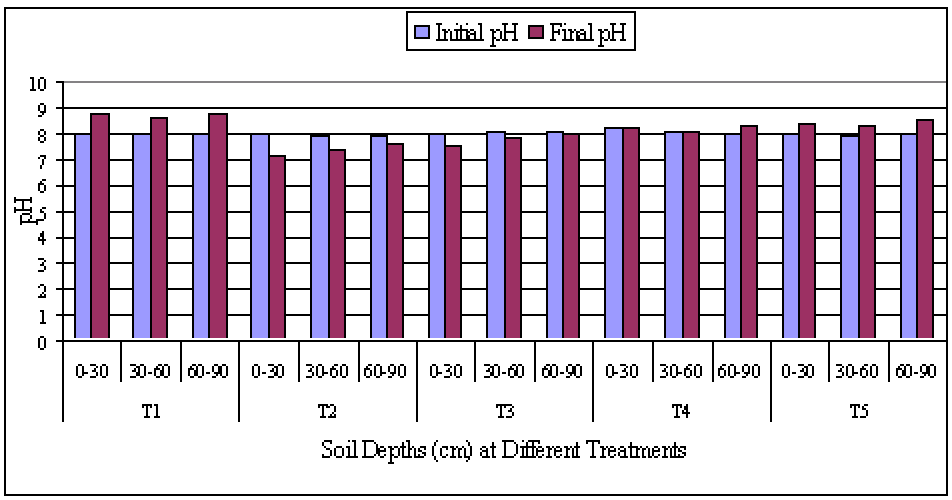



Figure 3: Changes in pH of Soil

**Table-3: Effect of Treatments on Crop-Yield (kg ha$^{-1}$)**

| Treatments | Wheat 1997-98 | Wheat 1998-99 | Increase (%) | Rice 1998 | Rice 1999 | Increase (%) |
|---|---|---|---|---|---|---|
| $T_1$ | 1042 | 1095 | 5 | 931 | 977 | 5 |
| $T_2$ | 1417 | 1855 | 31 | 1673 | 2035 | 22 |
| $T_3$ | 1268 | 1626 | 28 | 1407 | 1690 | 20 |
| $T_4$ | 1165 | 1362 | 17 | 1170 | 1392 | 19 |
| $T_5$ | 1121 | 1214 | 8 | 1023 | 1135 | 11 |

combinations of treated water with untreated tubewell water, so that minimum operation of plant could be worked out for minimizing the operational cost. The following treatments, with each of three replications, were evaluated, following wheat-rice crop rotation:

- $T_1$ Irrigation with untreated brackish tubewell water;
- $T_2$ Continuous irrigation with treated water;
- $T_3$ Alternate irrigation with treated water;
- $T_4$ One irrigation with treated water, after two irrigations with untreated water; and
- $T_5$ One irrigation with treated water, after three irrigations with untreated water.

The infiltration rate of experimental plots was measured in the beginning and just after harvesting of the crop by Standard Ring Method (Aronovici, 1955). The infiltration readings were taken after three hours and means of these readings were used to evaluate improvements in the infiltration-rate of soil. The first soil-sampling was undertaken at the start of the study from 0-30, 30-60 and 60-90 cm depth, to assess the benchmark pH, Electrical Conductivity of saturated extract ($EC_e$) and Sodium Adsorption Ratio (SAR) of experimental plots (US Salinity Laboratory Staff, 1954). The subsequent soil-samples were collected after harvesting of each crop, to evaluate changes in these parameters.

The main function of sulphurous acid generator plant is to treat brackish water by improving its pH and carbonate contents. As such, it reduces the RSC of water. To keep the pH and RSC of irrigation-water at desired useable level, different ratios of treated generator-water and untreated tubewell-water were tested in the laboratory and finally the ratio of 1:4 was found suitable (Table-2). This ratio was maintained throughout the study, by taking the required flow from the tubewell watercourse and generator discharge. However, it is pointed out that this ratio may change with the change of quality of drainage effluent Appropriate seedbeds were prepared before sowing the crops. Equal dose of all inputs, like fertilizers, hoeing, *etc.,* were applied to all study plots. The crop-yields were estimated on whole plot basis.

## RESULTS AND DISCUSSION

### Changes in Infiltration-Rate of Soil

Irrigation by treated water converted the insoluble carbonates and bicarbonates into soluble sulphates, which improved the soil permeability, soil aeration, *etc.* The initial average infiltration-rate of experimental plots was about 8.7 mm $hr^{-1}$. At the end of study, the maximum increase in infiltration rate was 64 percent over the initial infiltration rate, where continuous irrigations with treated water were applied (Figure-2). The 62 percent increase in infiltration rate occurred with alternate application of treated and untreated tubewell water. About 51 and 47 percent increase in infiltration rate was observed with one irrigation, with treated water, after two and three irrigations with untreated brackish tubewell water respectively. This showed that, even with decreased frequency of treated water, a considerable improvement in soil permeability occurred. However, the improvement would depend on the quality of brackish water as well as the texture, salinity and sodicity status of soil being reclaimed. The untreated tubewell-water irrigations enhanced infiltration rate only by 15 percent, which was mainly due to the management practices and effect of crop residues, *etc.* The results indicated a linear increase in infiltration-rate in all the cases of treated-water irrigations, whereas slight changes were found with untreated tubewell water use.

### Changes in pH of Soil

Due to the mixing of sulphuric acid, the average pH of treated water before mixing with untreated water varied between 2.8 to 4.0. The pH of untreated tubewell-water was 8.5. As planned in the study, the neutral pH of 7.0 for treated irrigation water was achieved with a 1:4 ratio between generator-water and untreated tubewell-water. The initial pH of experimental field ranged from 7.9 to 8.2. The application of untreated brackish tubewell-water increased the pH at all depths from 7 to 10 percent, because the treatment-plots were continuously irrigated with water having average pH of 8.5 (Figure-3). It showed that the continuous application of untreated tubewell water was harmful for the soil as far as pH was concerned. The continuous irrigations with treated water reduced pH at various sampling depths by 4 to 11 percent because the pH of irrigation-water in this case was maintained

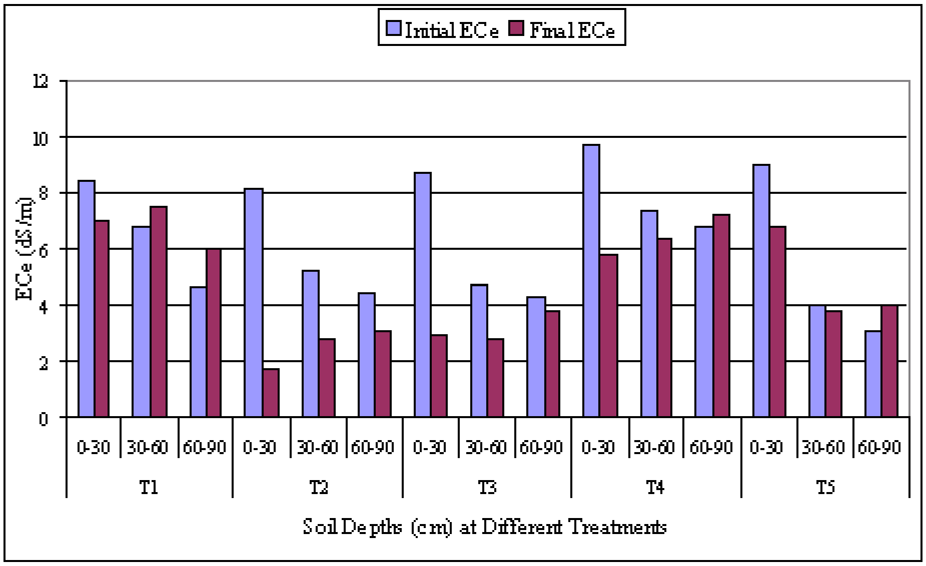



Figure - 4: Changes in $EC_e$ of Soil

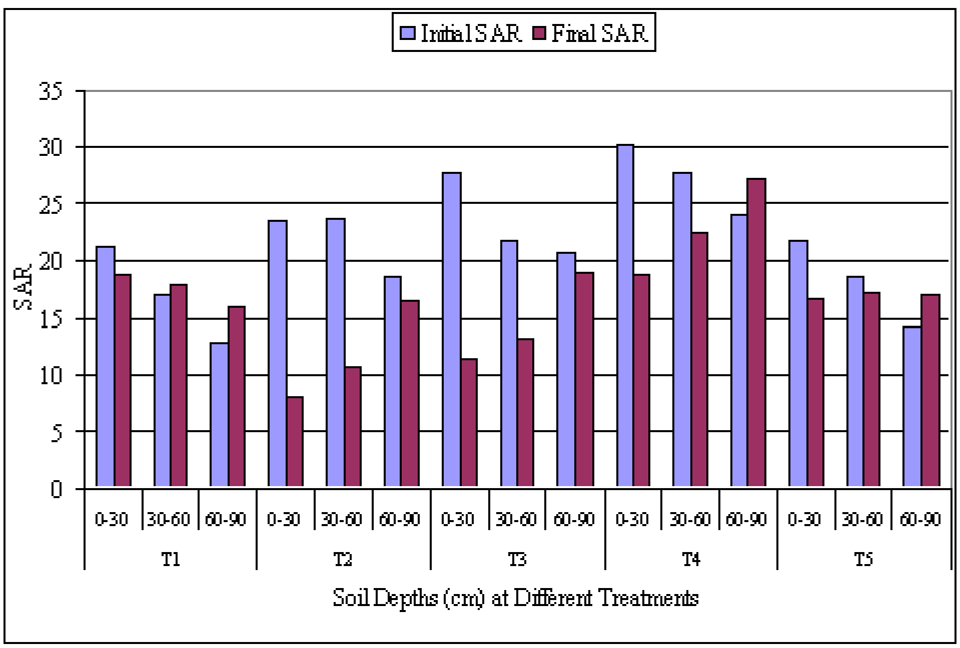



Figure 5: Changes in SAR of Soil

at 7.0. This is one of the major benefits of sulphuric acid generator, that it reduces and keeps the pH of treated water and irrigated soil at desired levels. The alternate irrigations with treated and untreated water also reduced the pH at all depths by 1 to 6 percent. In both these treatments, higher reduction in pH was at upper soil-sampling depth of 0-30 cm. This showed that, like the continuous treated-water irrigations, the alternate irrigations of treated and untreated water also improved the pH of whole soil profile. The changes in soil-pH with one irrigation of treated water and two irrigations of untreated water showed neither increase nor decrease at 0-30 and 30-60 cm depths, whereas 4 percent increase was recorded at 60-90 cm depth. This indicated that even applying two continuous irrigations of brackish tubewell water, one irrigation of treated water maintained the initial pH level of soil upto 60 cm soil depth. Among different irrigation-combinations of treated and untreated water evaluated in the study, the combination of one treated-water irrigation after three irrigations with untreated water enhanced the soil pH at all depths from 5 to 6 percent. It indicated that one treated irrigation after three untreated irrigations could not maintain the soil pH effectively and caused an increase.

**Changes in Electrical Conductivity of Soil**

The electrical conductivity ($EC_e$) of soil-profile depends on the movement of soluble salts with moved water in the soil matrix. If the movement of water is restricted by soil-crusting, hardening of any soil layer and inadequate drainage, *etc*., then soil-salinity is developed and, as such, $EC_e$ is increased and *vice versa*. The untreated tubewell-water had EC of 1.9 dS $m^{-1}$, whereas the generator-treated water prior to mixing with tubewell-water had EC of 2.3 dS $m^{-1}$. It showed that the generator-water had soluble salts even higher than the untreated tubewell-water due to soluble sulphates *etc*. With 1 to 4 ratio of treated and untreated water, the water used for the experiment had $EC_e$ of 2.0 dS $m^{-1}$, which is in useable marginal range of water-quality criterion. But the application of treated water improved the soil-porosity and permeability by converting the insoluble carbonates and bicarbonates into soluble sulphates. Due to the improvements in soil and increase in soluble salts, compared with insoluble salts, the $EC_e$ of soil was reduced with the use of treated water.

The benchmark $EC_e$ of study-field was higher at upper depths than at the lower depths. Because the field was abandoned before the experiment, the salts have moved towards the soil-surface with the evaporating water. Depending on the quality of water used, different treatments showed variable behaviour in changing $EC_e$ of soil (Figure-4). The irrigation with untreated tubewell water could reduce $EC_e$ only at 0-30 cm depth by 17 percent, mainly due to the management practices. On the other hand, $EC_e$ was increased by 10 and 30 percent at 30- 60 and 60-90 cm depth. It indicated that the salts leached from the soil-surface were accumulated within the root-zone and proper reclamation was not achieved. Significant reduction from 30 to 79 percent in soil $EC_e$ was recorded at various depths, when the continuous irrigations with treated water were applied. This was because the soil-conditions for adequate leaching were improved, crusting of soil-surface due to sodium ion was covered, insoluble carbonates and bicarbonates were converted into soluble sulphates and leaching of other salts, in addition to sodium, was increased. Likewise, continuous irrigations with treated water, produced 12 to 67 percent reduction in $EC_e$ with the alternate irrigations of treated and untreated water. Similar to the continuous and alternate irrigations with treated water, one irrigation with treated water, after two irrigations with untreated tubewell water, reduced soil $EC_e$ at 0-30 and 30-60 cm depth by 40 and 15 percent, respectively. But this treatment increased $EC_e$ at 60-90 cm depth by 6 percent. This indicated that the application of one treated irrigation after two untreated irrigations could not manage the salinity of lower soil-profile. The trend in $EC_e$ with one application of treated water after three applications of untreated water was similar to that recorded with one irrigation with treated water after two irrigations with untreated water, but with slower rate.

**Changes in Sodium Adsorption-Ratio of Soil**

The sulphuric acid mixed in irrigation-water in the generator reacts with the sodium carbonates and sodium bicarbonate in the soil and forms sodium sulphate. The sodium sulphate is water-soluble and subject to leaching with the moved water. Similarly the calcium carbonate reacts with sulphuric acid and forms water-soluble calcium sulphate. In this way the irrigation-water reduces the sodium-contents in the soil. Like $EC_e$, the trend in SAR varied with different treatments, due to the change in quality of irrigation-water used (Figure-5). The irrigation with untreated tubewell water reduced SAR by 12 percent only at 0-30 cm depth and increased SAR by 5 and 25 percent at 30-60 and 60-90 cm depth. The continuous irrigations with treated water significantly improved the soil SAR from 11 to 63 percent at different depths, indicating the effectiveness of continuous irrigation by treated water in effectively overcoming the sodicity problem in whole root-zone.

The reduction in SAR at all depths with the alternate irrigations by treated and untreated water was very close to that recorded with the continuous irrigations with treated water. One irrigation with treated water after two irrigations with untreated tubewell water reduced soil SAR only at 0-30 and 30-60 cm depth by 38 and 18 percents, respectively. But SAR was increased by 13 percent at 60-90 cm depth. One application of treated water, after three applications of untreated water, showed similar changes in SAR as was observed with one irrigation with treated water after two irrigations with untreated water. These results indicated that, depending on the changing trend in soil sodicity, the manager could decide and change the irrigation-combinations of treated and untreated water.

**Effect of Treated-Water on Crop-Yields**

The crop-yields of both wheat and rice were higher in their respective second seasons than the yield in the first seasons, indicating overall improvements in soil (Table-3).

Maximum yields of both wheat and rice were attained with continuous application of treated water, while the minimum yields were recorded with untreated tubewell-water irrigations. The continuous application of treated water produced 1417 and 1855 kg $ha^{-1}$ wheat yield in 1997-98 and 1998-99, indicating 31 percent increase in yield after only one season. The increase in wheat-yield with alternate treated and untreated water, irrigations were close to the yield with continuous irrigations with treated-water. Among different irrigation combinations of treated and untreated water, minimum wheat yield was achieved with one treated water irrigation after three untreated water irrigations. However, this yield was slightly higher than the yield obtained from untreated tubewell-water irrigations. This showed that one irrigation of treated water covered the adverse effects of brackish irrigations to a certain extent. The untreated tubewell-water produced 1042 and 1095 kg $ha^{-1}$ wheat yield in 1997-98 and 1998-99, showing only 5 percent increase mainly due to the improvement in soil near the surface through management-practices *etc.* The maximum rice-yield of 1673 and 2035 kg $ha^{-1}$ was recorded with continuous application of treated water, showing 22 percent increase, followed by 1407 and 1690 kg $ha^{-1}$ yield (20% increase) with alternate irrigations of treated and untreated water. The minimum yield of 931 and 977 kg $ha^{-1}$ was found with continuous application of untreated water indicating only 5 percent increase.

**CONCLUSIONS**

**Benefit-Cost Analysis:** During this study, the sulphurous acid generator plant was used to treat irrigation-water for two *Rabi* and two *Kharif* seasons. The capital cost of the plant was Rs. 250,000 with its life of 10 years. The water treated by the plant could be applied for irrigating 40 ha land. The operational cost per season was Rs. 4000. Based on this information and increased production with treated water, the total cost and benefits were calculated (Table-4). The calculated benefit-cost ratio (8.3:1) shows the usefulness of the technology.

The conclusions and recommendations drawn from this study are based on the quality of untreated soil and untreated water used in the study. The maximum increase in soil infiltration rate was recorded in case of continuous irrigations with treated water, followed by alternate application of treated and untreated tubewell water.

The continuous and alternate irrigations with treated water reduced pH of soil at all depths. One irrigation with treated water, after two irrigations with untreated water, did not show any change in pH of the soil at 0-30 and 30-60 cm depth and increase in pH at 60-90 cm depth. The application of untreated brackish tubewell-water, as well as one treated irrigation after three untreated irrigations, increased pH of soil at all depths.

The irrigation with untreated tubewell water reduced $EC_e$ only at 0-30 cm. Significant improvements in soil $EC_e$ were recorded at all depths when the continuous

**Table - 4: Benefit-Cost Analysis for Application of Sulphurous-Acid Generator**

| Year | Cost (Rs.) | | | | Benefits (Rs.) | | |
|---|---|---|---|---|---|---|---|
| | Fixed | Operational | | Total Cost | *Rabi* | *Kharif* | Total Benefit |
| | | *Rabi* | *Kharif* | | | | |
| 1 | 250000 | 4000 | 4000 | 258000 | 68160 | 207000 | 275160 |
| 2 | - | 4000 | 4000 | 8000 | 68160 | 207000 | 275160 |
| 3 | - | 4000 | 4000 | 8000 | 68160 | 207000 | 275160 |
| 4 | - | 4000 | 4000 | 8000 | 68160 | 207000 | 275160 |
| 5 | - | 4000 | 4000 | 8000 | 68160 | 207000 | 275160 |
| 6 | - | 4000 | 4000 | 8000 | 68160 | 207000 | 275160 |
| 7 | - | 4000 | 4000 | 8000 | 68160 | 207000 | 275160 |
| 8 | - | 4000 | 4000 | 8000 | 68160 | 207000 | 275160 |
| 9 | - | 4000 | 4000 | 8000 | 68160 | 207000 | 275160 |
| 10 | - | 4000 | 4000 | 8000 | 68160 | 207000 | 275160 |
| **Total** | | | | **330,000** | | | **2,751,600** |
| **Benefit-Cost Ratio = 8.3: 1** | | | | | | | |

and alternate irrigations with treated water were applied. As such, the treated water significantly leached soluble salts below the soil-surface. The trend in $EC_e$ with one application of treated water, after two and three applications of untreated water, was almost similar, which reduced $EC_e$ only upto 60 cm soil and increased below that depth.

The changes in soil SAR with different irrigations were almost similar to that of $EC_e$. The irrigation with untreated tubewell-water reduced SAR only at 0-30 cm depth. The continuous and alternate irrigations with treated water significantly improved the soil SAR of whole profile like $EC_e$. One irrigation with treated water, after two and three irrigations with untreated tubewell-water, reduced soil SAR only at 0-30 and 30-60 cm depths and not at 60-90 cm depth.

## RECOMMENDATIONS

- The crop-yields of both wheat and rice were higher in their respective second seasons than the yield in the first seasons, indicating the improvements in soil. The maximum yields of both wheat and rice were attained with continuous and alternate applications of treated water, while the minimum yields of these crops were recorded with untreated tubewell-water irrigations.

- The soils as well as the quality of groundwater in large areas of the country are saline sodic and sodic. The Sulphurous Acid Generator Plant is recommended for use in these areas not only to treat brackish water, but also to reclaim sodic soils.

- The tested plant was foreign manufactured and had high cost. Local manufacturers should be invited to manufacture it in the country, in order to reduce its cost. This method of reclaiming sodic soils was found a good alternative to gypsum.

- Little research on this reclamation method under different water and soil conditions has been carried out in the country. Therefore, studies should be carried out in different areas to further evaluate the sustainable application of Sulphurous Acid Generator.

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