

# Brackish Water for Irrigation: I. Effects on Yield of Wheat and Sorghum in Wheat-Sorghum Crop Rotation and Properties of the Rasulpur Soil Series

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## ABSTRACT

A pot experiment was carried out for four and a half years on a typical Haplocalcids to investigate the prediction of effect of irrigation water varying in EC, SAR and RSC on chemical ( $EC_e$  and SAR), physical (bulk density and saturated hydraulic conductivity) and yields of crops under wheat-sorghum rotation. Twenty undisturbed (structured) soil columns were collected in metallic cylinders (76-cm long and 30-cm diameter). The same number of packed columns in similar cylinders was also prepared. Wheat cv. Fasislabad-85 and sorghum cv. JS-88 were grown in these soil columns in their respective seasons during 1992-95. The columns were irrigated with five levels, each of EC, SAR and RSC @ 0.65, 2.0, 4.0, 6.0, 7.35  $dS\ m^{-1}$ ; 3.95, 9.65, 18.0, 26.35 and 32.04 and 0.65, 2.0, 4.0, 6.0, 7.35  $mmol_c\ L^{-1}$ , respectively. Grain yield of wheat increased up to  $EC_{iw}$  4.0  $dS\ m^{-1}$ ,  $SAR_{iw}$  9.65 and RSC 4.0  $mmol_c\ L^{-1}$  at coded “0” levels of  $SAR_{iw}$  and RSC;  $EC_{iw}$  and RSC;  $EC_{iw}$  and  $SAR_{iw}$ , respectively for the undisturbed and disturbed soils. The  $SAR_{iw}$  up to 18.0 did not affect the yield up to coded “-1” levels of  $EC_{iw}$  and RSC under both the conditions. Sorghum dry matter yield decreased linearly with  $EC_{iw}$  and  $SAR_{iw}$  at given coded levels of  $SAR_{iw}$  and RSC;  $EC_{iw}$  and RSC under undisturbed and disturbed soils. Contrary to  $EC_{iw}$  and  $SAR_{iw}$ , sorghum yield increased with RSC up to 2.0  $mmol_c\ L^{-1}$  at given coded levels of  $EC_{iw}$  and  $SAR_{iw}$  for both the conditions. Higher wheat and sorghum yields were predicted from the disturbed than that from the undisturbed soils with the same levels of  $EC_{iw}$ ,  $SAR_{iw}$  and/or RSC. Soil  $EC_e$  and SAR increased with an increase in  $EC_{iw}$ ,  $SAR_{iw}$  and RSC (except  $EC_e$ , which decreased with an increase in RSC of waters). However, the rate of increase in  $EC_e$  and SAR was more with high  $EC_{iw}$  and  $SAR_{iw}$ , particularly at higher coded levels of  $SAR_{iw}$  and RSC;  $EC_{iw}$  and RSC. It was noted that whole of the soil profile attained  $EC_e < 4.0\ dS\ m^{-1}$  and  $SAR > 13.3$ , which are the upper limits for saline-sodic and sodic soils in undisturbed and disturbed soils with  $EC_{iw}$  and  $SAR_{iw}$  at coded “0” levels of  $SAR_{iw}$  and RSC;  $EC_{iw}$  and RSC. Saturated hydraulic conductivity ( $K_s$ ) increased from 0.19 to 0.46; 0.20 to 0.56  $cm\ h^{-1}$  with  $EC_{iw}$  from 0.64 to 7.35  $dS\ m^{-1}$ , while decreased from 0.41 to 0.30 and 0.42 to 0.30  $cm\ h^{-1}$ ; 0.37 to 0.29 and 0.42 to 0.32  $cm\ h^{-1}$  with  $SAR_{iw}$  and RSC, respectively for undisturbed and disturbed soils. The decrease in bulk density was 7.87 and 6.39%, respectively with  $EC_{iw}$  7.35  $dS\ m^{-1}$  over  $EC_{iw}$  0.64  $dS\ m^{-1}$  at coded “0” levels of  $SAR_{iw}$  and RSC. The increase in bulk density was more (14.75%) in the undisturbed than disturbed columns (10.32%) with  $SAR_{iw}$  32.04 over  $SAR_{iw}$  3.95. Similar trend in bulk density with RSC was noted in our studies.

**Key Words:** Brackish water; Irrigation; Wheat; Sorghum

## INTRODUCTION

In arid and semi-arid regions, agriculture depends primarily on artificial irrigation for which farmers are forced to use poor quality ground water. Salt contents of these waters, amount and distribution of rainfall, cropping patterns and the irrigation practices followed usually govern the accumulation of salts in soil profiles and consequent reduction in crop yields (Chang, 1961; Ali *et al.*, 1981). Adsorption of dispersive cations such as sodium with high SAR and/or RSC waters affects soil physical properties such as structural stability, hydraulic conductivity and infiltration rate which consequently affect crop production (Zartman & Gichuru, 1984; Singh *et al.*, 1992; Ghafoor *et al.*, 1997). Soil SAR could increase in direct proportion to SAR of

irrigation water (Haider *et al.*, 1975). The  $EC_e$  and  $pH_s$  also increased relatively at lower rate. A permeability problem can occur if irrigation water does not enter into soil rapidly during its application. According to U.S. Salinity Lab. Staff (1954), if the hydraulic conductivity of surface soils is less than 0.1  $cm\ h^{-1}$ , leaching and irrigation may cause serious problems for sustainable crop growth.

In the past, there have been efforts to conduct laboratory experiments using brackish water on disturbed soil columns. However, information regarding undisturbed soil columns is limited. Moreover, only small numbers of combinations of  $EC_{iw}$ ,  $SAR_{iw}$  and RSC have been investigated. The present experiment was thus carried out under both the disturbed and undisturbed conditions to investigate the prediction of  $EC_{iw}$ ,  $SAR_{iw}$  and/or RSC

effects on salinization, sodication, bulk density, saturated hydraulic conductivity and yields of wheat and sorghum crops in wheat-sorghum crop rotation.

## MATERIALS AND METHODS

The present research work was conducted in a net-house, University of Agriculture, Faisalabad during 1991-95. The Rasulpur soil series (Coarse loamy, mixed, calcareous, hyperthermic Typic Haplocalcids) was sampled during September-October 1991 and this soil series had: sand 71.00%; silt 21.5%; clay 7.50% (sandy loam); pH<sub>s</sub> 7.65; EC<sub>e</sub> 2.4 dS m<sup>-1</sup>; CO<sub>3</sub> 3.00 mmol L<sup>-1</sup>; HCO<sub>3</sub> 7.5 mmol L<sup>-1</sup>; Cl 5.20 mmol L<sup>-1</sup>; SO<sub>4</sub> 8.30 mmol L<sup>-1</sup>; Ca + Mg 19.65 mmol L<sup>-1</sup>; Na 4.28 mmol L<sup>-1</sup>; SAR 1.37; CaCO<sub>3</sub> 3.42%; CEC 6.63 mmol<sub>c</sub> kg<sup>-1</sup>.

**Soil sampling and column preparation.** A 0.5-hectare of normal soil was delineated near Khurrianwala town in the district Faisalabad. Metallic cylinders (76-cm long & 30-cm diameter) were used to collect undisturbed soil columns. A piece of wood (35-cm x 35-cm & 8-cm thick) having circular groove that fitted snugly onto the upper edge of a cylinder was placed on the top. Cylinders were pushed vertically into moist soil (at 50% of time field capacity) by dropping a 20-kg weight on grooved wooden plank, tied with a strong string and controlled through a pulley, attached to a tripod. When cylinder was inserted up to 68-cm depth, soil around the cylinder was excavated up to 80-cm and soil column was 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 to collect 20 soil columns. 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 eluviation 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 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, passed through a 2 mm sieve and thoroughly mixed soil of the Rasulpur soil series. The soil filling was accomplished by first packing 1/3<sup>rd</sup> of the cylinder, by adding small increments through a long neck plastic funnel, 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<sub>iw</sub>, SAR<sub>iw</sub> and RSC levels were selected following Central Composite Rotatable

Second Order Design (Cochran & 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<sub>iw</sub> (X<sub>1</sub>), SAR<sub>iw</sub> (X<sub>2</sub>) and RSC (X<sub>3</sub>) were 0.65, 2.00, 4.00, 6.00 and 7.35 dS m<sup>-1</sup>, 3.95, 9.65, 18.00, 26.35 and 32.04 and 0.65, 2.00, 4.00, 6.00 and 7.35 mmol<sub>c</sub> L<sup>-1</sup>, 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<sub>iw</sub>, SAR<sub>iw</sub> and RSC is given as below:

$$x_1 = \frac{(X_1 - 4.0)}{2.0} \quad (1)$$

$$x_2 = \frac{(X_2 - 18.00)}{8.35} \quad (2)$$

$$x_3 = \frac{(X_3 - 4.0)}{2.0} \quad (3)$$

where  $x_1$ ,  $x_2$  and  $x_3$  are the coded scales for EC<sub>iw</sub>, SAR<sub>iw</sub> and RSC, respectively; X<sub>1</sub> (EC<sub>iw</sub>), X<sub>2</sub> (SAR<sub>iw</sub>) and X<sub>3</sub> (RSC).

The design matrix and treatment combinations investigated are presented in Table I. To verify the validity of model predictions with factors of Table I, five extra treatments (Table II) for wheat was run in the disturbed columns of the Rasulpur soil series. The procedure for preparation of disturbed soil columns was same as mentioned above. After getting near steady state, assessed on the basis of EC<sub>dw</sub>, wheat was grown in these extra lysimeters. These five treatments were selected without any consideration of the 20 treatments (Table I).

The Rotatable Central Composite Design (Cochran and Cox, 1957) has been followed in the present investigations. Detailed of the statistical design has been discussed earlier (Abid *et al.*, 2002). The underlying model is a second order polynomial of the form:

$$\hat{y} = \beta_0 + \sum_{i=1}^3 \beta_i x_i + \sum_{i=1}^3 \beta_{ii} x_i^2 + \sum_{i=1}^3 \sum_{j=1, j \neq i}^3 \beta_{ij} x_i x_j \quad (4)$$

Three factor CCD comprised of the following twenty points:

- Eight factorial points of 2<sup>3</sup> factorial experiments (±1, ±0, ±0);
- Six axial points, two on each axis (±1.682, 0, 0), (0, ±1.682, 0), (0, 0, ±1.682)
- Six central points (0, 0, 0)

**Brackish water preparation, application and growing of crops.** The required EC<sub>iw</sub>, SAR<sub>iw</sub> and RSC (Table I) were prepared by dissolving NaCl, NaHCO<sub>3</sub>, Na<sub>2</sub>SO<sub>4</sub>, CaCl<sub>2</sub>·2H<sub>2</sub>O and MgSO<sub>4</sub>·7H<sub>2</sub>O salts in canal water as explained by Ghafoor *et al.* (1988). Synthetic brackish waters having different solute composition were applied regularly to respective soil columns. After every irrigation, the drainage water from each lysimeter was collected, measured but were analyzed occasionally for cations and anions to monitor the progress towards steady-state. The chemical analysis of leachate and total amount of water

(brackish water + rainfall water) added to columns are presented at Tables III and IV, respectively.

After achieving a near steady-state with brackish waters (Table I), wheat-sorghum-wheat-sorghum-wheat cropping pattern was practiced in both the undisturbed and disturbed soils. Fifteen seeds of wheat variety Faisalabad-85 were sown on December 5, 1992; October 15, 1993; December 10, 1994, respectively as the first, second and third year crops in the columns. The N, P and K were applied @ 200, 150 and 100 kg ha<sup>-1</sup>, respectively as urea, single superphosphate (SSP) and sulphate of potash. The seedlings were thinned to three per pot, 10 days after germination in all the columns. During growth period, crop was sprayed with Novacron to protect it from insect attack. Brackish waters (Table I) were applied according to crop requirement. The crop was grown up to maturity and yield of three plants was recorded.

Ten seeds of sorghum variety JS-88 were sown after the harvest of wheat on May 25, 1993 (1<sup>st</sup> crop) and on May 10, 1995 (2<sup>nd</sup> crop) in all the columns. The N, P and K were applied @ 80, 50 and 30 kg ha<sup>-1</sup> as urea, SSP and K<sub>2</sub>SO<sub>4</sub>. Fifteen days after germination, plant stand was thinned out to two per column. The crop was grown up to 44 days with designed waters (Table I) and dry matter yield was recorded.

After termination of the experiments, saturated hydraulic conductivity (K<sub>s</sub>) was determined by falling head method (Jury *et al.*, 1991) and bulk density by core method (Blake & Hartge, 1986). The soil samples from 0-15, 15-30, 30-45 and 45-60 cm, were taken from all the columns. Soil samples were air-dried, ground to pass through a 2-mm sieve and analysed for EC<sub>e</sub>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, Na<sup>+</sup>, CO<sub>3</sub><sup>2-</sup>, HCO<sub>3</sub><sup>-</sup>, Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup> and SAR following methods described by the U.S. Salinity Lab. Staff (1954).

**Data analysis.** The data analysis was followed as described by Cochran and Cox (1957). During the data analysis and plotting graph, negative signs of the predicted soil characteristics and crop yield with respect to EC<sub>iw</sub>, SAR<sub>iw</sub> and RSC were observed when original form of the model equation was followed (Equation 4). However, this was overcome by taking log of output. The log and exponential forms of the model are:

$$\log \hat{y} = \beta_0 + \sum_{i=1}^3 \beta_i x_i + \sum_{i=1}^3 \beta_{ii} x_i^2 + \sum_{i=1}^3 \sum_{j=1}^3 \beta_{ij} x_i x_j \quad (5)$$

$$\hat{y} = e^{\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{33} x_3^2 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3} \quad (6)$$

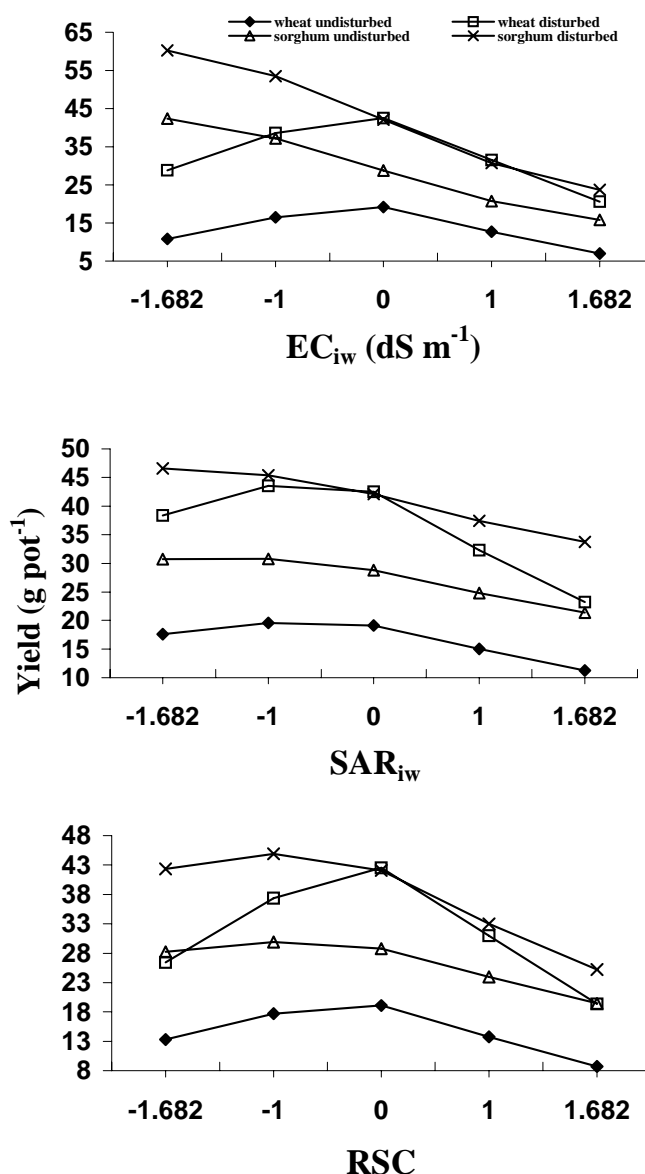
The coefficients were determined using multiple regression analyses. This was accomplished by using Minitab software (Minitab, 1989). To draw quadratic graphs for all dependent variables, following the general form of the model:

$$\log \hat{y}_i = \beta_0 + \beta_i x_i + \beta_{ii} x_i^2 \quad (7)$$

## RESULTS AND DISCUSSION

The range between the observed and model predicted grain yield of wheat (Table V) was 1.27 to 2.97 g for the disturbed soil columns. Owing to small differences between observed and predicted values, model fitted the data adequately. In a pot study, Rashid (1983) reported 1.0 to 5.0 g per pot difference between observed and model predicted values for paddy yield. It was further reported that model fitted the data adequately with this range of difference between observed and predicted values.

**Fig. 1. Effects of brackish water on yield of designed crop:**



**Table I. Design matrix and treatment combinations used during experiments**

Coded scale			Original level		
x <sub>1</sub>	x <sub>2</sub>	x <sub>3</sub>	EC <sub>iw</sub> (dS m <sup>-1</sup> )	SAR <sub>iw</sub> (mmol L <sup>-1</sup> ) <sup>1/2</sup>	RSC (mmol <sub>c</sub> L <sup>-1</sup> )
-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
0	0	0	4.00	18.00	4.00

**Table II. Five extra treatment combinations run to test the model validity**

Coded scale			Original level		
x <sub>1</sub>	x <sub>2</sub>	x <sub>3</sub>	EC <sub>iw</sub> (dS m <sup>-1</sup> )	SAR <sub>iw</sub> (mmol L <sup>-1</sup> ) <sup>1/2</sup>	RSC (mmol <sub>c</sub> L <sup>-1</sup> )
-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

**Table III. The EC and SAR of drainage/leachate water at steady-state soil conditions**

Designed brackish water			Undisturbed		Disturbed	
EC <sub>iw</sub>	SAR <sub>iw</sub>	RSC	EC <sub>dw</sub>	SAR <sub>dw</sub>	EC <sub>iw</sub>	SAR <sub>dw</sub>
2.00	9.65	2.00	1.95	8.0	2.00	8.1
6.00	9.65	2.00	4.45	17.2	4.23	16.3
2.00	26.35	2.00	2.70	10.1	2.71	12.3
6.00	26.35	2.00	6.39	26.4	6.12	25.2
2.00	9.65	6.00	1.99	12.1	1.82	12.1
6.00	9.65	6.00	5.42	17.0	5.51	15.5
2.00	26.35	6.00	2.70	11.8	2.67	16.0
6.00	26.35	6.00	6.58	22.8	5.91	21.4
0.65	18.00	4.00	1.09	5.0	2.30	17.2
7.35	18.00	4.00	6.58	26.9	6.63	24.8
4.00	3.95	4.00	5.39	2.9	5.72	2.7
4.00	32.04	4.00	4.58	9.4	4.28	18.2
4.00	18.00	0.65	4.00	13.3	3.89	13.5
4.00	18.00	7.35	3.84	18.3	3.75	15.9
4.00	18.00	4.00	4.22	15.8	3.92	17.9
4.00	18.00	4.00	4.22	19.4	4.08	18.8
4.00	18.00	4.00	4.21	14.2	3.95	18.0
4.00	18.00	4.00	3.78	14.3	3.65	17.0
4.00	18.00	4.00	3.93	17.6	3.88	22.0
4.00	18.00	4.00	4.12	18.5	4.05	18.7

EC<sub>iw</sub> and EC<sub>dw</sub> = dS m<sup>-1</sup>; SAR<sub>iw</sub> and SAR<sub>dw</sub> = (mmol L<sup>-1</sup>)<sup>1/2</sup>; RSC = mmol<sub>c</sub> L<sup>-1</sup>

**Crop yield.** Crop yields declined with an increase in EC<sub>iw</sub>, SAR<sub>iw</sub> and/or RSC. This has been shown through the best fit of linear, quadratic and interactive relationships between grain and dry matter yields of wheat and sorghum and EC<sub>iw</sub>, SAR<sub>iw</sub> and RSC in Table VI. The coefficients of determination (R<sup>2</sup>) were high and the predicted values were close to the observed ones. At given SAR<sub>iw</sub> and RSC levels, grain yield of wheat increased with an increase in EC<sub>iw</sub> up to 4.0 dS m<sup>-1</sup> under both the soil conditions. Thereafter, yield decreased with further increase in EC<sub>iw</sub> from 4.0 to 7.35 dS m<sup>-1</sup> at coded “0” levels of SAR<sub>iw</sub> and RSC (Fig. 1). It is evident that reduction in grain yield was more with EC<sub>iw</sub> at coded “0, 1 and 1.682” levels of SAR<sub>iw</sub> and RSC than that with EC<sub>iw</sub> at coded “-1.682 and -1” levels of SAR<sub>iw</sub> and RSC (Table VI). For instance, grain yield of wheat was 5.06, 7.20, 6.96, 3.49 and 1.49; 12.37, 19.48, 20.54, 10.47 and 4.36 g pot<sup>-1</sup>, respectively for the undisturbed and disturbed soils with EC<sub>iw</sub> 7.35 dS m<sup>-1</sup> at coded “-1.682, -1, 0, 1 and 1.682” levels of SAR<sub>iw</sub> and RSC. The rate of decrease in yield with high EC<sub>iw</sub> (7.35 dS m<sup>-1</sup>) at coded “0” levels of SAR<sub>iw</sub> and RSC (SAR<sub>iw</sub> 18.0 and RSC 4.0 mmol<sub>c</sub> L<sup>-1</sup>) was more (35.67%) in undisturbed than that in disturbed (28.82%) columns over EC<sub>iw</sub> 0.64 dS m<sup>-1</sup>. An increase in wheat yield with EC<sub>iw</sub> up to 4.0 dS m<sup>-1</sup> could be because of moderately salt tolerance nature of crop (Maas & Holfman, 1977). Sorghum dry matter yield decreased linearly with an increase in EC<sub>iw</sub> at coded “0” levels of SAR<sub>iw</sub> and RSC (Fig.1). This indicated that sorghum fodder yield was more sensitive to EC<sub>iw</sub> than that of wheat grain at given levels of SAR<sub>iw</sub> and RSC. Similarly, EC<sub>iw</sub> at coded “1 and 1.682” levels of SAR<sub>iw</sub> and RSC depressed dry matter yield of sorghum more than that at coded “-1.682 and -1 and 0” levels of SAR<sub>iw</sub> and RSC (Table VI).

Crop yields also decreased with an increase in SAR<sub>iw</sub> at given levels of EC<sub>iw</sub> and RSC in both the undisturbed and disturbed soils (Fig. 1). The grain yield of wheat increased up to SAR<sub>iw</sub> of 18.0 at coded “-1.682 and -1” levels of EC<sub>iw</sub> and RSC. At coded “0, 1 and 1.682” levels of EC<sub>iw</sub> and RSC, yield of wheat increased up to SAR<sub>iw</sub> 9.65, indicating that a water having SAR<sub>iw</sub> > 9.65 will be injurious to wheat grain yield at high EC<sub>iw</sub> and RSC levels (Table VI). The rate of increase in yield with SAR<sub>iw</sub> 18.0 over SAR<sub>iw</sub> 3.95 was more in undisturbed than that in disturbed columns at coded “0” levels of EC<sub>iw</sub> and RSC. Linear decrease in sorghum dry matter yield was recorded for both the soil conditions with an increase in SAR<sub>iw</sub> at all the coded levels of EC<sub>iw</sub> and RSC (Fig.1 & Table VI). The adverse effect of SAR<sub>iw</sub> was even more severe on crops yield at high water EC and RSC than that at low levels. It might be due to poor structure and/or nutritional imbalance (Khandewal & Lal, 1991). Higher levels of SAR<sub>iw</sub> increased exchangeable sodium percentage (ESP) and pH of the saturated soil paste (pH<sub>s</sub>) and this situation probably resulted in nutritional imbalance and consequently decrease the crop yields (Khandewal & 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 into poor structured soil prevailing in the root zone or sodium may directly become toxic to wheat plant (Ayres & Westcot, 1985).

At given  $EC_{iw}$  and  $SAR_{iw}$ , high RSC waters depressed the yield of crops. Grain yield increased with RSC waters up to 4.0 mmol<sub>c</sub> L<sup>-1</sup>, thereafter decreased with further increase in RSC at coded "0" levels of  $EC_{iw}$  and  $SAR_{iw}$  (Fig.1) under both undisturbed and disturbed conditions. However, the increase in wheat grain yield with RSC 4.0 mmol<sub>c</sub> L<sup>-1</sup> was more in the disturbed than that in undisturbed soil columns. It is interesting to note that at coded "1.682" levels of  $EC_{iw}$  and  $SAR_{iw}$  ( $EC_{iw}$  7.35 dS m<sup>-1</sup> and  $SAR_{iw}$  32.04), the yield increased up to RSC 2.0 mmol<sub>c</sub> L<sup>-1</sup> in undisturbed soil. The rate of decrease in grain yield with high RSC waters was more in undisturbed than that in disturbed soil at coded "0 and 1.682" levels of  $EC_{iw}$  and  $SAR_{iw}$ , respectively (Table VI). Contrary to wheat yield, sorghum dry matter yield increased up to RSC 2.0 mmol<sub>c</sub> L<sup>-1</sup>

<sup>1</sup> at all the designed coded levels of  $EC_{iw}$  and  $SAR_{iw}$  (Fig. 1 & Table VI). Thereafter, it decreased almost linearly with an increase in RSC from 4.0 to 7.35 mmol<sub>c</sub> L<sup>-1</sup> at coded "-1.682, -1, 0, 1 and 1.682" levels of  $EC_{iw}$  and  $SAR_{iw}$ . More dry matter yield was recorded with similar RSC of waters from disturbed than that from undisturbed soil at coded "0" levels of  $EC_{iw}$  and  $SAR_{iw}$  (Fig.1).

In general, the plots were parabolic for the effect of  $EC_{iw}$ ,  $SAR_{iw}$  and/or RSC on wheat yield both in undisturbed and disturbed soils. This shape of graphs reflects favorable effects of  $EC_{iw}$ ,  $SAR_{iw}$  and/or RSC at low levels up to coded value of zero, beyond which adverse effects dominated and rate of which differed with soil conditions. The reduction in yield of crops at higher levels of these water quality parameters might be due to osmotic effects of salts in irrigation water (Greenway & Munns, 1980), antagonistic/synergistic effects of Na<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, CO<sub>3</sub><sup>2-</sup>, HCO<sub>3</sub><sup>-</sup>, Cl<sup>-</sup> and SO<sub>4</sub><sup>2-</sup> (Staple & Toennissen, 1984) or specific ion toxicity (Ayres & Westcot, 1985). Since salts

**Table IV. Average amount of irrigation, rainfall and temperature values during different crop growth periods (1991-1995)**

Determinant	Steady-state		Wheat (December-April)		Sorghum (May-July)		Fallow (Aug-Nov.)	
	Undisturbed	Disturbed	Undisturbed	Disturbed	Undisturbed	Disturbed	Undisturbed	Disturbed
Brackish water irrigation (mm)	1132	1217	764	821	311	354	-	-
Rainfall (mm)	-	-	252	252	276	276	276	276
Total water input (mm)	1132	1217	1016	1073	587	630	276	276
Temperature (°C)								
Minimum		7		5		26		13
Maximum		41		34		43		38

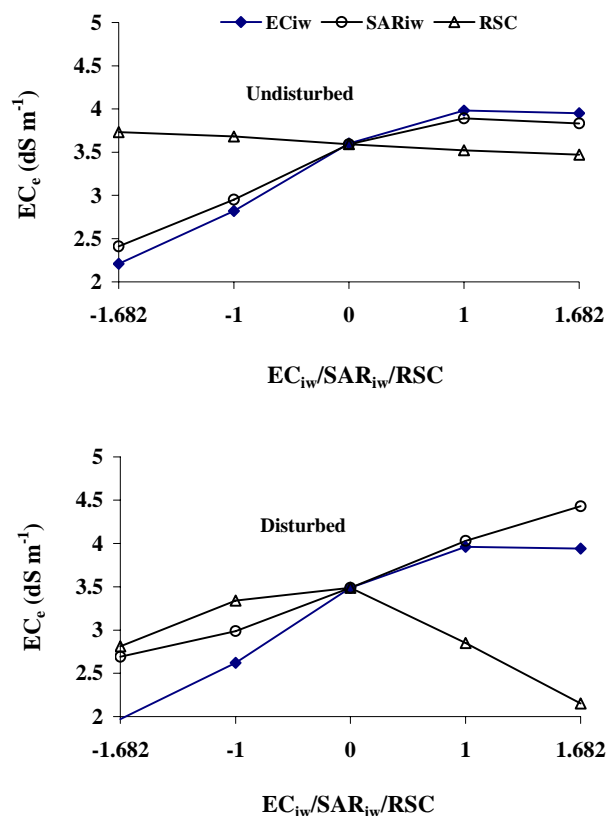
**Table V. Observed and predicted grain yield (g) of wheat as affected with  $EC_{iw}$ ,  $SAR_{iw}$  and RSC**

$EC_{iw}$	$SAR_{iw}$	RSC	Observed	Predicted
2.00	18.00	0.65	16.61	13.64
4.00	18.00	2.00	32.20	30.29
4.00	26.35	4.00	25.52	23.47
6.00	26.35	7.35	9.11	6.37
7.35	26.35	0.65	4.60	3.38

**Table VI. Regression coefficients (b) and coefficient of determination ( $R^2$ ) for wheat and sorghum yields and soil properties as affected with  $EC_{iw}$ ,  $SAR_{iw}$  and RSC (log values)**

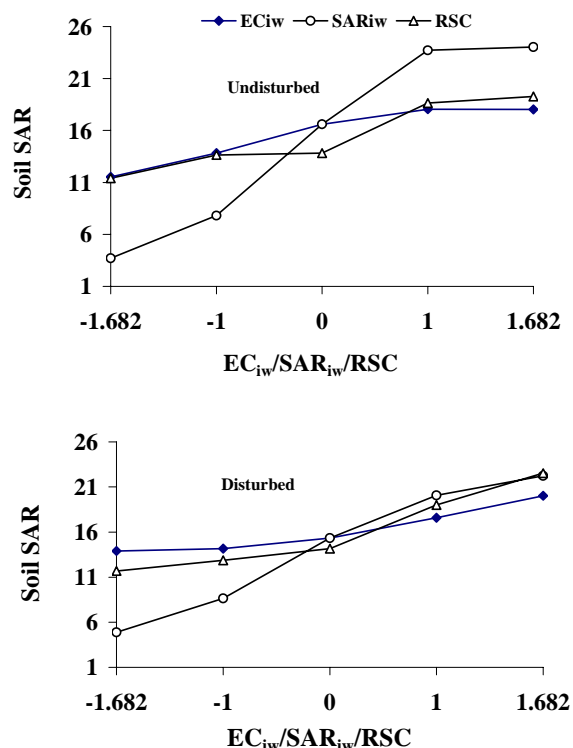
Soil condition/crop	b <sub>0</sub>	b <sub>1</sub>	b <sub>2</sub>	b <sub>3</sub>	b <sub>11</sub>	b <sub>22</sub>	b <sub>33</sub>	b <sub>12</sub>	b <sub>13</sub>	b <sub>23</sub>	R <sup>2</sup>
<b>Wheat grain yield (average of three years)</b>											
Undisturbed	2.950**	-0.131**	-0.132**	-0.126**	-0.279**	-0.108**	-0.203**	-0.033ns	-0.029ns	-0.017ns	0.953**
Disturbed	3.750**	-0.101**	-0.149**	-0.093*	-0.197**	-0.125**	-0.223**	-0.028ns	-0.013ns	-0.017ns	0.947**
<b>Sorghum yield (average of two years)</b>											
Undisturbed	3.363**	-0.293**	-0.108*	-0.111*	-0.038ns	-0.041ns	-0.073ns	-0.009ns	-0.023ns	0.013ns	0.868**
Disturbed	3.736**	-0.277**	-0.096*	-0.154**	-0.038ns	-0.021ns	0.089ns	-0.001ns	-0.015ns	0.017ns	0.877**
EC (undisturbed)	1.278**	0.173**	0.138**	-0.022ns	-0.078**	-0.017ns	-0.037*	-0.085**	0.008ns	-0.016ns	0.971**
EC (disturbed)	1.634**	0.364**	0.116**	-0.132**	-0.097**	-0.008ns	-0.030ns	-0.031ns	0.073*	-0.008ns	0.974**
SAR (und.)	2.809**	0.133**	0.556**	0.156**	-0.050ns	-0.222**	-0.043ns	-	-0.037ns	0.084ns	0.967**
SAR (disturbed)	2.727**	0.108**	0.422**	0.195**	0.031ns	-0.153*	0.01ns	-	-0.059ns	0.011ns	0.923**
BD (undisturbed)	0.509**	-0.251*	0.041**	0.019*	0.013ns	0.003ns	0.011ns	0.001ns	0.002ns	0.015ns	0.824*
BD (disturbed)	0.475**	-0.019**	0.029**	0.010ns	0.012*	0.004ns	0.006ns	0.002ns	-0.002ns	0.005ns	0.850**
Ks (undisturbed)	-1.068**	0.265**	-0.092**	-0.068**	-0.056ns	0.013ns	-0.015ns	-0.008ns	-0.004ns	0.006ns	0.951**
Ks (disturbed)	-1.012**	0.251**	-0.096**	-0.081**	-0.071*	-0.009ns	0.004ns	-0.003ns	-0.004ns	0.007ns	0.930**

\* = Significant at 0.01 level of probability; \*\* = Significant at 0.05 level of probability; ns = Non-significant; BD = Bulk density (Mg cm<sup>-3</sup>); K<sub>s</sub> = Saturated hydraulic conductivity (cm h<sup>-1</sup>); (und.) = Undisturbed

**Fig. 2.** Effect of  $EC_{iw}$ ,  $SAR_{iw}$  and RSC on  $EC_e$  ( $dS\ m^{-1}$ )


were added into soil profile with irrigation, the fluctuation in osmotic potential adversely influenced the availability of water (Suarez & Lebron, 1993). Under saline environment, plants expend extra metabolic energy to extract water at the cost of vegetative growth. As a result of which plant could not maintain turgor (Arif, 1990) and suffered poor growth.

**Soil Salinity ( $EC_e$ ).** Brackish irrigation waters tend to deteriorate soil properties when use is prolonged without scientific management. This has been shown through the fitted regression models (Table VI). For simplicity, few selected values ( $EC_{iw}$  0.65 to 7.35  $dS\ m^{-1}$  at coded "0" levels of  $SAR_{iw}$  and RSC;  $SAR_{iw}$  3.95 to 32.04 at coded "0" levels of  $EC_{iw}$  and RSC; RSC 0.65 to 7.35  $mmol_c\ L^{-1}$  at coded "0" levels of  $EC_{iw}$  and  $SAR_{iw}$ ) have been depicted in Fig. 2 and 3. The soil salinity (0-15 cm) increased linearly with an increase in the  $EC_{iw}$  at given coded levels of  $SAR_{iw}$  and RSC. At coded "0" levels of  $SAR_{iw}$  and RSC, the  $EC_e$  increased from 2.21 to 3.98 and 1.97 to 3.96  $dS\ m^{-1}$  as the  $EC_{iw}$  increased from 0.65 to 6.0  $dS\ m^{-1}$  for undisturbed and disturbed soil conditions, respectively. It became flattened with further increase in  $EC_{iw}$  (Fig. 2). It is obvious that the  $EC_e$  with  $EC_{iw}$  0.65, 2.0, 4.0, 6.0 and 7.35  $dS\ m^{-1}$  was 2.21, 2.82, 3.60, 3.89 and 3.95  $dS\ m^{-1}$  which was 21, 30, 26 and 21% of the EC of respective water used for irrigation for the undisturbed soil. The  $EC_e$  resulted from  $EC_{iw}$  0.65  $dS\ m^{-1}$  was less than the original soil salinity (2.4  $dS\ m^{-1}$ ) for both

**Fig. 3.** Effect of  $EC_{iw}$ , SAR and RSC on SAR of soil


the undisturbed and disturbed soils, respectively at all the coded 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 2.62, 3.49, 3.96 and 3.94  $dS\ m^{-1}$  which was 11, 27, 26 and 21% of the EC of respective water at coded "0" levels of  $SAR_{iw}$  and RSC. Results indicated that  $EC_e$  remained below the critical limits of 4.0  $dS\ m^{-1}$  as ascribed by U.S. Salinity Laboratory Staff (1954) at all the coded levels of  $SAR_{iw}$  and RSC for both the undisturbed and disturbed soils. Similar trend in  $EC_e$  was noted with  $EC_{iw}$  at coded "-1.682, -1, 1 and 1.682" levels of  $SAR_{iw}$  and RSC (Table VI). The differences in  $EC_e$  of the undisturbed and disturbed soils remained small. The lower values of  $EC_e$  compared to  $EC_{iw}$  at given levels of  $SAR_{iw}$  and RSC prevailed because of the light texture of the soil with good saturated hydraulic conductivity as an increase in  $K_s$  was noted with  $EC_{iw}$  (Fig. 7).

The  $EC_e$  increased significantly with  $SAR_{iw}$  at given  $EC_{iw}$  and RSC levels. It is interesting to note that at similar  $EC_{iw}$  and RSC (4.0  $dS\ m^{-1}$  and 4.0  $mmol_c\ L^{-1}$ ), irrigation with higher SAR (32.04) waters caused higher accumulation of salts in disturbed (4.43  $dS\ m^{-1}$ ) than that of undisturbed soil (3.83  $dS\ m^{-1}$ ). Similar results regarding the effect of  $SAR_{iw}$  on  $EC_e$  were reported by Singh *et al.* (1992).

It is apparent (Fig.2) that  $EC_e$  of undisturbed behaved differentially to RSC waters at given  $EC_{iw}$  and  $SAR_{iw}$  than that of disturbed ones. The EC of undisturbed soil decreased almost linearly with an increase in RSC at a given  $EC_{iw}$  and

$SAR_{iw}$ . Contrary to this, the  $EC_e$  of disturbed soil increased from 2.81 to 3.49  $dS\ m^{-1}$  with an increase in RSC from 0.65 to 4.0  $mmol\ L^{-1}$  at  $EC_{iw}$  4.0  $dS\ m^{-1}$  and  $SAR_{iw}$  18.0. While decreased from 3.49 to 2.15  $dS\ m^{-1}$  with further increase in RSC. This trend in soil salinity reduction was similar with RSC water at coded “-1.682 and 1.682” levels of  $EC_{iw}$  and  $SAR_{iw}$ . Results indicated that high RSC waters decreased more  $EC_e$  at given EC and SAR of waters. Hausenbuiller *et al.* (1960) and Muhammed and Rauf (1983) reported that high bicarbonate contents of water decreased  $EC_e$  through precipitation of  $Ca^{2+}$  and  $Mg^{2+}$  as calcium carbonate and magnesium silicate.

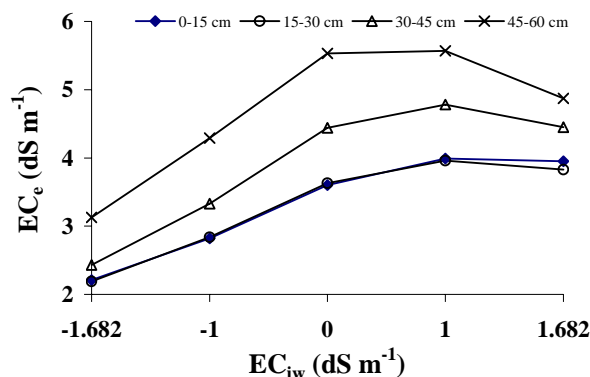
**Soil sodicity (SAR).** The soil SAR increased with an increase in the  $EC_{iw}$  at coded “0” levels of  $SAR_{iw}$  and RSC for undisturbed and disturbed soils (Fig. 3). The SAR was < 8.1 with  $EC_{iw}$  0.65 to 7.35  $dS\ m^{-1}$  at coded “-1.682 and -1” levels of  $SAR_{iw}$  and RSC. It was > 13.3 with the same levels of  $EC_{iw}$  at coded “0, 1 and 1.682” levels of  $SAR_{iw}$  and RSC for both the soil conditions (Table VI). Soil SAR build up with  $EC_{iw}$  at coded “-1.682 and -1” was lower than at coded “0, 1 and 1.682” levels of  $SAR_{iw}$  and RSC (i.e. 32.04 & 7.35  $mmol\ L^{-1}$ ). Moreover, the SAR for undisturbed and

disturbed soil was similar with  $EC_{iw}$  7.35  $dS\ m^{-1}$  at high SAR and RSC of waters. Singh *et al.* (1992) reported that SAR of normal soil increased with an increase in  $SAR_{iw}$ . An increase in soil SAR with increasing  $EC_{iw}$  at given  $SAR_{iw}$  and RSC may be due to greater possibility of precipitation of  $Ca^{2+}$  and  $Mg^{2+}$  as calcium carbonate and magnesium silicate (Eaton, *et al.*, 1968). Increased sodication of soil profile at higher values of  $EC_{iw}$  and RSC apparently resulted in greater reduction in yields of crops with  $SAR_{iw}$  (Fig. 1). At a given  $EC_{iw}$  and RSC, the  $SAR_{iw}$  significantly increased the soil SAR under both the soil conditions. Soil SAR receiving water of SAR 3.95, 9.65, 18.0, 26.35 and 32.04 attained SAR levels of 3.70, 7.8, 16.61, 23.71 and 24.03, respectively which is 59.9, 66.6, 84.7, 84.8 and 70.7% of the  $SAR_{iw}$  at coded “0” levels of  $EC_{iw}$  and RSC for the undisturbed soil. The corresponding SAR of disturbed soil was 4.89, 8.63, 15.33, 20.07 and 22.23, which is 89.11, 75.23, 77.6, 71.0 and 65.1% of the  $SAR_{iw}$ . The increase in soil SAR was more pronounced with  $SAR_{iw}$  at coded “0, 1 and 1.682” than that at coded “-1.682 and -1” levels of  $EC_{iw}$  and RSC (Table VI). Soil SAR was more with similar  $SAR_{iw}$  at given coded levels of  $EC_{iw}$  and RSC in the undisturbed than that in the disturbed soils. As expected, the higher levels of  $Na^+$ ,  $HCO_3^-$  and  $SAR_{iw}$  resulted in a higher Na saturation in the soil with  $EC_{iw}$  at higher (0, 1 & 1.682) than that at lower (-1.682 & -1) coded levels of  $SAR_{iw}$  and RSC. The RSC has also resulted increased in soil SAR at given levels of  $EC_{iw}$  and  $SAR_{iw}$ . This increase in soil SAR with RSC of water was more at coded “1.682” levels of  $EC_{iw}$  and RSC (7.35  $dS\ m^{-1}$  and 7.35  $mmol\ L^{-1}$ ) than that for remaining coded levels of  $EC_{iw}$  and  $SAR_{iw}$ . Furthermore, at coded “0” levels of  $EC_{iw}$  and  $SAR_{iw}$ , the SAR build up was more in disturbed than that in undisturbed soil with similar RSC (Fig. 3). This could be due to the reason that at high RSC waters, bicarbonate ions precipitated  $Ca^{2+}$  and the residue of  $CO_3^{2-}$  combines with  $Na^+$  to form  $Na_2CO_3$  and  $NaHCO_3$  in the irrigated soils, thereby more sodicate of soils (Gupta, 1980).

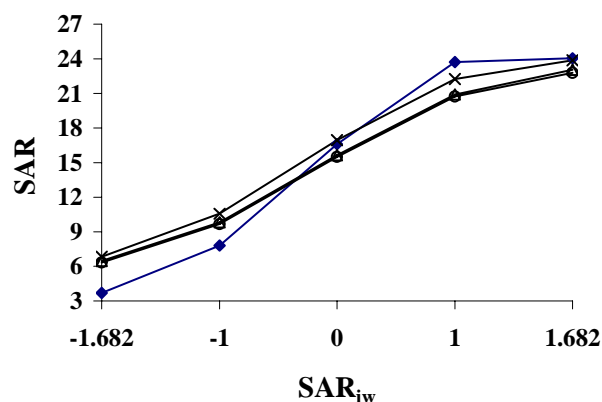
The depth-wise soil EC and SAR is presented in Fig. 4 and 5. The  $EC_e$  and soil SAR increased significantly with depth. Similar trend in the increase of  $EC_e$  and soil SAR was noted for disturbed soil. Results divulged that after the termination of the experiment, whole of the soil profile (undisturbed and disturbed) attained  $EC_e < 2.0\ dS\ m^{-1}$  and SAR values > 13 which are the upper limit for the saline-sodic and sodic soils (U.S. Salinity Lab. Staff, 1954). The build up of soil SAR, however, did not differ for both the soil conditions.

**Soil bulk density.** Bulk density decreased with an increase in  $EC_{iw}$  at given  $SAR_{iw}$  and RSC for both the soil conditions (Fig. 6). Reduction in bulk density was more with  $EC_{iw}$  at “-1.682, and -1” than that at “0, 1 and 1.682” coded levels of  $SAR_{iw}$  and RSC (Table VI). Costa *et al.* (1991) recorded a decrease in bulk density with  $EC_{iw}$  2.98  $dS\ m^{-1}$  and  $SAR_{iw}$  8.0 from 0.06 to 0.04  $Mg\ m^{-3}$ . They concluded that this

**Fig. 4. Effect of  $EC_{iw}$  on  $EC_e$  for different soil depth at “0” coded levels of  $SAR_{iw}$  and RSC**



**Fig. 5. Effect of  $SAR_{iw}$  on SAR for different soil depth at coded “0” levels of  $EC_{iw}$  and RSC**





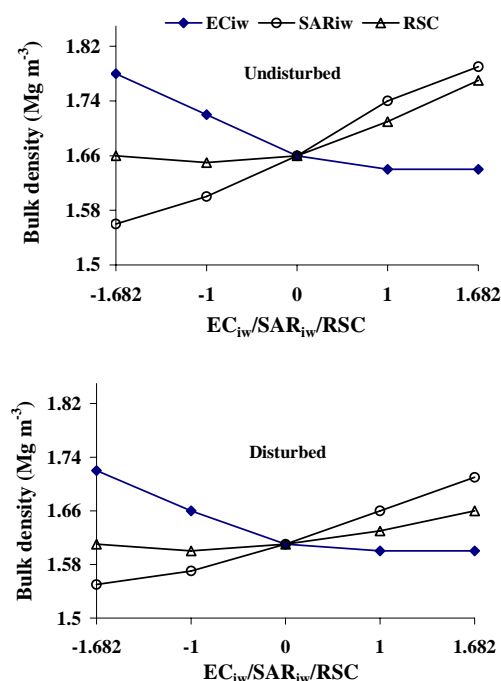
decrease in bulk density was due to the presence of high  $\text{Ca}^{2+}$  (6.3 to 11.6  $\text{mmol}_c \text{L}^{-1}$ ) in irrigation water used.

At given  $\text{EC}_{\text{iw}}$  and RSC and/or  $\text{EC}_{\text{iw}}$  and  $\text{SAR}_{\text{iw}}$ , bulk density increased with increasing  $\text{SAR}_{\text{iw}}$  and/or RSC of waters (Table VI & Fig.6). It is interesting to note that an increase in bulk density from 1.68 to 1.92 and 1.67 to 1.79  $\text{Mg m}^{-3}$  with  $\text{SAR}_{\text{iw}}$  from 3.95 to 32.04 was more at coded “-1.682” levels of  $\text{EC}_{\text{iw}}$  and RSC as compared with similar levels of  $\text{SAR}_{\text{iw}}$  at coded “-1, 0, 1 and 1.682” levels of  $\text{EC}_{\text{iw}}$  and RSC. Similar trend in bulk density was recorded for undisturbed and disturbed soil with RSC water at coded “0” levels of  $\text{EC}_{\text{iw}}$  and  $\text{SAR}_{\text{iw}}$  (Fig. 6). Higher bulk density resulted as RSC increased from 0.65 to 7.35  $\text{mmol}_c \text{L}^{-1}$  at coded “1.682” levels of  $\text{EC}_{\text{iw}}$  and  $\text{SAR}_{\text{iw}}$  for both the soil conditions. It is evident that at given coded levels of  $\text{EC}_{\text{iw}}$  and RSC, more increase in bulk density was noted with  $\text{SAR}_{\text{iw}}$  than that of RSC water at given coded levels of  $\text{EC}_{\text{iw}}$  and  $\text{SAR}_{\text{iw}}$ . Moreover, high bulk density values were recorded for undisturbed than that for disturbed columns with  $\text{SAR}_{\text{iw}}$  and/or RSC at given levels of  $\text{EC}_{\text{iw}}$  and RSC and/or  $\text{EC}_{\text{iw}}$  and  $\text{SAR}_{\text{iw}}$ . Adsorption of Na ions with high  $\text{SAR}_{\text{iw}}$  might lead to affect a decrease in pore space, which consequently increased bulk density. Moreover, an increase in bulk density with RSC waters may be due to precipitation of  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  as calcium carbonate and magnesium silicate that increased concentration of adsorbed  $\text{Na}^+$ , which lead to increase bulk density due to decreased porosity.

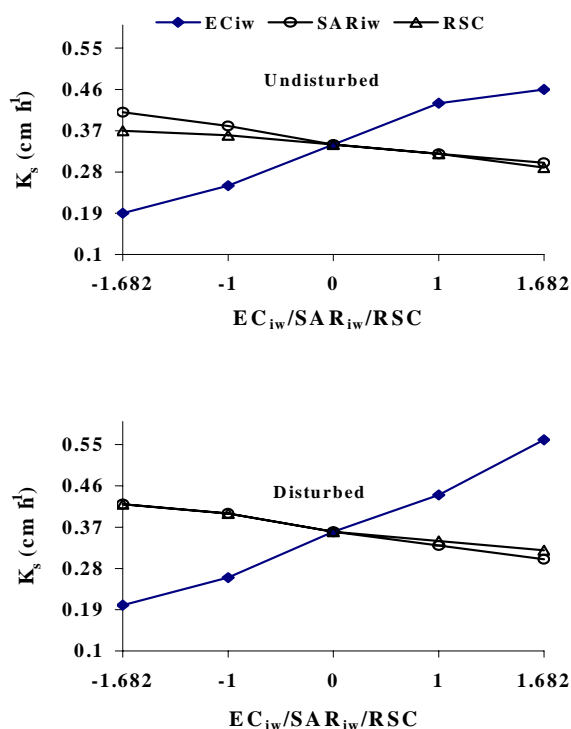
**Saturated hydraulic conductivity ( $K_s$ ).** Saturated hydraulic conductivity increased with an increase in  $\text{EC}_{\text{iw}}$  at given levels of  $\text{SAR}_{\text{iw}}$  and RSC. At coded “0” levels of

$\text{SAR}_{\text{iw}}$  and RSC, it increased from 0.191 to 0.462 and 0.201 to 0.563  $\text{cm h}^{-1}$  with an increase in  $\text{EC}_{\text{iw}}$  from 0.65 to 7.35  $\text{mmol}_c \text{L}^{-1}$  for both the undisturbed and disturbed soil conditions (Fig. 7). Results indicated that at similar  $\text{EC}_{\text{iw}}$ , the rate of increase in saturated hydraulic conductivity was more at lower coded levels of these parameters. For instance, it was 0.559  $\text{cm h}^{-1}$  with  $\text{EC}_{\text{iw}}$  7.35  $\text{mmol}_c \text{L}^{-1}$  at coded “-1.682” levels of  $\text{SAR}_{\text{iw}}$  and RSC. While it was 0.352  $\text{cm h}^{-1}$  with the same  $\text{EC}_{\text{iw}}$  at coded “1.682” levels of  $\text{SAR}_{\text{iw}}$  and RSC. It is worth to note that with the same  $\text{EC}_{\text{iw}}$ , higher values of  $K_s$  were observed for the disturbed than that for the undisturbed soil condition at low  $\text{SAR}_{\text{iw}}$  and RSC levels (Table VI). Siyaz *et al.* (1983) and Minhas *et al.* (1994) also reported an increase in  $K_s$  with an increase in  $\text{EC}_{\text{iw}}$ . Lower  $K_s$  values with similar  $\text{EC}_{\text{iw}}$  at coded “1.682” levels of SAR and RSC could be due to high  $\text{Na}^+$  and  $\text{HCO}_3^-$  concentrations which tended to reduce the porosity of soil. In general, high EC waters increased  $K_s$  of both the soils at low  $\text{SAR}_{\text{iw}}$  and RSC more than that at higher levels of  $\text{SAR}_{\text{iw}}$  and RSC. The thickness of diffuse double layer decreased as the square root of the bulk salt concentration and directly with the valency of the exchangeable cations (Bohn *et al.*, 1985). This phenomenon is a prerequisite to flocculate the soil particles (Bohn *et al.*, 1985). Thus the increase in  $K_s$  with high  $\text{EC}_{\text{iw}}$  could be due to improvement in soil flocculation. High  $\text{EC}_{\text{iw}}$  rarely cause soil dispersion or deteriorate physical characteristics when used for irrigation (Suraz *et al.*, 1993).

**Fig. 6. Effect of  $\text{EC}_{\text{iw}}$ ,  $\text{SAR}_{\text{iw}}$  and RSC on bulk density ( $\text{Mg m}^{-3}$ ) of soil**



**Fig. 7. Effect of  $\text{EC}_{\text{iw}}$ ,  $\text{SAR}_{\text{iw}}$  and RSC on saturated hydraulic conductivity ( $\text{cm h}^{-1}$ ) of soil**





As expected, high SAR and/or RSC waters had negative impact on  $K_s$  at given levels of  $EC_{iw}$  and RSC and/or  $EC_{iw}$  and  $SAR_{iw}$  under both the soil conditions (Table VI & Fig. 7). The  $K_s$  decreased from 0.412 to 0.301 and 0.422 and 0.302  $cm\ h^{-1}$  as  $SAR_{iw}$  increased from 3.95 to 32.04 at coded "0" levels of  $EC_{iw}$  and RSC (i.e.  $EC_{iw}$  4.0  $dS\ m^{-1}$  and RSC 4.0  $mmol_c\ L^{-1}$ ) for undisturbed and disturbed soils. It was noted that the rate of decrease in  $K_s$  was more pronounced with similar SAR waters at coded "-1.682" levels of  $EC_{iw}$  and RSC (i.e. 0.65  $dS\ m^{-1}$  and 0.65  $mmol_c\ L^{-1}$ , respectively) than that at coded "1.682" levels of  $EC_{iw}$  and RSC (i.e. 7.35  $dS\ m^{-1}$  and 7.35  $mmol_c\ L^{-1}$ , respectively). Similar was the case for  $K_s$  with SAR water under disturbed soil conditions. The difference in  $K_s$  between undisturbed and disturbed soils with similar  $SAR_{iw}$  (e.g. 32.04) was in the order of 0.006 and 0.018  $cm\ h^{-1}$  at coded "-1.682" and "1.682" levels of  $EC_{iw}$  and RSC. This indicated that SAR water depressed  $K_s$  more at low coded "-1.682 and -1" than that at coded "1 and 1.682" levels of  $EC_{iw}$  and RSC (Table VI). It is well documented that  $Na^+$  hazard potential of water is often evaluated from the SAR and EC. At the same SAR, the dispersion potential of a low electrolyte water is greater than that for a high electrolyte water (Suarez & Lebron, 1993). There was direct correlation between soil SAR and  $SAR_{iw}$  (Fig. 3), which possibly resulted in defloculation of soil and consequently  $K_s$  was decreased. It might be possible that irrigation water having higher concentration of  $Na^+$  increased desorption of  $Ca^{2+}$  by  $Na^+$  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 rather became unsatisfied charged in soil, which caused dispersion. This dispersion decreased the porosity of soil and as a result  $K_s$  decreased. The results (Table VI) depicted that the waters with higher SAR and RSC significantly reduced  $K_s$  of soil under both the conditions. At coded "0" level of  $EC_{iw}$  and  $SAR_{iw}$ , increase in RSC from 0.65 to 7.35  $mmol_c\ L^{-1}$  decreased hydraulic conductivity from 0.374 to 0.298 and 0.422 to 0.321  $cm\ h^{-1}$  for the undisturbed and disturbed soil conditions. Similar was the trend in reduction of  $K_s$  with increasing RSC of waters at coded "-1.682, -1, 1 and 1.682" levels of  $EC_{iw}$  and  $SAR_{iw}$ . Depressive effect of high bicarbonate water on  $K_s$  has been reported previously (Oster & Schroer, 1979; Muhammed & Rauf, 1983). Dispersion and/or particle loading into pores are considered important factors affecting the  $K_s$  of salt-affected soils (Rengasamy *et al.*, 1984). Irrigation water having higher SAR and RSC increased sodium in soil solution. The reactions like cation exchange and precipitation of  $CaCO_3$  might have resulted in an elevation of ESP, which in turn induced clay dispersion to affect a decrease in  $K_s$  (Rhoades & Ingvalson, 1969; Yousaf *et al.*, 1987).

## CONCLUSIONS

The yields of crops decreased with  $EC_{iw}$ ,  $SAR_{iw}$  and RSC. However, grain yield of wheat increased up to  $EC_{iw}$  4.0  $dS\ m^{-1}$ ,  $SAR_{iw}$  9.65 and RSC 4.0  $mmol_c\ L^{-1}$  at coded "0" levels of  $SAR_{iw}$  and RSC;  $EC_{iw}$  and RSC;  $EC_{iw}$  and  $SAR_{iw}$ , respectively for the undisturbed and disturbed soils. The  $SAR_{iw}$  up to 18.0 did not affect the yield up to coded "-1" levels of  $EC_{iw}$  and RSC under both the soil conditions. Sorghum dry matter yield decreased linearly with  $EC_{iw}$  and  $SAR_{iw}$  at given coded levels of  $SAR_{iw}$  and RSC;  $EC_{iw}$  and RSC under undisturbed and disturbed soils. Sorghum yield increased with increasing RSC up to 2.0  $mmol_c\ L^{-1}$  at given coded levels of  $EC_{iw}$  and  $SAR_{iw}$  for both the conditions. Higher wheat and sorghum yields were predicted from the disturbed than that from the undisturbed soils with the same levels of  $EC_{iw}$ ,  $SAR_{iw}$  and/or RSC. The  $EC_e$  and SAR increased with increasing  $EC_{iw}$ ,  $SAR_{iw}$  and RSC (with exception to  $EC_e$ , which decreased with RSC waters). However, the rate of increase in  $EC_e$  and SAR was more with high  $EC_{iw}$  and  $SAR_{iw}$  particularly at higher coded levels of  $SAR_{iw}$  and RSC; or  $EC_{iw}$  and RSC. After four and a half years application of brackish waters, it was noted that whole of the soil profile attained  $EC_e < 4.0\ dS\ m^{-1}$  and  $SAR > 13.3$ , which are the upper limits for saline-sodic and sodic soils in undisturbed and disturbed soils with  $EC_{iw}$  and  $SAR_{iw}$  at coded "0" levels of  $SAR_{iw}$  and RSC;  $EC_{iw}$  and RSC. The  $K_s$  increased from 0.19 to 0.46; 0.20 to 0.56  $cm\ h^{-1}$  with as  $EC_{iw}$  increased from 0.64 to 7.35  $dS\ m^{-1}$ , while decreased from 0.41 to 0.30 and 0.42 to 0.30  $cm\ h^{-1}$ ; 0.37 to 0.29 and 0.42 to 0.32  $cm\ h^{-1}$  as  $SAR_{iw}$  and RSC increased, respectively for the undisturbed and disturbed soils. The decrease in bulk density was 7.87 and 6.39%, respectively with  $EC_{iw}$  7.35  $dS\ m^{-1}$  over  $EC_{iw}$  0.64  $dS\ m^{-1}$  at coded "0" levels of  $SAR_{iw}$  and RSC. The increase in bulk density was more (14.75%) in the undisturbed than that in disturbed (10.32%) soil with  $SAR_{iw}$  32.04 over  $SAR_{iw}$  3.95. Similar trend in bulk density with RSC was noted in present studies.

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