Asian Journal of Plant Sciences

ISSN 1682-3974

Asian Journal of Plant Sciences 2 (9): 661-672, 2003
ISSN 1682-3974

Brackish Water for Irrigation: III Effects on Yields of Crops in Wheat-Rice Rotation and Properties of the Bhalike Soil Series

Muhammad Abid, [1]Anwar-ul-Hassan, [1]Abdul Ghafoor and [2]M.M. Iqbal
University College of Agriculture, Bahauddin Zakariya University, Multan, Pakistan
[1]Department of Soil Science, University of Agriculture, Faisalabad, Pakistan
[2]Department of Statistics, Bahauddin Zakariya University, Multan, Pakistan

Abstract: Deterioration of soil health and reduction in plant growth are characteristics of long-term irrigation with brackish waters. In the present investigations, we evaluated the effects of such waters on the declining rate of wheat and paddy yields and properties of the Bhalike soil series for four and a half years. Five levels, each of EC, SAR and RSC at 0.65, 2.0, 4.0, 6.0, 7.35 dS m^{-1}; 3.95, 9.65, 18.0, 26.35 and 32.04 (mmol $L^{-1})^{1/2}$ and 0.65, 2.0, 4.0, 6.0, 7.35 $mmol_c$ L^{-1}, respectively, were applied to 30 x 68 cm undisturbed and disturbed soil columns taken in metallic cylinders (30 x 76 cm). Results indicate that brackish water with an EC_{iw} of ≤ 4.0 and 4.0 dS m^{-1}; SAR_{iw} ≤ 9.65 and 18.0; RSC ≤ 4.0 and 4.0 $mmol_c$ L^{-1} may be used for irrigation of wheat without yield reduction up to coded "-1.682, -1 and 0" levels of SAR_{iw} and RSC; EC_{iw} and RSC; EC_{iw} and SAR_{iw}, respectively, for the undisturbed and disturbed soil columns. Paddy yield decreased linearly with EC_{iw} at given levels of SAR_{iw} and RSC. The SAR_{iw} up to 26.35 at coded "-1.682 and –1" levels of EC_{iw} and RSC did not affect the paddy yield in both the undisturbed and disturbed soils. At higher coded "0, 1 and 1.682" levels of EC_{iw} and RSC, the SAR_{iw} became narrow, i.e. 9.65 for paddy yield. The RSC up to 2.0 and 4.0 $mmol_c$ L^{-1} were observed safe for paddy yield in the undisturbed and disturbed soils, respectively. The rate of yield reduction with similar EC_{iw}, SAR_{iw} and/or RSC was high in the undisturbed than that in the disturbed soils. Higher grain and paddy yields were predicted in the disturbed than that in the undisturbed soil columns with the same levels of EC_{iw}, SAR_{iw} and RSC. The soil EC and SAR tended to increase with EC_{iw}, SAR_{iw} and/or RSC, with exception to EC_e which decreased with RSC waters. However, the rate of increase in EC_e and SAR was high with EC_{iw} and SAR_{iw} particularly at higher levels of SAR_{iw} and RSC; EC_{iw} and RSC. It was observed that whole of the undisturbed and disturbed soil profile attained EC_e >4.0 dS m^{-1} and SAR values >13.3 which are the upper limits for saline-sodic soils. The bulk density (BD) decreased by 4.9 and 4.4 %, respectively, for the undisturbed and disturbed soils with EC_{iw}, 7.35 dS m^{-1} over EC_{iw} 0.64 dS m^{-1} at coded "0" levels of SAR_{iw} and/or RSC of waters. The BD was 18.1, 9.3 and 14.3; 9.5 %, respectively, with SAR_{iw} 32.04 and RSC 7.35 $mmol_c$ L^{-1} over SAR_{iw} 3.95 and RSC 0.64 $mmol_c$ $L^{-1}$for the undisturbed and disturbed soils. The increase in K_s was 0.048, 0.118, 0.172 and 0.190; 0.043, 0.109, 0.170 and 0.197 cm h^{-1}, respectively, with EC_{iw} 2.0, 4.0, 6.0 and 7.35 dS m^{-1} over EC_{iw} 0.64 for the undisturbed and disturbed soils. At given levels of EC_{iw} and RSC; EC_{iw} and SAR_{iw}, the SAR_{iw} and RSC reduced the K_s of the soils. For instance, reduction in K_s was 0.003, 0.036 and 0.069 cm h^{-1}; 0.01, 0.042 and 0.071 cm h^{-1} with SAR_{iw} 18.0, 26.35 and 32.04, respectively, over SAR_{iw} 3.95 at coded "0" levels of EC_{iw} and SAR_{iw} [4.0 dS m^{-1} and 18.0 (mmol $L^{-1})^{1/2}$]. At coded "0" levels of EC_{iw} and SAR_{iw}, the RSC waters up to 2.0 $mmol_c$ L^{-1} increased the K_s of both the soils.

Key words: Soil disturbance, RSC, EC, SAR, brackish water, wheat-rice rotation

Introduction

Irrigation is becoming a practical means to use groundwater in the arid and semi-arid regions due to insufficient rainfall. Most of the ground waters occurring in these areas are of poor quality as they contain variable amounts of sodium and bicarbonate ions (Malik *et al.*, 1984; Ayres and Westcot, 1985). The effects of soluble salts from irrigation water on soil properties have been investigated intensively. Most studies indicate that calcium (Ca^{+2}) salts generally improve soil physical properties by flocculating soil particles (Rengasamy, 1984), whereas sodium (Na) salts cause deterioration of soil physical properties because of its dispersive effects (Shainberg and Letey, 1983). The dispersion of soil particles has been reported to reduce hydraulic conductivity (Quirk and Schofield, 1955) and increase bulk density (Waldron *et al.*, 1979). Increase in saturated paste extract electrical conductivity (EC_e) and sodium adsorption ration (SAR) were commonly reported in soil profile irrigated with brackish water (Sing *et al.*, 1992), which in turn reduced the crop yield (Bajwa and Josan, 1989).

Effects of brackish water irrigation on crops have been reported (Bajwa *et al.*, 1983; Bhatti *et al.*, 1981; Francois *et al.*, 1986). However, limited work has been done to predict the rate at which yields of wheat (*Triticum aestivum* L.) and rice (*Oryza sativa* L.) started declining over the years due to long-term irrigation with brackish irrigation water on yields of crops and physico-chemical properties of the soils. Most of the research work has been done previously on crops and soils under disturbed soil conditions by using limited number of combinations of EC_{iw}, SAR_{iw} and/or RSC. However, little emphasis has been placed on yields of crops under undisturbed soil conditions with brackish irrigation waters. Such information is necessary for efficient management of poor quality waters so that a high agricultural production is maintained.

The present long-term experiment was carried out under both the disturbed and undisturbed conditions to investigate the possibility of predicting EC_{iw}, SAR_{iw} and/or RSC effects on salinization, sodication, bulk density, saturated hydraulic conductivity and yields of wheat and rice crops in wheat-rice cycle.

Materials and Methods

The present research work was conducted in a net-house, University of Agriculture, Faisalabad during 1991-95. Bhalike soil series (Coarse silty, mixed, hyperthermic Mollic Epiaquepts) was sampled during September-October 1991. Physico-chemical properties of this soil series were: sand 33.49; silt 38.70%; clay 27.82% (clay loam); pH_s 7.65; EC_e 2.41 dS m^{-1}; CO_3 2.00 mmo L^{-1}; HCO_3 9.35 mmo L^{-1}; Cl 6.28 mmo L^{-1}; SO_4 5.89 mmo L^{-1}; Ca + Mg 10.38 mmol L^{-1}; Na 13.19 mmol L^{-1}; SAR 5.80 (mmol $L^{-1})^{1/2}$; $CaCO_3$ 6.49% ; CEC 11.18 $cmol_c$ kg^{-1}.

Soil sampling and columns preparation: Metallic cylinders (76 cm long and 30 cm diameter) were used to collect the undisturbed soil samples. A piece of wood (35 cm x 35 cm and 8 cm thick) having circular groove that fitted snugly on the upper edge of the cylinder was placed on the top. Cylinder were pushed vertically into the moist soil (at 50 % field capacity) by dropping a 20 kg weight on the grooved wooden planks, tied with a strong string and controlled through a pulley, attached to a tripod. When cylinder was inserted up to 68 cm depth, the soil around the cylinder was excavated up to 80 cm and soil columns were removed by titling it. This excavated soil was used for preparing the disturbed soil columns. The extra soil at the bottom of the cylinder was removed with the help of a sharp knife. This procedure was repeated for 20 cylinders. A thin layer of glass wool and sand on stainless steel screen (35 cm x 35 cm) was placed and was attached at the bottom of the cylinders with the help of a rubber inner tube band. These cylinders were placed on metallic funnels, fixed on iron stands and leveled. The main objective of glass wool and sand was to minimize the movement of finer particles in the leachate.

For the preparation of disturbed soil columns, stainless steel wire gauze (35 cm x 35 cm) was fixed at the bottom of the empty cylinders with the help of a rubber inner tube band. A thin layer of glass wool and sand were spreaded on the wire gauze before attaching it with the cylinder. These cylinders were placed on metallic funnels and fixed on leveled iron stands. The cylinders were filled with air-dried, ground and sieved (2 mm) soil. The soil filling was accomplished by first packing 1/3rd of the cylinder, by adding small increments through a plastic funnel attached to a plastic pipe and gently tapping the sides of the column followed by settling of soil with canal water. This was used to fill the soil until 68 cm level was reached.

Irrigation water quality: Fourteen design points/treatment combinations having different EC_{iw}, SAR_{iw} and RSC levels were selected following Central Composite Rotatable Second Order Design (Cochran and Cox, 1957). The beauty of this design is that prediction can be made for 125 treatment combinations by using only fifteen of them. Five levels each of EC_{iw} (X_1), SAR_{iw} (X_2) and RSC (X_3) were 0.65, 2.00, 4.00, 6.00 and 7.35 dS m^{-1}, 3.95, 9.65, 18.00, 26.35 and 32.04 (mmol $L^{-1})^{1/2}$ and 0.65, 2.00, 4.00, 6.00 and 7.35 $mmol_c$ L^{-1}, respectively. The levels were coded as –1.682, -1, 0, 1 and 1.682, respectively, for each variable. The relationship between coded levels and actual levels for EC_{iw}, SAR_{iw} and RSC is given at the foot of Table 1. The central point (all variables at coded zero levels) was repeated six times. The choice of six central points was made so that a uniform precision design could be attained. In a uniform precision design, variance of y at the origin is equal to the variance of y at unit distance from its origin. Thus design gives much more protection against bias in the regression analysis (Montgomery, 1997). The design matrix and treatment combinations investigated are presented in Table 1.

To verify the validity of model predictions with factors of Table 1, five extra treatments (Table 2) for wheat were run in the disturbed columns of Bhalike soil series. The procedure for preparation of disturbed soil columns was same as mentioned above. After getting near chemical steady state, assessed on the basis of EC_{dw} (EC of drainage water) wheat was grown in these extra lysimeters. These five treatments were selected without any consideration of the 20 treatments (Table 1).

Table 1: Design matrix and treatment combinations used during experiments

Coded scale			Original level		
x_1	x_2	x_3	Ec_{iw} (dS m^{-1})	SAR_{iw} (mmol L^{-1})$^{1/2}$	RSC (mmol$_c$ L^{-1})
-1	-1	-1	2.00	9.65	2.00
1	-1	-1	6.00	26.35	2.00
-1	1	-1	2.00	9.65	2.00
1	1	-1	6.00	26.35	2.00
-1	-1	1	2.00	9.65	6.00
1	-1	1	6.00	26.35	6.00
-1	1	1	2.00	9.65	6.00
1	1	1	6.00	26.35	6.00
-1.682	0	0	0.65	18.00	4.00
1.682	0	0	7.35	18.00	4.00
0	-1.682	0	4.00	3.95	4.00
0	1.682	0	4.00	32.04	4.00
0	0	-1.682	4.00	18.00	0.65
0	0	1.682	4.00	18.00	7.35
0	0	0	4.00	18.00	4.00
0	0	0	4.00	18.00	4.00
0	0	0	4.00	18.00	4.00
0	0	0	4.00	18.00	4.00
0	0	0	4.00	18.00	4.00
0	0	0	4.00	18.00	4.00

$$X_1 = \frac{(X_1\text{-}4.0)}{2.0} \quad (1)$$

$$X_2 = \frac{(X_2\text{-}18.00)}{8.35} \quad (2)$$

$$X_3 = \frac{(X_3\text{-}4.0)}{2.0} \quad (3)$$

Table 2: Five extra treatment combinations run to test the model validity

Coded scale			Original level		
x_1	x_2	x_3	Ec_{iw} (dS m^{-1})	SAR_{iw} (mmol L^{-1})$^{1/2}$	RSC (mmol$_c$ L^{-1})
-1	0	-1.682	2.00	18.00	0.65
0	0	-1	4.00	18.00	2.00
0	1	0	4.00	26.35	4.00
1	1	1.682	6.00	26.35	7.35
1.682	1	-1.682	7.35	26.35	0.65

Preparation of brackish water, application and steady-state soil conditions: The desired levels of EC_{iw}, SAR_{iw} and RSC (Table 1) were prepared by dissolving NaCl, $NaHCO_3$, Na_2SO_4, $CaCl_2$ and $MgSO_4$ salts in canal water [EC 0.35 dS m^{-1}; Ca+Mg 2.44 mmol L^{-1}; Na 1.06 mmol L^{-1}; SAR 0.94 (mmol L^{-1})$^{1/2}$]. For every irrigation, calculated amounts of these salts were dissolved and applied to the respective soil columns. After each irrigation, drainage water from lysimeters was measured and analyzed occasionally for EC_{dw} (EC of drainage water), cations and anions to monitor the progress towards steady state. Application of brackish water was started on February 15, 1992 and the near chemical steady-state soil conditions were achieved on November 23, 1992 (Table 3).

Table 3: Chemical analysis of drainage water (EC and SAR values) collected at steady-state soil conditions

Designed brackish waters			Undisturbed		Disturbed	
Ec_{iw}	SAR_{iw}	RSC	EC_{dw}	SAR_{dw}	EC_{dw}	SAR_{dw}
2.00	9.65	2.00	2.3	4.4	2.3	6.6
6.00	9.65	2.00	6.3	11.3	4.4	10.9
2.00	26.35	2.00	2.7	9.6	2.6	12.9
6.00	26.35	2.00	7.0	12.6	6.6	22.1
2.00	9.65	6.00	2.8	6.7	2.1	10.1
6.00	9.65	6.00	5.3	8.6	5.4	7.2
2.00	26.35	6.00	2.6	6.9	2.8	9.1
6.00	26.35	6.00	2.1	9.7	6.3	19.3
0.65	18.00	4.00	5.3	5.8	2.2	10.0
7.35	18.00	4.00	4.9	16.2	4.9	14.7
4.00	3.95	4.00	3.8	5.5	4.6	3.1
4.00	32.04	4.00	4.7	13.4	4.0	12.8
4.00	18.00	0.65	4.2	7.7	4.3	11.2
4.00	18.00	7.35	3.9	9.5	4.2	9.9
4.00	18.00	4.00	5.2	8.1	3.0	10.7
4.00	18.00	4.00	5.0	7.6	3.4	12.4
4.00	18.00	4.00	1.8	8.1	3.6	7.8
4.00	18.00	4.00	4.4	14.5	5.1	17.4
4.00	18.00	4.00	3.9	6.1	4.2	11.5
4.00	18.00	4.00	4.4	9.0	4.2	15.6

Ec_{iw} and EC_{dw} = dS m^{-1}
SAR_{iw} = (mmol L^{-1})$^{1/2}$
RSC = mmol$_c$ L^{-1}

Crops: Wheat (*Triticum aestivum* L.) variety Faisalabad-85 and rice (*Oryza sativa* L.) variety KS-282 were chosen and were grown in the wheat-rice rotation, commonly followed in the region. Wheat crop was sown on December 16, 13 and 12, 1992, 1993 and 1994 in both the disturbed and undisturbed soil columns at a density of 15 grains soil^{-1} columns. This number was reduced to three column^{-1} 10-days after germination. The N, P and K were applied at 150, 100 and 75 kg ha^{-1}, respectively, to all the soil columns as urea, single super phosphate (SSP) and Sulphate of potash (K_2SO_4). During growth period, the crop was sprayed with Novacron to protect it from insect attack. Brackish waters (Table 1) were applied through out the growth period of the crop. The crop was harvested on May 2, April 26 and April 24, 1993, 1994 and 1995, respectively. Forty days old 2-3 rice seedlings per hill were transplanted (three hills per lysimeter) on July 18, 1993 and July 10, 1994 in both the disturbed and undisturbed soil columns. The N, P and K were applied at 100, 80 and 50 kg ha^{-1} as urea, SSP and K_2SO_4, respectively. The zinc was also applied as zinc sulphate ($ZnSO_4$) at 12 kg ha^{-1}. The soil columns were kept submerged through out rice growth period with designed waters. The crop was harvested on November 2, 1993 and November 4, 1994 and paddy yield was recorded. Average paddy yield of three plants per pot was used for statistical analysis. The total amount of water (brackish water + rainfall) added to soil columns is presented in Table 4. After termination of the experiments, saturated hydraulic conductivity (K_s) with falling head method (Jury, 1991)

Table 4: Total depth of irrigation and rainfall values at experimental site during the period of February 1992 to April 1995

	Steady-state		Wheat (December-April)		Rice (July-November)		Fallow (April-June)	
Determinants	Undisturbed	Disturbed	Undisturbed	Disturbed	Undisturbed	Disturbed	Undisturbed	Disturbed
Brackish water irrigation (mm)	1131.8	1202.5	650.8	700.4	962.0	1004.4	-	-
Rainfall (mm)	-	-	446.1	446.1	407.4	407.4	263.9	263.9
Total water input (mm)	1131.8	1202.5	1096.9	1146.5	1369.4	1411.8	263.9	263.9

Table 5: Observed and predicted grain yield (g) of wheat as affected with EC_{iw}, SAR_{iw} and RSC

Treatment			Bhalike soil series	
EC_{iw}	SAR_{iw}	RSC	Observed	Predicted
2.00	18.00	0.65	8.6	5.35
4.00	18.00	2.00	9.35	11.66
4.00	26.35	4.00	8.34	13.81
6.00	26.35	7.35	1.57	9.27
7.35	26.35	7.35	3.25	1.09

and bulk density by core method from 0-10 cm (Blake and Hartge, 1986) were determined. The soil samples from 0-15, 15-30, 30-45 and 45-60 cm were drawn from the undisturbed and disturbed columns. The soil samples were air-dried, ground and passed through a 2 mm sieve and were analysed for EC_e, TSS, Ca^{+2}, Mg^{+2}, Na^+, CO_3^{2-}, HCO_3^-, SO_4^{2-}, SAR and pH_s (U.S. Salinity Lab. Staff, 1954).

Data analysis: The coefficients in Table 4 were determined using multiple regression analysis. This was accomplished by using computer software Minitab version 7.1. To draw quadratic graph for all dependent variables, following form of the model was followed:

$$\log y_i = \beta_0 + \beta_i x_i + \beta_{ii} x_i^2$$

To show the effect of independent variable on a dependent variable in a quadratic graph, the other two variables were kept at coded "0" levels. The actual values of independent variables could be transformed from the coded values by equations given at the foot of Table 1.

Results and Discussion

The observed and model predicted grain yield data of wheat are presented in Table 6. Results indicated that the range of difference between observed and model predicted yield was 1.93 to 3.75 g for the undisturbed and disturbed soil columns. The difference between observed and predicted values were not large, hence model fitted the data adequately. In a pot study conducted at International Rice Research Institute (IRRI), Los Banos, Philippines, Rashid (1983) reported 1.0 to 5.0 g difference between observed and model predicted values for paddy yield. He further reported that model fitted the data adequately with this range of difference between observed and predicted values.

Soil Salinity (Ec_e): Salt accumulation in soil profile was determined at the end of the experiments. The electrical conductivity of the saturation extract (EC_e) before the start of brackish water irrigation was 2.41. It increased during the experiments. This has been shown through the best-fit quadratic relationships between EC_e and EC_{iw}, SAR_{iw} and RSC ($\log EC_e = b_o + b_1x_1 + b_2x_2 + b_3x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3$, where x_1, x_2 and x_3 are the EC_{iw}, SAR_{iw} and RSC and b_0, b_1, b_2, b_3, b_{11}, b_{22}, b_{33}, b_{12}, b_{13} and b_{23} are the regression coefficients) in Table 6. The values of coefficients of determination (R^2) were highly significant and the predicted EC_e, SAR, yield of crops, etc. were fairly close to the observed values of these responses.

At given SAR_{iw} and RSC, increase in EC_{iw} tended to cause an increase in EC_e in both the undisturbed and disturbed soil columns. Due to space limitation, graphs with changing levels of one parameter on all responses at coded "0" levels of other two parameters were depicted here. It is evident that soil salinity increased from 2.49 to 6.55 and 2.36 to 6.53 in the top 0-15 cm with increasing EC_{iw} from 0.65 to 7.35 dS m^{-1} for both the undisturbed and disturbed soils. It is interesting to note that increase in EC_e with EC_{iw} was higher at coded "-1.682 and –1" levels of SAR_{iw} and RSC than at higher coded "0, 1 and 1.682" levels of these parameters in the undisturbed and disturbed soil conditions. The difference in EC_e with EC_{iw} at given SAR and RSC waters was quite narrow between undisturbed and disturbed soil columns (Fig.2). Results indicated that the EC_e with EC_{iw} 0.65, 2.0, 4.0, 6.0 and 7.35 d S m^{-1} was 2.49, 3.26, 4.53, 5.79 and 6.55 which was 12.31, 42.5, 53.0, 56.33 and 56.34 % of the EC of respective water used for irrigation for the undisturbed soil. The increase in EC_e with EC_{iw} 0.65 dS $m^{-1}$was less than the original EC_e (2.41 dS m^{-1}) in the disturbed soil at coded "-1.682, -1 and 0" levels of SAR_{iw} and RSC. Similarly, the EC_e with EC_{iw} 2.0, 4.0, 6.0 and 7.35 dS m^{-1} was 3.12, 4.39, 5.71 and 6.53 dS m^{-1} which was 35.5, 49.5, 55.0 and 56.05 % of the EC of respective water at coded "0" levels of SAR_{iw} and RSC [(18.0 mmol $L^{-1})^{1/2}$ and 4.0 $mmol_c$ L^{-1}]. Higher the salinity of water, higher saline is the soil. Saleem *et al.* (1993) also recorded similar results and reported that EC_e of clay loam soil increased from 2.88 to 4.0 dS m^{-1} after four years application of water having EC_{iw} 2.4 dS m^{-1}, SAR_{iw} 9.2 and RSC 5.7 $mmol_c$ L^{-1}. It means that salts continued to accumulate resulting in increased EC_e in the soil profile. It is evident that EC_e was < 4.0 dS m^{-1} with EC_{iw} up to 2.0 dS m^{-1} at coded "-1.682 and –1" levels of SAR_{iw} and RSC for

Table 6: Regression coefficients (b) and coefficient of determination (R^2) for wheat and paddy yields and soil properties as affected with EC_{iw}, SAR_{iw} and RSC (log values)

Soil condition/crop	B_0	b_1	b_2	b_3	b_{11}	b_{22}	b_{33}	b_{12}	b_{13}	b_{23}	R^2
Wheat grain yield (average of three years)											
Undisturbed	3.575**	-0.202**	-0.218**	0.133**	-0.255**	-0.132**	-0.380**	-0.084*	0.029ns	0.005ns	0.985**
Disturbed	4.359**	-0.121**	-0.109**	-0.258**	-0.138**	-0.116**	-0.307**	0.008ns	-0.062ns	-0.075*	0.977**
Paddy yield (average of two years)											
Undisturbed	4.342**	-0.279**	-0.094**	-0.139**	-0.037ns	-0.051ns	-0.091**	-0.047ns	0.025ns	-0.014ns	0.940**
Disturbed	4.656**	-0.244**	-0.114**	-0.068*	-0.129**	-0.079**	-0.101**	-0.011ns	0.044ns	-0.013ns	0.958**
EC (undisturbed)	1.509**	0.287**	0.151**	-0.108**	-0.041ns	-0.061ns	-0.065ns	-0.091ns	0.024ns	-0.007ns	0.930**
EC (disturbed)	1.476**	0.303**	0.157**	-0.108**	-0.042ns	0.052ns	-0.063ns	-0.095*	0.035ns	0.001ns	0.932**
SAR (und.)	3.089**	0.154**	0.458**	0.156**	-0.029ns	-0.155**	0.005ns	-0.101*	-0.035ns	-0.053ns	0.972**
SAR (disturbed)	3.046**	0.184**	0.455**	0.165**	-0.025*	-0.170ns	-0.004ns	-0.073ns	-0.028ns	-0.020ns	0.942**
BD (undisturbed)	0.480**	-0.016*	0.044**	0.027**	-0.009ns	-0.027**	-0.012ns	-0.013ns	0.004ns	0.007ns	0.901**
BD (disturbed)	0.460**	-0.013ns	0.038**	0.028**	-0.009ns	-0.019*	-0.010ns	0.008ns	0.013ns	-0.011ns	0.881**
Ks (undisturbed)	-1.323**	0.045**	-0.087*	-0.086*	-0.059ns	-0.046ns	-0.040ns	0.003ns	0.003ns	0.006ns	0.875**
Ks (disturbed)	-1.332**	0.244**	-0.083*	-0.092*	-0.045ns	-0.044ns	-0.031ns	0.001ns	-0.002ns	0.008ns	0.863**

* = Significant at 0.01 level of probability
** = Significant at 0.05 level of probability
ns = Non-significant
BD = Bulk density (Mg cm^{-3})
K_s = Saturated hydraulic conductivity (cm h^{-1})
(und.) = Undisturbed

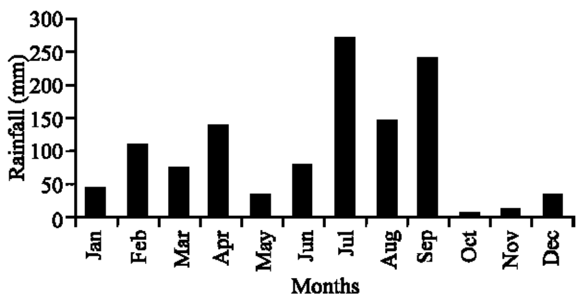

Fig. 1: Average annaul rainfall data (mm) from October 1992 to April 1995

both the soil conditions. It was >4.0 dS m^{-1} with EC_{iw} from 4.0 to 7.35 dS m^{-1} at coded "0, 1 and 1.682" levels of SAR_{iw} and RSC, which was the upper limit for saline-sodic and sodic soils as ascribed by U.S. Salinity Lab. Staff (1954) and Ayres and Westcot (1985). It is also evident that salinity increased with depth in both the soil conditions. This might be due to leaching of solutes to lower depths. Medium textured soil exhibits better drainage than that of fine textured soils. Hussain *et al.*, (1993) and Hamdy *et al.* (1993) also reported that EC_e of normal soils increased with EC_{iw}.

Soil salinity increased significantly with an increase in SAR_{iw} at a given salinity and RSC of waters. Results (Table 6) revealed that EC_e increased with changing levels of SAR_{iw} only at lower coded values of EC_{iw} and RSC, whereas it decreased and/or remained constant with EC_{iw} at higher coded values of these two parameters. For instance, the EC_e increased with SAR_{iw} only up to 26.35, thereafter it remained almost constant with SAR_{iw} 32.04 at coded "0" levels of EC_{iw} and RSC for both the undisturbed and disturbed soils. It is clear from the data (Table 6) that

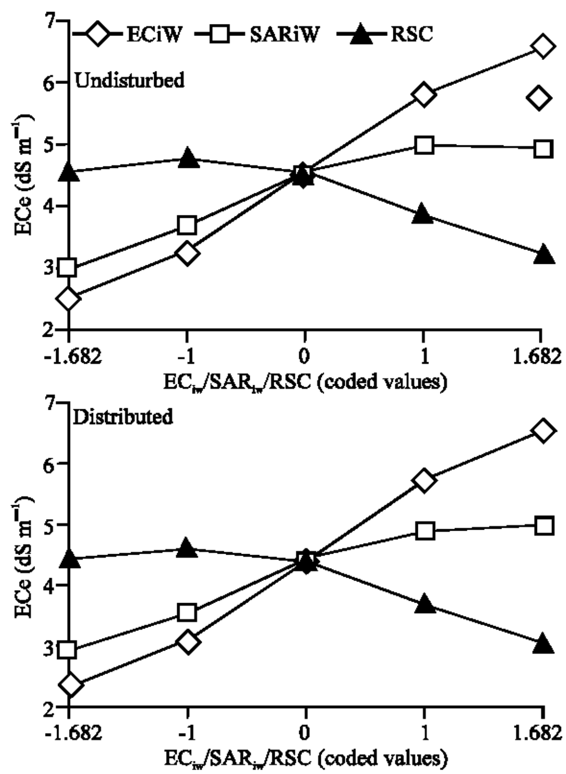

Fig. 2: Response of Ec_e to Ec_{iw}, SAR_{iw} and RSC

an increase in the EC_e with SAR_{iw} from 3.95 to 32.04 could be due to the reason that high SAR saline water deteriorated the soil structure and thereby reduced permeability of soils. At a given EC_{iw} and SAR_{iw}, the RSC of water tended to cause decrease in EC_e (Fig. 2). Both the soil conditions behaved similarly regarding the effect of RSC on soil salinity at coded "0" levels of EC_{iw} and SAR_{iw}. The EC_e with RSC 0.65 to 7.35 dS m^{-1} was still higher than

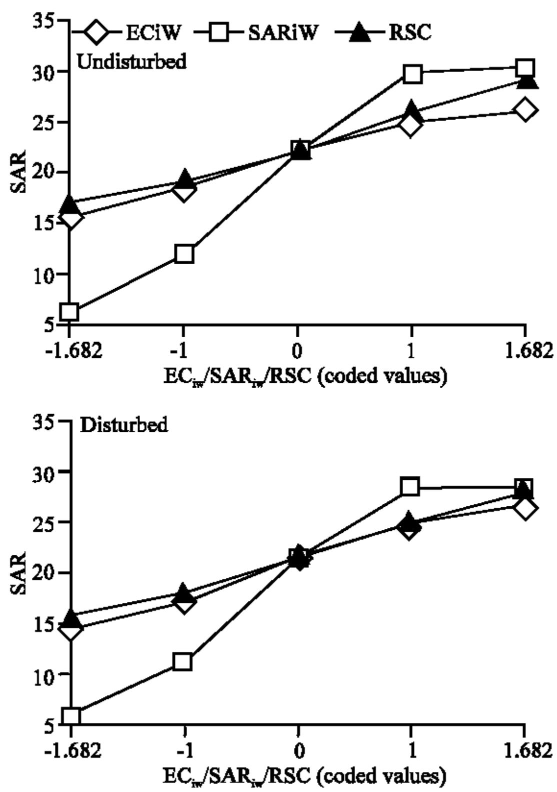

Fig. 3: Response of SAR to Ec_{iw}, SAR_{iw} and RSC

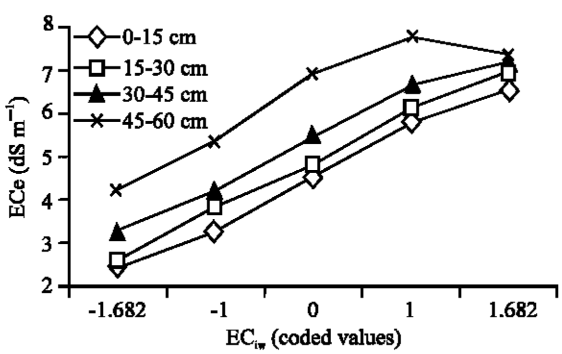

Fig. 4: Depth-wise Ec_e (dS m^{-1}) as affected with Ec_{iw} at coded "0" levels of SAR_{iw} and RSC

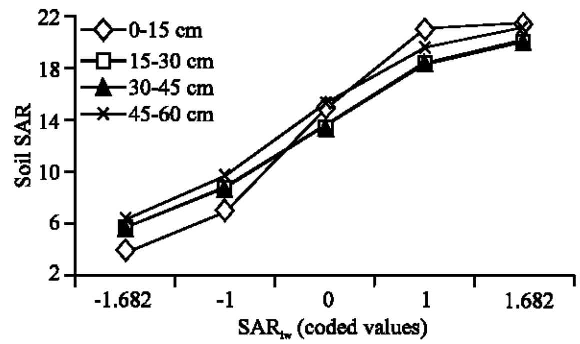

Fig. 5: Depth-wise soil SAR as affected with SAR_{iw} at coded levels of SAR_{iw} and RSC

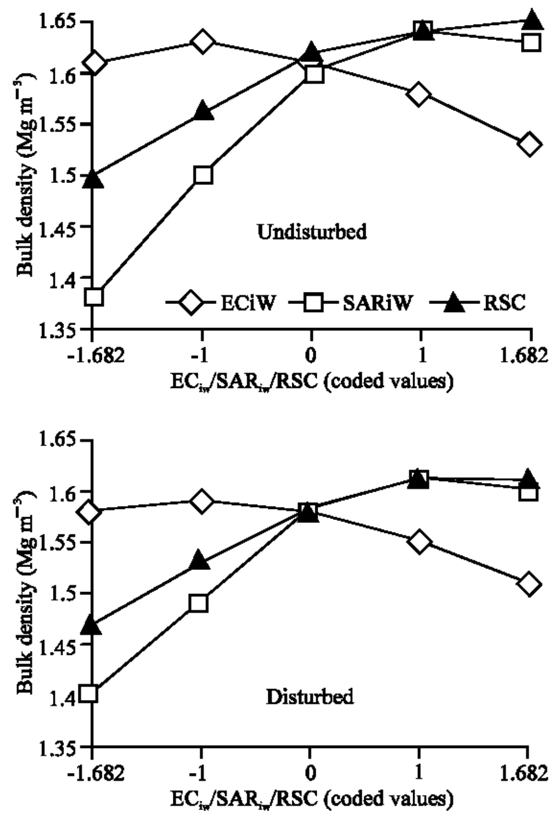

Fig. 6: Response of bulk density to EC_{iw}, SAR_{iw} and RSC

the original salinity of the soil (2.41 dS m^{-1}). In several studies, it was shown that HCO_3 content of water decreased soil salinity through precipitation of Ca^{+2} and Mg^{+2} as $CaCO_3$ and $MgSIO_2$ (Hausenbuiller *et al.*, 1960; Muhammed and Rauf, 1983).

Soil sodication (SAR): Fig. 3 shows that, in the top 0-15 cm, there was an appreciable increase in SAR_{iw} with EC_{iw} at coded "0" levels of SAR_{iw} and RSC (18 and 4.0 $mmol_c$ L^{-1}). Data in Table 6 revealed that sodicity build up in both the soil conditions with EC_{iw} was less at coded "-1.682 and –1" than that at higher coded "0, 1 and 1.682" levels of SAR_{iw} and RSC. It is evident that undisturbed and disturbed soils behaved similarly in sodicity build-up with EC_{iw} at al the five coded levels of SAR_{iw} and RSC. It is interesting to note that at similar SAR_{iw} and RSC, irrigation with high salinity water (EC_{iw} 7.35 dS m^{-1}) caused high accumulation of salts and also increased the SAR of soil solution. Singh *et al.* (1992), Bajwa and Josan (1989) and Hussain *et al.* (1993) recorded similar results and reported that sodicity of normal soils increased with Ec_{iw}.

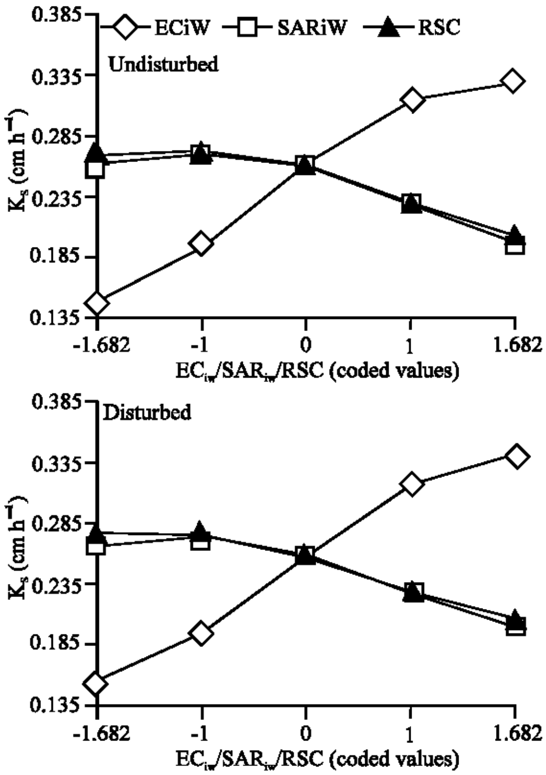

Fig. 7: Response of saturated hydraulic conductivity (K_s) to EC_{iw}, SAR_{iw} and RSC

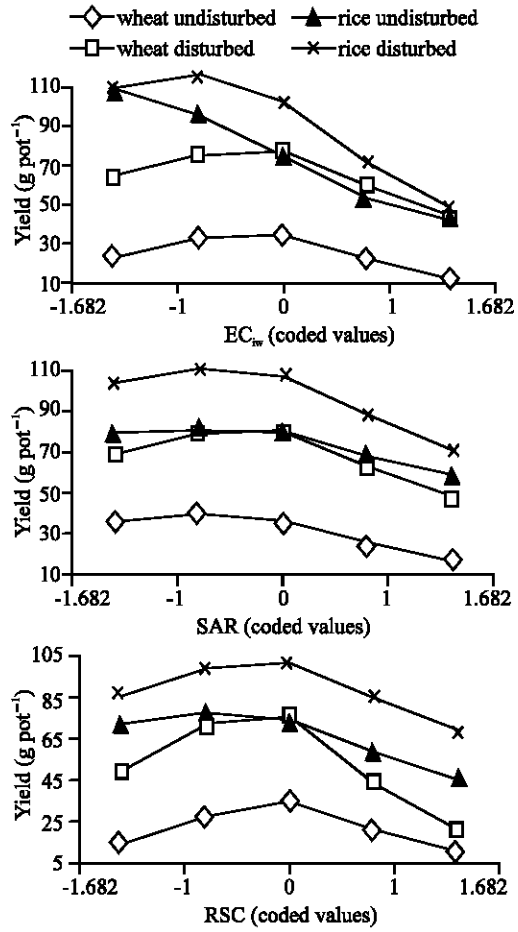

Fig. 8: Yields of designed crops to Ec_{iw}, SAR_{iw} and RSC

At a given EC_{iw} and RSC, the increasing SAR_{iw} tended to cause an increase in SAR of the both the soil contiontons. This increase, however, was more pronounced with similar SAR_{iw} at higher coded "1 and 1.682" levels of EC_{iw} and RSC under both the soils. Results indicated that at coded "0" levels of EC_{iw} and RSC, soil SAR with SAR_{iw} 3.95, 9.65, 18.00, 26.35 and 32.04 was 6.47, 11.85, 21.98, 26.61 and 30.22; 6.07, 11.30, 21.12, 28.08 and 28.06, respectively, which was 16.96, 62.69, 89.89, 90.36 and 76.22 %; 6.84, 56.99, 85.11, 84.55 and 69.48 % of the SAR of respective water used for irrigation for undisturbed and disturbed soil columns. Thus it could be seen that more sodicity was build up with similar SAR_{iw} in the undisturbed than that in the disturbed soils. Interestingly, build up of sodicity was more with SAR_{iw} 32.04) at coded "1.682" levels of EC_{iw} and RSC (7.35 dS m^{-1} and 7.35 $mmol_c$ L^{-1}) than that at coded "-1.682" levels of EC_{iw} and RSC (0.65 dS m^{-1} and 0.65 $mmol_c$ L^{-1}) for both the soil conditions. The build up of soil SAR seemed to be higher than expected with SAR_{iw} of 32.04 at higher than that at lower coded levels of EC_{iw} and RSC. This could be due to the reason that water had quite high residual alkalinity and soluble salts in addition to high SAR_{iw}. Therefore, precipitation of carbonates resulted in higher Na saturation of the soil.

The RSC waters significantly increased SAR of soil solution at given levels of EC_{iw} and SAR_{iw}. A minor difference in SAR with RSC waters at coded "0" levels of EC_{iw} and SAR_{iw} (4.0 dS m^{-1} and 18.0) was noted between undisturbed and disturbed soils (Fig. 3). More SAR was resulted with RSC waters at higher than that at lower coded levels of EC_{iw} and SAR_{iw} (Table 6). The increase in SAR with RSC waters could be due to the reason that at high RSC waters, bicarbonate ions precipitated Ca^{+2} ions and the residue of the CO_3 pairs with Na to form Na_2CO_3 and $NaHCO_3$ in the irrigated soils, thereby sodicating the soil more (Gupta, 1980).

The depth-wise distribution of EC_e and SAR, after the termination of experiments is presented in Fig. 4 and 5. The tendency of soils irrigated with higher EC_{iw} at given SAR_{iw} and RSC; SAR_{iw} at a given EC_{iw} and RSC for build-up of more EC_e and SAR is evident. For instance, even the lower soil layers accumulated more solutes than that of the upper with EC_{iw}, SAR_{iw} and/or RSC waters. Singh *et al.* (1992) recorded the similar results and reported that salts were accumulated more in the lower layers of sandy loam soil with high EC_{iw} (12 dS m^{-1} and SAR 40) water. The higher accumulation of soluble salts and sodium in the soil profile was due to the high amount of electrolytes, exchangeable Na and carbonates added through a large number of irrigations (Table 4). After four and a half years application of designed brackish waters, whole of the soil profile attained EC_e >4.0 dS m^{-1} and SAR >13.3, which is the upper limit for the saline-sodic and sodic soils as ascribed by U.S. Salinity Lab Staff (1954).

Bulk density (BD): The effect of EC_{iw} on bulk density (BD) was negative and significantly, indicating that BD decreased with increasing EC_{iw} levels at coded "0" levels of SAR_{iw} and RSC (Fig. 6). The BD increased with EC_{iw} up to 2 dS m^{-1}, thereafter it decreased with further increase in EC_{iw} from 4.0 to 7.35 dS m^{-1} at higher (1 and 1.682) than that at lower (-1.682 and –1) coded levels of SAR_{iw} and RSC in the undisturbed soil. The reduction in BD was 1.24, 0.25, 1.86 and 4.97 %; 0.63, 0.19, 0.89 and 4.43 %, respectively, with EC_{iw} 2.0, 4.0, 6.0 and 7.35 dS m^{-1} over 0.64 dS m^{-1} at coded "0" levels of SAR_{iw} and RSC for the undisturbed and disturbed soil columns (Table 6). Coasta *et al.* (1991) recorded the similar results and reported that for 0-15 cm, the BD decreased from 0.06 to 0.04 Mg m^{-3} with water having EC 2.98 dS m^{-1} and SAR 8.0. However, Zartman and Gichuru (1984) reported that Na accumulation with EC_{iw} 12 dS m^{-1} and SAR_{iw} 11.0 did not affect the BD of soils.

The BD decreased with SAR_{iw} and/or RSC at given coded levels of EC_{iw} (Table 6). It is interesting to note that BD increased with SAR_{iw} up to 26.35, became flattened with further increase in water sodicity for both the soil conditions. The increase in BD, however, was more pronounced with high SAR_{iw} and/or RSC at higher than that at lower coded levels of EC_{iw} and RSC. It is evident that at coded "0" levels of EC_{iw} and RSC, an increase in the BD was 8.69, 15.94, 18.40 and 18.12 %; 6.43, 12.86, 15.00 and 14.29 % with SAR_{iw} 9.65, 18.0, 26.35 and 32.04 over SAR_{iw} 3.95, respectively, for the undisturbed and disturbed soil. Bulk density increased linearly with RSC waters at coded "0" levels of EC_{iw} and SAR_{iw} (4.0 dS m^{-1} and 18.0) for both the soil conditions (Table 6). However, it also increased with RSC up to 6.0 $mmol_c$ L^{-1}, thereafter it flattened with further increase in RSC waters in the case of disturbed soil columns. The increase in BD with RSC waters was more pronounced at higher coded levels of EC_{iw} and SAR_{iw} (i.e. 1 and 1.682). The increase in BD with RSC waters of 2.0, 4.0, 6.0 and 7.35 $mmol_c$ L^{-1} was 4.0, 8.0, 9.33 and 9.34 %; 4.08, 7.48, 9.52 and 9.53 % over RSC 0.64 $mmol_c$ L^{-1}, respectively, for the undisturbed and disturbed soils. Precipitation of Ca^{+2} and Mg^{+2} ions and accumulation of Na ion on the exchange sites lead to decrease in the pore-space consequently increased in BD of soils. Shainberg and Letey (1983) have also reported the similar results.

Saturated hydraulic conductivity (K_s): Increasing electrolyte concentration in water at given SAR_{iw} and RSC generally tended to increase in K_s of both the soil conditions. At coded "0" levels of SAR_{iw} and RSC, more K_s values were registered for disturbed than that for the undisturbed soil columns (Fig. 6). High K_s was recorded with similar EC_{iw} at lower than that at higher coded levels of SAR_{iw} and RSC (Table 6). For instance, the K_s with EC_{iw} 7.35 dS m^{-1} was 0.354 and 0.369 cm h^{-1}; 0.402 and 0.397 cm h^{-1} at coded "-1.682 and –1" levels of SAR_{iw} and RSC. Similarly, it was 0.266 and 0.204; 0.276 and 0.217 cm h^{-1} with similar EC waters at coded "1 and 1.682" levels of SAR_{iw} and RSC. The increase in K_s was 0.048, 0.118, 0.172 and 0.191 cm h^{-1}; 0.043, 0.109, 0.170 and 0.197 cm h^{-1}, respectively, with EC_{iw} 2.0, 4.0, 6.0 and 7.35 dS m^{-1} over EC_{iw} 0.64 for the undisturbed and disturbed soils.

The SAR_{iw} and/or RSC waters at given levels of EC_{iw} and RSC; EC_{iw} and SAR_{iw} have resulted decrease in K_s of both the soil conditions. It is interesting to note that K_s of both the soil conditions increased with SAR_{iw} up to 9.65, decreased with further increase in SAR_{iw} from 18.0 to 32.04 (Fig. 6). Comparatively more K_s values were generated with similar SAR_{iw} for the disturbed than that for the undisturbed soil columns. Data (Table 6) revealed that more decrease in K_s was resulted with SAR_{iw} from 3.95 to 32.04 at lower than that at higher coded levels of EC_{iw} and RSC. The reduction in K_s was 0.003, 0.036 and 0.069 cm h^{-1}; 0.01, 0.042 and 0.071 cm h^{-1} with SAR_{iw} 18.0, 26.35 and 32.04, respectively, over SAR_{iw} 3.95 at coded "0" levels of EC_{iw} and SAR_{iw} At coded "0" levels of EC_{iw} and SAR_{iw}, the RSC waters up to 2.0 $mmol_c$ L^{-1} increased K_s, thereafter it decreased with RSC from 4.0 to 7.35 $mmol_c$ L^{-1} (Fig.6). Higher K_s (0.208 cm h^{-1}) was resulted with similar RSC waters (7.35 $mmol_c$ L^{-1}) in the disturbed than that in the undisturbed (0.206 cm h^{-1}) soils at coded "0" levels of EC_{iw} and SAR_{iw} (i.e. EC_{iw} 4.0 dS m^{-1} and SAR_{iw} 18.0). The decrease in K_s was 0.003, 0.009, 0.041 and 0.07 cm h^{-1}; 0.003, 0.02, 0.05 and 0.076 cm h^{-1} with RSC 7.35 $mmol_c$ L^{-1} over RSC 0.64 $mmol_c$ L^{-1}, respectively, for the undisturbed and disturbed soils at coded "0" levels of EC_{iw} and SAR_{iw} (Table 6).

It is well documented that presence of salts in irrigation water tends to flocculate the soil particles while exchangeable Na tend to deflocculated, thereby reduced the K_s of the irrigated soils. High saline waters rarely produce dispersion or poor soil physical characteristics when used for irrigation. Despite the fact that most saline waters are very high in Na and relatively deficient in Ca^{+2}

and to a lesser degree Mg^{+2}, they almost always maintain a well flocculated soil conditions due to high electrolyte concentration. Data in Table 6 demonstrated that increase in K_s was even more with similar EC_{iw} at lower than that at higher SAR_{iw} and RSC levels. For instance, the K_s with EC_{iw} 7.35 dS m^{-1} was 0.354 and 0.369 cm h^{-1} at coded "-1.682 and –1" (i.e. SAR_{iw} 3.95 and RSC 0.65 $mmol_c$ L^{-1}; SAR_{iw} 9.65 and RSC 2.00 $mmol_c$ L^{-1}). Similarly it was 0.266 and 0.204 cm h^{-1} with similar EC_{iw} (7.35 dS m^{-1}) at coded "1 and 1.682" (SAR_{iw} 26.35 and RSC 6.0; SAR 32.04 and RSC 7.35 $mmol_c$ L^{-1}) levels of SAR_{iw} and RSC. Suarez and Lebron (1993) reported that at the same SAR_{iw}, the dispersion potential of low electrolyte water is greater than that for high electrolyte water. There was direct correlation between soil SAR and SAR_{iw} (Fig. 3), which resulted in deflocculating of soil and consequently K_s, was decreased. It might be possible that irrigation water having higher concentration of Na increased replacement of Ca^{+2} by Na on the exchange sites. The replacement of divalent (Ca^{+2}) ion by the higher hydrated size monovalent (Na) ion could not neutralize net negative charge on soil colloids, which caused dispersion. This dispersion decreased the porosity of soil and as a result hydraulic conductivity decreased. The results showed that the waters with higher SAR and RSC significantly reduced K_s of both the soil conditions. Depressive effect of high bicarbonate water on K_s has been reported in previously (Muhammed and Rauf, 1983; Oster and Schorer, 1979). Dispersion and/or particle translocation into pores are considered important factors affecting the hydraulic conductivity of salt-affected soils (Rengasamy *et al.*, 1984). According to U.S. Salinity Lab. Staff (1954), the K_s values less than 0.1 cm h^{-1} could create problem for leaching. In the present studies, all the five levels of SAR_{iw} and/or RSC have resulted more K_s than 0.1 cm h^{-1} at all the five coded levels of EC_{iw} and RSC; EC_{iw} and SAR_{iw}. The K_s started to decline beyond SAR_{iw} 9.65 and RSC 2.0 $mmol_c$ L^{-1} at given EC_{iw} and RSC; EC_{iw} and SAR_{iw}. Thus the SAR_{iw} up to 9.65 and RSC 2.0 $mmol_c$ L^{-1} were considered the safe levels for K_s of the clay loam soil under investigation.

Yields of crops: The yields obtained during the periods 1992-93, 1993-94 and 1994-95 for wheat and 1993 and 1994 for rice were pooled for statistical analysis and the average values are presented in Table 6. Compared with low levels of EC_{iw}, SAR_{iw} and RSC (i.e. 0.64 dS m^{-1}, 3.95 and 0.64 $mmol_c$ L^{-1}), higher levels of these three water quality parameters significantly decreased yields of both the crops. Grain yield of wheat increased up to EC_{iw} 4.0 dS m^{-1} at coded "-1.682, -1 and 0" levels of SAR_{iw} and RSC. The increase and/or decrease in yield with EC_{iw} has been depicted in Fig. 8 at coded "0" levels of SAR_{iw} and RSC. Thereafter, it decreased with further increase in EC_{iw} from 4.0 to 7.35 mmo_c L^{-1} for both the undisturbed and disturbed soils. The rate of increase in grain yield with EC_{iw} up to coded "0" levels was more in the disturbed than that for the undisturbed soil conditions. Moreover, higher grain yield was predicted with the same EC_{iw} from the disturbed than that in the undisturbed soil columns. The disturbed soil may have the advantage of good internal drainage than that of undisturbed (natural ones) soil where applied brackish water probably rapidly moved out of the root zone and thus resulted in comparatively low salinity and sodicity hazard. The saturated hydraulic conductivity data (Fig. 7) confirmed that disturbed soil columns exhibited more flux of water per unit time than that of undisturbed columns with similar EC_{iw} at given coded levels of SAR_{iw} and RSC. Contrary to this, yield increased with EC_{iw} only up to 2.0 dS m^{-1} at higher coded (i.e. 1 and 1.682) levels of SAR_{iw} and RSC, indicating that a water having EC >2 dS $^{-1}$ becomes injurious to yield particularly at high SAR_{iw} (26.35 and 32.04) and RSC (6.0 and 7.35 $mmol_c$ L^{-1}). An increase in wheat grain yield could be because of moderately salt tolerance nature of the crop (Maas and Holfman, 1977). Gupta and Yadav (1986) reported that wheat could be grown without any reduction in yield with EC_{iw} 5 dS m^{-1} and with 10-25% reduction up to EC_{iw} 10-12 dS m^{-1} in coarse textured soils for an average rainfall of the area (580 mm) after four years. This critical limit of EC_{iw} for the same crop was narrow, i.e. 2.7 dS m^{-1} for 10% reduction and 7.4 dS m^{-1} for 25 % reduction in yield of wheat on fine textured soils. Paddy yield decreased almost linearly in the case of undisturbed while increased for the disturbed soils with an increase in EC_{iw} up to 0.65 to 2.0 dS m^{-1} at coded "0" levels of SAR_{iw} and RSC. The rate of decrease in paddy yield was more with EC_{iw} in the undisturbed particularly at higher coded levels of SAR_{iw} and RSC than that in the disturbed soil conditions. For instance, the reduction in paddy yield with EC_{iw} 7.35 dS m^{-1} was 73.96 and 46.96 %, respectively, as compared to EC_{iw} 0.65 dS m^{-1} at coded "1.682" levels of SAR_{iw} and RSC (32.04 and 7.35 $mmol_c$ L^{-1}), indicating that high EC was more injurious to paddy yield. However, an increase in paddy yield with EC_{iw} up to 2.0 dS m^{-1} was noted at a given levels of SAR_{iw} and RSC. A decrease in paddy yield might be due to its sensitivity to water salinity. Ayres and Westcot (1985) reported a threshold value of EC_{iw} 2.0 dS m^{-1} for rice. The data (Table 6) depicted that high EC water was even more injurious to paddy yield at coded "1" (SAR_{iw} 26.35 and RSC 6.0 $mmol_c$ L^{-1}) and "1.682" (SAR_{iw} 32.04 and RSC 7.35 $mmol_c$ L^{-1}) than at coded "-1.682" (SAR_{iw} 3.95 and RSC 0.65 $mmol_c$ L^{-1}) and "-1" (SAR_{iw} 9.65 and RSC 2.0 $mmol_c$

L^{-1}) levels of SAR_{iw} and RSC. Reduction in paddy yield with EC_{iw} was also reported by Jamil (1972) and Girdhar (1988). Gupta and Yadav (1986) observed similar results and reported that paddy yield decreased by 50 % with EC_{iw} 5 dS m^{-1}.

Decrease in crops yield with high EC_{iw} might be due to osmotic effect of salts in irrigation water (Greenway and Munns, 1980), antagonistic/synergistic effect of Na, Ca^{+2}, Mg, CO_3, HCO_3, Cl and SO_4^{-2} ions (Staple and Toenniessen, 1984) or specific ion toxicity (Ayres and Westcot, 1985). Addition of salts in irrigation water continuously keeps changing osmotic potential of soil solutions. This fluctuation in osmotic potential might adversely influence the availability of water, which is largely a function of the difference between the osmotic potential of plant root cell and the sum of the osmotic potential of the soil solution (van Hoorn *et al.*, 1993). As a result of which plant cannot maintain turgor pressure (Arif, 1990; Wyn Jones, 1991), thus decreased crop yield.

It is evident (Fig. 8) that wheat yield increased with SAR_{iw} up to 9.65 in the undisturbed soil columns at coded "0" levels of EC_{iw} and RSC. Contrary to this, yield increased with SAR_{iw} up to 18.0 in the disturbed soil at given levels of EC_{iw} and RSC. The rate of yield reduction with higher SAR of irrigation water was more in the undisturbed than that in the disturbed soils. For instance, the reduction in wheat yield with SAR_{iw} (32.04) was 51.98 and 30.70 %, respectively, for the undisturbed and disturbed soils over SAR_{iw} 3.95. Data (Table 6) revealed that the effect of SAR_{iw} on yield was more pronounced at higher than that at lower coded levels of EC_{iw} and RSC with the same SAR of irrigation water. Similar trend in paddy yield was noted with changing levels of SAR_{iw} at given levels of EC_{iw} and RSC. The rice tolerated SAR_{iw} up to 26.35 and 18.0, respectively, at coded "-1.682 and –1" levels of EC_{iw} and RSC in the undisturbed and disturbed soil conditions. The effect of SAR_{iw} at given EC and RSC of waters was more pronounced at high levels than that at low levels on paddy yield. For instance, paddy yield was 31.85 and 27.11%, respectively, less with SAR_{iw} 32.04 over 3.95 under the disturbed and undisturbed conditions. It is interesting to note that the rate of decrease in paddy yield with SAR_{iw} up to coded "0" was more in disturbed than that in the undisturbed soils. Contrary to this, SAR_{iw} from coded "1 and 1.682" depressed more paddy yield in the undisturbed that that in the disturbed soil columns. Reduction in paddy yield with sodic water was reported by Haq (1979) and Hussain *et al.* (1993). They reported SAR_{iw} threshold of 10 for paddy yield. In lysimeter study on loamy clay, Jamil (1972) reported that SAR_{iw} of 16 was injurious to paddy yield and that with SAR_{iw} 20 did not prove useful even if amended with gypsum. The adverse effect of SAR_{iw} was even more severe on crops yield at high water salinity and RSC than that at low levels in the present studies. It might be due to poor structure and/or nutritional imbalance. Higher levels of SAR_{iw} increased exchangeable sodium percentage (ESP) and pH of the saturated soil paste (pH_s) of soils and this situation probably resulted in nutritional imbalance and consequently decrease the crop yields (Khandewal and Lal, 1991). A decrease in yield may also be due to accumulation of exchangeable Na (Pearson, 1960), which may cause mechanical impedance to root penetration to poor soil structure prevailing in the root zone or sodium may directly toxic to wheat plant (Ayres and Westcot, 1985).

Like EC_{iw} and SAR_{iw}, yield of wheat increased with RSC waters up to 4.0 $mmol_c$ L^{-1} at coded "0" levels of EC_{iw} and SAR_{iw} (Fig. 8) under both the soil conditions. Thereafter, yield started declining with further increasing RSC waters. The rater of yield reduction was 58.02 and 36.05% in the disturbed and undisturbed soils with high RSC waters (i.e. 7.37 $mmol_c$ L^{-1}) over low RSC waters (0.65 $mmol_c$ L^{-1}). It was further noted that at higher coded "1 and 1.682" levels of EC_{iw} and SAR_{iw}, increase in yield was up to RSC 2.0 $mmol_c$ L^{-1} for the disturbed soil columns. Paddy yield increase with RSC waters up to 2.0 and 4.0 $mmol_c$ L^{-1}, respectively, in the undisturbed and disturbed soil conditions. The rate of reduction of paddy yield with high RSC waters (7.35 $mmol_c$ L^{-1}) was more in the undisturbed (37.43 %) than that in the disturbed (20.45 %) over the low level of RSC waters (0.65 $mmol_c$ L^{-1}) at coded "0" levels of EC_{iw} and SAR_{iw}. Similar trend in increasing and/or decreasing in paddy yield with changing levels of RSC was registered at coded "-1.682, -1, 1 and 1.682" levels of EC_{iw} and SAR_{iw} (Table 6). Low yield of crops with high RSC waters at given EC_{iw} and SAR_{iw} may be due to toxic effect of bicarbonate ions (Muhammed *et al.*, 1977) and/or induced nutritional imbalance. The precipitation of HCO_3 in soil as $CaCO_3$ may also result in the accumulation of Na in soil (Bower *et al.*, 1965). Excess of bicarbonate ions may also have adverse effect on nutrition of plants and tend to cause chlorosis (Miller, 1959). In India, however, water having SAR_{adj} up to 20 and RSC up to 10 $mmol_c$ L^{-1} have been used successfully on sandy loam soils under high rainfall (650-700 mm $annum^{-1}$) conditions without reduction in economic yield of wheat (Gupta, 1980).

References

Arif, H., 1990. Water relations of salt stressed wheat. Ph.D. Thesis, Univ. of Wales, Bangor, UK.

Ayres, R.S. and D.W. Westcot, 1985. Water quality for agriculture. FAO Irrigation and Drainage. Paper 29, Rome, Italy.

Bajwa, M.S. and A.S. Josan, 1989. Prediction of sustained sodic irrigation water on soil and crop yields in rice-wheat rotation. Agric Water Management, 16: 53-61.

Bajwa, M.S., G.S. Hira and S.T. Singh, 1983. Effect of sodium and bicarbonate irrigation waters on sodium accumulation and on maize and wheat yields in northern India. Irrigation Sci., 4: 191-199.

Bhatti, H.M., B. Ahmad, M. Aslam and R. Ahmad, 1981. Irrigation water quality and soil salinity. In: Proc. Workshop on Membrane biophysics and salt tolerance in plants, Faisalabad, Pakistan, pp: 152-163.

Blake, G.R. and K.H. Hartge, 1986. Bulk density. In: A. Klute (Ed.) Methods of soil analysis. Part I. 2nd edition. Agronomy No. 9, SSSA, Madison, WI, USA, pp: 363-373.

Bower, C.A., L.V. Wilcox, G.W. Akin and M.G. Keyes, 1965. An index of tendency of CaCO3 to precipitation from irrigation water. Soil Sci. Soc. Am. Proc., 29: 91-92.

Cochran, W.G. and G. Cox, 1957. Some methods for the study of response surfaces. In: Experimental designs. 2nd edition. John Wiley, New York, USA, pp: 335-357.

Costa, J.L., L. Prunty, B.R. Montgomery, J.L. Richardson and R.S. Alessi, 1991. Water quality effect on the soils and alfalfa. Soil Sci. Soc. Am. J., 55: 203-209.

Francois, L.E., E.V. Maas, T.J. Donovan and V.L. Youngs, 1986. Effect of salinity on grain yield and quality, vegetative growth and germination of semi-dwarf and durum wheat. Agron. J., 78: 1053-1058.

Girdhar, I.K., 1988. Effect of saline irrigation water on the growth, yield and chemical composition of rice crop grown in a saline soil. J. Indian Soc. Soil Sci., 11: 1-4.

Gupta, I.C. and J.S.P. Yadav, 1986. Crop tolerance to saline irrigation water. J. Indian Soc. Soil Sci., 34: 79-86.

Greenway, H. and R. Munns, 1980. Mechanisms of salt tolerance in non-halophytes. Ann. Rev. Plant Physiol., 31: 149-190.

Gupta, I.C., 1980. The effect of irrigation with high sodium waters on soil properties and the growth of wheat. In: Proc. Int. Symp. on Salt-Affected Soils. Feb. 8-16, 1980. Central Soil Salinity Research Inst., Karnal, India, pp: 382-388.

Hamdy, A., S.A. Dayem and M.A. Zeid, 1993. Saline water management for optimum crop production. Agric Water Management, 24: 189-203.

Haq, A., 1979. Management of saline sodic water for rice production with chemical amendments. M.Sc. (Hons.) Agri. Thesis. Dept. Soil Sci., Univ. Agric., Faisalabad, Pakistan.

Hausenbuiller, R.L., M.A. Haque and A. Wahhab, 1960. Some effects of irrigation waters of differing quality on soil properties. Soil Sci., 90: 357-364.

Hussain, T., G. Jillani, A. Haq and R. Ahmad, 1993. Management of brackish irrigation water with chemical amendments in conjuction with rice culture. Pak. J. Soil Sci., 8: 42-47.

Jamil, M., 1972. Yield and composition of rice as affected by saline irrigation water of different EC and SAR values applied at various growth stages. M.Sc. Thesis, Dept. Soil Sci., Univ. Agric., Faisalabad, Pakistan.

Jury, W.A., W.R. Gardner and W.H. Gardner, 1991. Soil Physics. 5th edition. John Wiley and Sons, Inc. New York, USA, pp: 80-82.

Khandelwal, R.B. and P. Lal, 1991. Effect of salinity, sodicity and boron of irrigation water on the properties of different soils and yield of wheat. J. Indian Soc. Soil Sci., 39: 537-541.

Maas, E.V. and G.F. Holfman, 1977. Crop salt tolerance-Current assessment. J. Irrig. Drain. Div. Am. Soc. Civ. Engg., 103: 115-134.

Malik, D.M., M.A. Khan and B. Ahmad, 1984. Gypsum and fertilizer use efficiency of crops under different irrigation system in Punjab. Presented in Seminar on Optimising Crop Production Through Management of Soil Resources. May 12-13, Lahore, Pakistan, pp: 27.

Miller, G.W., 1959. Metabolic process in higher plants in relation to chlorosis and bicarbonate ions. Program and Abstracts of Paper for 1959 Western Soc. Soil Sci. ARS-USDA, Fort Collins, Colorado, USA.

Minhas, P.S. and R.K. Gupta, 1993. Using high salinity and SAR waters for crop production-Some Indian experiences. In: Leith, H. and Al-Masoom (Eds.). Towards the rational use of high salinity tolerant plants (vol.2.). Kluwer Academic Publishers, Amsterdam, The Netherlands. pp: 423-432.

Montgomery, D.S., 1997. Design and analysis of experiments. 4th Ed. John Wiley and Sons, Inc., NY, USA.

Muhammed, S. and A. Rauf., 1983. Management of high bicarbonate irrigation water. Final Report PL-480 Project No. PK-ARS 22. Dept. Soil Sci., Univ. Agric., Faisalabad, Pakistan.

Muhammed, S., M. Ahmad and A. Rauf, 1977. Effect of saline-sodic waters on soil properties and plant growth. In: Proc. Exxon Seminar on Water Management for Agriculture. Nov. 15-17, 1975, Lahore, Pakistan, pp: 293-305.

Oster, J.D. and F.W. Schorer, 1979. Infiltration as influenced by irrigation water quality. Soil Sci. Soc. Am. J., 43: 444-447.

Pearson, G.A., 1960. Tolerance of crops to exchangeable sodium. USDA. Agri. Inf. Bull. No. 216, pp: 1-4.

Quirk, J.P. and R.K. Schofield, 1955. The effect of electrolyte concentration on soil permeability. J. Soil Sci., 6: 163-178.

Rashid, M., 1983. Response of rice to five levels of salinity, sodicity, Zn and Cu in a wetland soil. Ph.D. Thesis, Univ. Philippine, Los Banos, Philippines.

Rengasamy, P., R.S.B. Greeve, G.W. Ford and A.H. Mehanni, 1984. Identification of dispersive behaviour and the management of red-brown earths. Aust. J. Soil Res., 22: 413-431.

Saleem, Z., M. Rashid and M. Ishaq, 1993. Growing crops with brackish water without affecting the soil health. Pak. J. Soil Sci., 9: 41-46.

Shainberg, I. and J. Letey, 1983. Response of soils to sodic and saline conditions. Hilgardia, 25: 1-57.

Singh, R.B., P.S. Minhas, C.P.S. Chauhan and R.K. Gupta, 1992. Effect of high salinity and SAR waters on salinization, sodication and yields of pearl-millet and wheat. Agric. Water Management, 21: 93-105.

Staple, R.C. and G.H. Toenniessen (Eds.), 1984. Salinity tolerance in plants: Strategies for crop improvement. Wiley Interscience Series of Texts and Monographs, London, UK.

Suarez, D. L. and I. Lebron, 1993.Water quality criteria for irrigation with high saline water. In: Leith, H. and A. Al. Masoom (Eds.). Towards the rational use of high salinity tolerant plants (Vol. 1). Kluwer Academic Publishers, The Netherlands, pp: 389-397.

U.S. Salinity Laboratory Staff, 1954. Diagnosis and improvement of saline and alkali soils. USDA Hand Book 60. Washington, DC, USA.

Van Hoorn, J.W., N. Ketergi. A. Hamdy and M. Mastrorilli, 1993. Effect of saline water on soil salinity and on water stress, growth and yield of wheat and potatoes. Agric. Water Management, 23: 247-265.

Waldron, L.J., J.L. McMurdie and J.A. Vomocil, 1979. Hydraulic conductivity of an isotropic ally compressed soil. Soil Sci. Soc. Am. J. , 34: 393-396.

Wyn Jones, R.G., 1991. Salt tolerance. In: Jonston, C.B. (Ed.). Physiological processes limiting plant productivity. Butter worth, London, U.K., pp: 271-292.

Yousaf, M., O. Ali. and J.D. Rhoades, 1987. Clay dispersion and hydraulic conductivity of some salt-affected arid land soils. Soil Sci. Soc. Am. J., 51: 905-907.

Zartman, R.E. and M. Gichuru, 1984. Saline irrigation water: Effects on soil chemical and physical properties. Soil Sci., 138: 417-422.