

# Brackish Water for Irrigation: II Effects on Yield of Wheat and Properties of the Bhalwal Soil Series

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## ABSTRACT

The salt built up with  $EC_{iw}$ ,  $SAR_{iw}$  and/or RSC and their subsequent detrimental effects on chemical and physical properties of the Bhalwal soil series and yield of wheat cv. Faisalabad-85 were studied. Irrigation waters of 15 qualities were applied to 30 cm x 68 cm undisturbed and disturbed soil columns. Grain yield decreased linearly with  $EC_{iw}$  at given levels of  $SAR_{iw}$  and RSC. The  $SAR_{iw}$  up to 18.0 at coded "0" levels of  $EC_{iw}$  and  $SAR_{iw}$  ( $4.0 \text{ dS m}^{-1}$  and  $4.0 \text{ mmol}_c \text{ L}^{-1}$ ) did not affect the yield in both the undisturbed and disturbed soil columns. Yield increased with RSC waters up to 2.0 and  $4.0 \text{ mmol}_c \text{ L}^{-1}$  at levels of  $EC_{iw}$  up to  $4.0 \text{ dS m}^{-1}$  and  $SAR_{iw}$  up to 18.0 in the undisturbed and disturbed soils, respectively. Overall, the adverse effect of  $EC_{iw}$ ,  $SAR_{iw}$  and RSC was more on wheat grain yield under undisturbed than that under the disturbed soil columns. Higher grain yield with similar  $EC_{iw}$ ,  $SAR_{iw}$  and/or RSC were recorded from disturbed than that of the undisturbed soil columns. The soil EC and SAR increased with  $EC_{iw}$ ,  $SAR_{iw}$  and RSC, except  $EC_e$  which decreased with RSC of waters. However, increase in  $EC_e$  and SAR was more with poor quality water for undisturbed than that for disturbed conditions. It was observed that whole of the undisturbed and disturbed soil profile attained  $EC_e > 4.0 \text{ dS m}^{-1}$  and  $SAR > 13.0$  which are the upper limits for saline-sodic soils. Soil bulk density decreased with  $EC_{iw}$  at levels of  $SAR_{iw}$  and RSC up to 32.04 and  $7.35 \text{ mmol}_c \text{ L}^{-1}$ . It increased with  $SAR_{iw}$  and/or RSC at levels of  $EC_{iw}$  and RSC up to  $7.35 \text{ dS m}^{-1}$  and  $7.35 \text{ mmol}_c \text{ L}^{-1}$ ;  $EC_{iw}$  and  $SAR_{iw}$  up to  $7.35 \text{ dS m}^{-1}$  and 32.04 for both the undisturbed and disturbed soils. An increase in saturated hydraulic conductivity was noted with  $EC_{iw}$  at levels of  $SAR_{iw}$  up to 32.04 and RSC up to  $7.35 \text{ mmol}_c \text{ L}^{-1}$ . It decreased with  $SAR_{iw}$  and RSC at levels of  $EC_{iw}$  and RSC up to  $7.35 \text{ dS m}^{-1}$  and  $7.35 \text{ mmol}_c \text{ L}^{-1}$ ;  $EC_{iw}$  and  $SAR_{iw}$  up to  $7.35 \text{ dS m}^{-1}$  and 32.04.

**Key Words:** Brackish water; Saturated HC; BD; Wheat; SAR; EC

## INTRODUCTION

Unscientific uses of brackish waters reduce the value and productivity of soils. Accumulation of soluble salts in the soils imposes stress on crops leading to decreased yields (Francois *et al.*, 1986), and that of sodium (soluble & adsorbed) affects soil physical properties, which in turn greatly affect crop production (Shainberg & Letey, 1984).

The data regarding the long-term effect of brackish water on soils and crops is insufficient since mostly research has been focused on minimizing salt build up in soils. In the past, greenhouse and/or laboratory experiments disturbed soil columns have been used. Information regarding undisturbed soil is lacking. Limited number of combinations of  $EC_{iw}$ ,  $SAR_{iw}$  and/or RSC levels were investigated. Thus the objective of the present study was to evaluate the long-term effects of using various combinations of  $EC_{iw}$ ,  $SAR_{iw}$  and RSC on soil salination, sodication, bulk density, saturated hydraulic conductivity and yield of wheat grown under undisturbed and disturbed columns of the Bhalwal (silty clay loam) soil series. The results will help successful planning of ground water development and future salinity related programme for crop production.

## MATERIALS AND METHODS

Research work was conducted in wire-house at University of Agriculture, Faisalabad during 1991-95 using Bhalwal soil series (Fine-silty, mixed, hyperthermic Ustollic Calcicargids). This soil was sandy clay loam in texture (sand 35%; silt 50%; clay 15%) and has pH<sub>s</sub> 7.7;  $EC_e$   $2.2 \text{ dS m}^{-1}$ ;  $SAR$   $3.3 (\text{mmol L}^{-1})^{1/2}$ ;  $CaCO_3$  6.8% and CEC  $10.4 \text{ cmol}_c \text{ kg}^{-1}$ .

**Columns preparation.** Metallic cylinders (76-cm long and 30-cm diameter) were pushed vertically into the moist soil ( $\approx 50\%$  field capacity) by dropping a 20 kg weight on the grooved wooden planks through a pulley up to 68 cm depth, soil around the cylinder was excavated up to 80 cm and soil columns were removed. This excavated soil was used for preparing disturbed soil columns. A thin layer of glass wool and sand on stainless steel wire gauze (35 cm x 35 cm) was placed to minimize the movement of finer particles in the leachate at the bottom of cylinders and were placed on metallic funnels, fixed on iron stands.

For the preparation of disturbed soil columns, a thin layer of glass wool and sand were spreaded on the stainless steel 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 soil of the Bhalwal series. The soil filling up to 68 cm was accomplished 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.

**Irrigation water quality.** Fourteen design points having different  $EC_{iw}$ ,  $SAR_{iw}$  and RSC levels were selected following Central Composite Rotatable Second Order Design (Montgomery, 1997). Five levels each of  $EC_{iw}$  ( $X_1$ ),

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

Coded scale			Original level		
$x_1$	$x_2$	$x_3$	$EC_{iw}$ ( $dS\ m^{-1}$ )	$SAR_{iw}$ ( $mmol\ L^{-1}$ ) <sup>1/2</sup>	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

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

Coded scale			Original level		
$x_1$	$x_2$	$x_3$	$EC_{iw}$ ( $dS\ m^{-1}$ )	$SAR_{iw}$ ( $mmol\ L^{-1}$ ) <sup>1/2</sup>	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

$$x_1 = (X_1 - 4.00)/2.0; x_2 = (X_2 - 18.00)/8.35; x_3 = (X_3 - 4.00)/2.0$$

$SAR_{iw}$  ( $X_2$ ) 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 ( $mmol\ L^{-1}$ )<sup>1/2</sup>, 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 (Table I). The central point (all variables at coded zero levels) was repeated six times, so that a uniform precision design could be attained. In a uniform precision design, variance of  $\hat{y}$  at the origin is equal to the variance of  $\hat{y}$  at unit distance from its origin. This design gives much more protection against

bias in the regression analysis (Montgomery, 1997).

To verify the validity of these model predictions with factors of Table I, five extra treatments (Table II) for wheat were run in disturbed columns of Bhalwal soil series. After getting near-steady state, assessed on the basis of  $EC_{dw}$  (EC of drainage water) wheat was grown in these lysimeters.

**Brackish water preparation, application and steady-state soil conditions.** The desired levels of  $EC_{iw}$ ,  $SAR_{iw}$  and RSC (Table I) were prepared by dissolving calculated amounts of NaCl,  $NaHCO_3$ ,  $Na_2SO_4$ ,  $CaCl_2$  and  $MgSO_4$  salts in canal water. After each irrigation, drainage water (dw) for each lysimeter was measured and analyzed occasionally for  $EC_{dw}$  to monitor the progress towards steady-state. Application of brackish water was started on March 14, 1992 and the near steady-state soil conditions were achieved on April 14, 1993. Total 42 L water was added to each column of the undisturbed and disturbed soils, respectively.

**Crops.** Wheat (*Triticum aestivum* L.) cv. Faisalabad-85 was sown on December 14, 1992 and December 15, 1993. A basal dose of N, P and K were applied @ 150, 100 and 75  $kg\ ha^{-1}$ , respectively to all the soil columns as urea, single super phosphate and sulphate of potash. During growth period, crop was sprayed with Novacron to protect it from insect pest attack. Brackish waters (Table II) were applied through out the growth period of the crop according to crop requirement. The crops were harvested on May 3, 1993 and May 6, 1994.

After termination of the experiment, saturated hydraulic conductivity ( $K_s$ ) with falling head method (Jury et al., 1991) and bulk density by core method (Blake & Hartge, 1986) were determined. Soil samples from 0-15, 15-30, 30-45 and 45-60 cm were drawn from soil columns and were analysed for  $EC_e$ , SAR and  $pH_s$  (U.S. Salinity Lab. Staff, 1954).

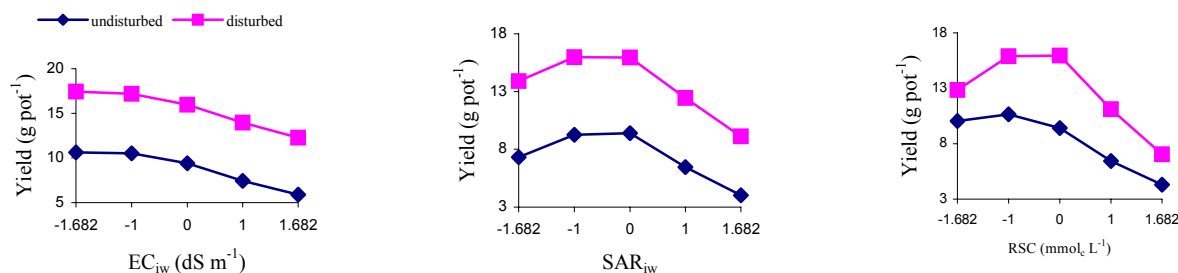
**Data analysis.** The coefficients (Table III) were determined using multiple regression analysis using Minitab software programme (Minitab, 1989). To draw quadratic graph for all the dependent variables, form of the model used was:

$$\log \hat{y}_i = \beta_0 + \beta_1 x_i + \beta_{ii} x_i^2$$

## RESULTS AND DISCUSSION

**Grain yield of wheat.** A constant decrease in wheat yield resulted with an increase in  $EC_{iw}$  at coded "0" levels of both the  $SAR_{iw}$  and RSC (Fig. 1), yield reduction being more in undisturbed than that in disturbed soil columns. About 50% yield was decrease with  $EC_{iw}$  7.35  $dS\ m^{-1}$  over  $EC_{iw}$  0.65  $dS\ m^{-1}$  at coded "0" levels of  $SAR_{iw}$  and RSC (18.0 and 4.0  $mmol_c\ L^{-1}$ ) in the undisturbed soil columns.

Wheat yield increased with  $SAR_{iw}$  up to 18.0 at coded "0" levels of  $EC_{iw}$  and RSC, thereafter it decreased in both the soil conditions (Fig. 1). Decrease in yield was more with  $SAR_{iw}$  from disturbed than that from the undisturbed soil

**Fig. 1.** Effect of  $EC_{iw}$ ,  $SAR_{iw}$  and RSC on yield of wheat

columns at coded “0” levels of  $EC_{iw}$  and RSC. Wheat grain yield was more with similar  $SAR_{iw}$  at all the five coded levels of  $EC_{iw}$  and RSC from the disturbed than that from the undisturbed soil conditions. Reduction in yield was more conspicuous with  $SAR_{iw}$  at higher coded levels  $EC_{iw}$  and RSC (Table III).

Grain yield increased with RSC up to 2.0 mmol<sub>c</sub> L<sup>-1</sup> at coded “0” levels of  $EC_{iw}$  and  $SAR_{iw}$ , remained almost constant up to 4.0 mmol<sub>c</sub> L<sup>-1</sup> and then decreased in disturbed soil columns (Fig. 1). Contrary to this, yield increased up to RSC 2.0 mmol<sub>c</sub> L<sup>-1</sup>, thereafter it decreased with further increase in RSC up to 7.35 mmol<sub>c</sub> L<sup>-1</sup> in the undisturbed soil. At similar RSC of waters, reduction in yield was more at higher than that lower levels of  $EC_{iw}$  and  $SAR_{iw}$ , which could be due to adverse effect of  $HCO_3^-$  in applied irrigation water (Muhammed & Rauf, 1983).

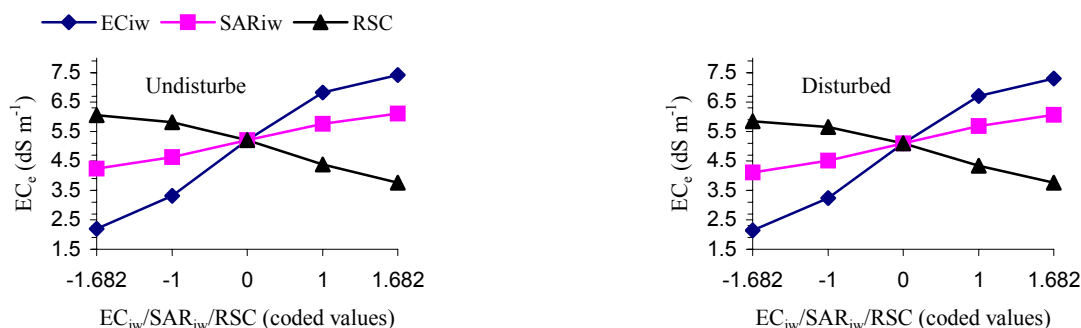
In general, wheat grain yield decreased with  $EC_{iw}$ ,  $SAR_{iw}$  and/or RSC, magnitude of which was different for undisturbed and disturbed soil columns. Reduction in yield was more with  $EC_{iw}$  at  $SAR_{iw} \geq 18.0$  and/or RSC  $\geq 4.0$  mmol<sub>c</sub> L<sup>-1</sup> than that at lower  $SAR_{iw}$  and RSC. Higher wheat grain yield was noted at a given  $EC_{iw}$  from the disturbed than that from the undisturbed conditions (Fig. 1). The  $EC_e$  and SAR values with  $EC_{iw}$  were less in disturbed than that of the undisturbed soil columns. It is apparent from results that more reduction in yield was probably due to high  $EC_e$  and/or restricted internal drainage conditions of the undisturbed soil columns (Fig. 1). The high  $EC_e$  reduce in

physiological availability of water but promoted accumulation of toxic ions (e.g.  $Na^+$  and  $Cl^-$ ) in plants (Greenway & Munns, 1980).

Wheat yield increased with  $SAR_{iw}$  up to 9.65, remained similar with  $SAR_{iw}$  up to 18.0 and decreased with further increase in  $SAR_{iw}$  from both the undisturbed and disturbed soil columns. Reduction in yield was more with  $SAR_{iw}$  for the undisturbed than that for disturbed soil columns at all the five levels of  $EC_{iw}$  and RSC. The adverse effect of  $SAR_{iw}$  was more on yield at higher  $EC_{iw}$  and RSC than that at lower  $EC_{iw}$  and RSC. A decrease in yield may be due to accumulation of exchangeable  $Na^+$  (Khandewal & Lal, 1991) which might have increased mechanical impedance to root penetration due to poor soil structure or directly  $Na^+$  toxicity to wheat plant.

Yield increased with RSC of waters up to 2.0 mmol<sub>c</sub> L<sup>-1</sup> and decreased with further increase in RSC from the undisturbed soil columns and from disturbed soil columns, yield increased with RSC up to 4.0 mmol<sub>c</sub> L<sup>-1</sup> at coded “-1.682, -1 and 0” levels of  $EC_{iw}$  and  $SAR_{iw}$ . This increase in yield with RSC of waters up to 4.0 mmol<sub>c</sub> L<sup>-1</sup> could be attributed due to better internal conditions of the disturbed as compared with the undisturbed soil conditions. Yield response was similar to RSC of waters at coded “1 and 1.682” levels of  $EC_{iw}$  and  $SAR_{iw}$ . A decrease in yield at high levels of RSC  $\geq 6.0$  mmol<sub>c</sub> L<sup>-1</sup> seemed due to  $HCO_3^-$  toxicity (Muhammed *et al.*, 1977).

#### Soil Characteristics

**Fig.2.** Effect of  $EC_{iw}$ ,  $SAR_{iw}$  and RSC on  $EC_e$  of soil

**Table III. Regression coefficients (b) and coefficient of determination ( $R^2$ ) for wheat yield 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 1992-93 and 1993-94 years)											
Undisturbed	2.239**	-0.175**	-0.179**	-0.251**	-0.061ns	-0.194**	-0.126*	-0.051 ns	-0.009 ns	0.034 ns	0.906**
Disturbed	2.766**	-0.104*	-0.125*	-0.178**	-0.031ns	-0.123*	-0.183**	-0.015 ns	-0.024 ns	0.001 ns	0.861*
EC (undisturbed)	1.654**	0.362**	0.109**	-0.141**	-0.097**	-0.009ns	-0.031ns	-0.023ns	0.079*	-0.008ns	0.972**
EC (disturbed)	1.634**	0.364**	0.116**	-0.132**	-0.097**	-0.008ns	-0.030ns	-0.031ns	0.073*	-0.008ns	0.951**
SAR(undisturbed)	3.219**	0.153**	0.475**	0.157**	-0.062ns	-0.161**	-0.017ns	-0.074ns	-0.022ns	-0.046ns	0.861*
SAR (disturbed)	3.212**	0.154**	0.489**	0.184**	-0.051ns	-0.171**	-0.015ns	-0.069ns	-0.037ns	-0.063ns	0.962**
BD (undisturbed)	0.436**	-0.013*	0.035**	0.025**	0.005ns	-0.011ns	-0.001ns	0.014ns	0.002ns	-0.001ns	0.894**
BD (disturbed)	0.424**	-0.011	0.031**	0.022**	0.006ns	-0.012*	-0.001ns	0.013ns	0.006ns	-0.002ns	0.861**
Ks (undisturbed)	-1.948**	0.037*	-0.093**	-0.097**	0.015ns	-0.022ns	0.014ns	-0.014ns	0.012ns	0.029ns	0.932**
Ks (disturbed)	-1.983**	0.032ns	-0.078**	-0.088**	0.072**	0.027ns	0.007ns	-0.010ns	0.006ns	-0.006ns	0.871**

\* = Significant at 0.01 level of probability; \*\* = Significant at 0.05 level of probability; ns = Non-significant; BD = Bulk density;  $K_s$  = Saturated hydraulic conductivity

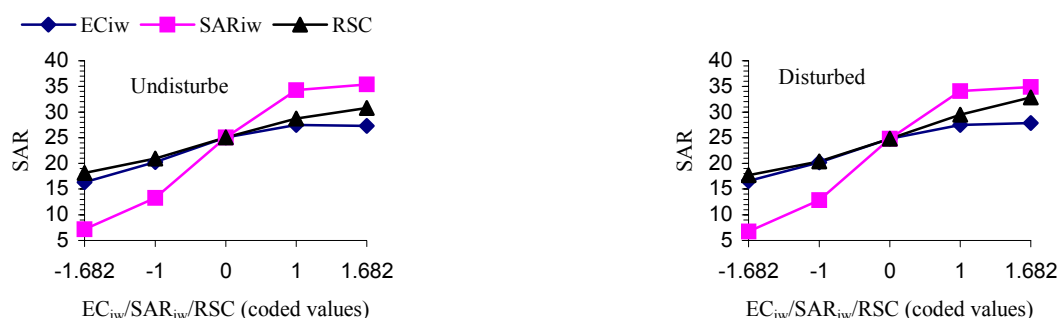
**Soil salinity ( $EC_e$ ).** The  $EC_e$  and SAR before the start of experiment were 2.20 dS  $m^{-1}$  and 3.34, significantly increased years application of brackish waters (Table I). This has been shown through the best-fit quadratic relationships between  $EC_e$ , SAR, etc and  $EC_{iw}$ ,  $SAR_{iw}$  and RSC (Table III). The values of coefficients of determination ( $R^2$ ) are highly significant and predicted  $EC_e$ , SAR and yield were fairly close to the observed values (five extra treatments) of these dependent variables.

The  $EC_e$  of undisturbed and disturbed soils increased with an increase in  $EC_{iw}$ . At "0" coded levels of  $SAR_{iw}$  and RSC, the  $EC_e$  increased from 2.20 to 7.42 and 2.14 to 7.30 dS  $m^{-1}$  for both the undisturbed and disturbed soil conditions, respectively (Fig. 2). Soil  $EC_e$  with  $EC_{iw}$  0.65, 2.0, 4.0, 6.0 and 7.35 dS  $m^{-1}$  was 2.20, 3.31, 5.21, 6.83 and 7.42 dS  $m^{-1}$ ; 2.14, 3.24, 5.10, 6.71 and 7.30 dS  $m^{-1}$ , respectively which was 3.07, 56.5, 75.75, 77.5 and 71 % of the EC of respective water used for irrigation for the undisturbed and disturbed soils. The increase in soil salinity was more with  $EC_{iw}$  at higher than that at lower levels of  $SAR_{iw}$  and RSC for both the soil conditions. Lower soil  $EC_e$  resulted with similar  $EC_{iw}$  at given coded levels of  $SAR_{iw}$  and RSC in the undisturbed than that in disturbed soil columns. Increase in soil  $EC_e$  with  $EC_{iw}$  of normal soils were reported by Singh *et al.* (1992) and Rashid *et al.* (1994). Results indicated that  $EC_e$  was < 4.0 dS  $m^{-1}$  with  $EC_{iw}$  up to 2.0 dS  $m^{-1}$  at given levels of  $SAR_{iw}$  and RSC, which was > 4.0 dS  $m^{-1}$  with  $EC_{iw} \geq 4.0$  dS  $m^{-1}$  at all the five levels of  $SAR_{iw}$  and RSC. The  $EC_e$  4.0 dS  $m^{-1}$  is the upper limit for saline-sodic soils (U.S. Salinity Lab. Staff, 1954).

Soil  $EC_e$  increased significantly with  $SAR_{iw}$  at given  $EC_{iw}$  and  $SAR_{iw}$  for both the soil conditions (Fig. 2). At  $EC_{iw}$  and RSC levels of 4.0 dS  $m^{-1}$  and 4.0 mmol $_e$   $L^{-1}$ ,

higher  $SAR_{iw}$  32.0 resulted in more  $EC_e$  (6.11 and 6.06 dS  $m^{-1}$ ) for the undisturbed and disturbed soils, the  $EC_e$  remained higher than with  $SAR_{iw} > 3.95$  (Table III). At given  $EC_{iw}$  and  $SAR_{iw}$ , the RSC waters tended to decrease  $EC_e$ . The  $EC_e$  of undisturbed and disturbed soil behaved similarly to RSC waters at coded "0" levels of  $EC_{iw}$  and  $SAR_{iw}$  (Fig. 2). Results indicated that RSC of waters resulted in lower  $EC_e$  at coded levels of -1 and -1.682 than that at coded levels of 0, 1 and 1.682 of  $EC_{iw}$  and  $SAR_{iw}$ . The  $EC_e$  with  $SAR_{iw}$  up to 18 was < 4.0 dS  $m^{-1}$  at coded -1 and -1.682 levels of both the  $EC_{iw}$  and RSC. Contrary to this, the  $EC_e$  was > 4.0 dS  $m^{-1}$  with  $SAR_{iw} \geq 18$  at coded 0, 1 and 1.682 levels of both the  $EC_{iw}$  and RSC. Higher  $SAR_{iw}$  at a given  $EC_{iw}$  and/or RSC levels increased  $EC_e$  more than that with lower  $SAR_{iw}$  in both the soil conditions. This might be due to reduced permeability of soil resulting from irrigation with high sodicity (SAR and RSC) of waters, as a decrease in hydraulic conductivity was observed with high  $SAR_{iw}$  (Table III). A linear reduction in  $EC_e$  was noted with RSC of waters at given levels of  $EC_{iw}$  and  $SAR_{iw}$ . It has been reported that  $HCO_3^-$  of water decreased soil salinity through precipitation of  $Ca^{2+}$  and  $Mg^{2+}$  (Muhammed & Rauf, 1983).

**Soil sodication (SAR).** The SAR was higher with  $EC_{iw}$  at coded levels of 0, 1 and 1.682 than that at -1.682 and -1 levels of  $SAR_{iw}$  and RSC, respectively (Table III). At given  $SAR_{iw}$  and RSC, the  $EC_{iw}$  increased soil SAR under both the soil conditions (Fig. 3). Similar SAR resulted with  $EC_{iw} \geq 0.65$  dS  $m^{-1}$  for undisturbed and disturbed soils at coded levels 1 and 1.682 of both the  $SAR_{iw}$  and RSC. Bajwa *et al.* (1992) reported an increase in SAR of normal soils with an increase in  $EC_{iw}$ . An increase in soil SAR with increasing  $EC_{iw}$  at given  $SAR_{iw}$  and RSC may be due to greater formation of calcium carbonate and magnesium silicate

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

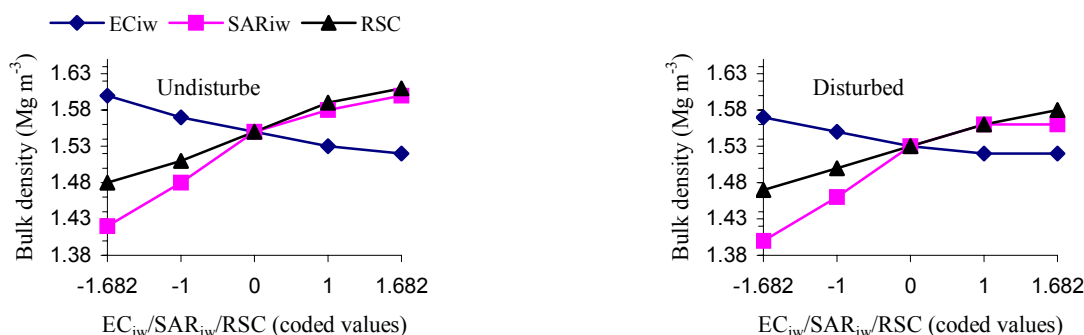
(Eaton, *et al.*, 1968). In general, at a given  $EC_{iw}$  and RSC, increasing  $SAR_{iw}$  increased SAR, the effect being more pronounced at higher coded levels 0, 1 and 1.682 of both the  $EC_{iw}$  and RSC. Soil SAR receiving water of SAR 3.95, 9.65, 18.0, 26.35 and 32.04 attained SAR levels of 7.16, 13.26, 25.03, 34.29 and 35.39, respectively which is 97, 103, 121, 117 and 100 % of the  $SAR_{iw}$  at coded "0" levels of  $EC_{iw}$  and RSC for the undisturbed soil. The corresponding SAR of disturbed soil was 6.73, 12.82, 24.38, 34.09 and 34.87, which is 86, 98, 119, 117 and 98 % of the  $SAR_{iw}$ .

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. Higher levels of  $Na^+$ ,  $HCO_3^-$  and  $SAR_{iw}$  resulted in a higher  $Na^+$  saturation of soil at a given  $EC_{iw}$  and RSC. The increase in soil SAR with RSC of water was more at coded "1.682" levels of  $EC_{iw}$  and  $SAR_{iw}$  than that for the remaining levels of  $EC_{iw}$  and  $SAR_{iw}$ . Furthermore, at coded "0" levels of  $EC_{iw}$  and  $SAR_{iw}$ , increase in soil SAR was for disturbed than that for undisturbed columns with similar RSC (Fig. 3). This could be due to high RSC of waters, which caused formation of  $Na_2CO_3$  and  $NaHCO_3$  in soils, thereby more sodic of soil (Gupta, 1980).

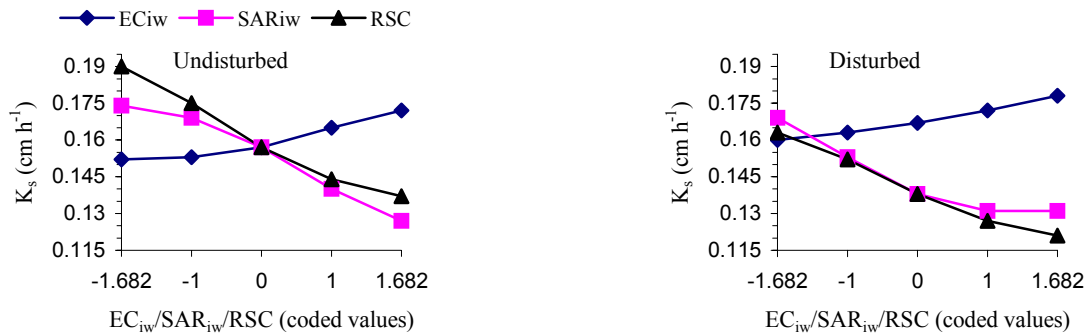
**Soil bulk density.** In general, bulk density of soil decreased with an increase in electrolytes at a given SAR and RSC of waters. It decreased from 1.60 to 1.53 and 1.57 to 1.52  $Mg\ m^{-3}$

with an increase in  $EC_{iw}$  at coded "0" levels of  $SAR_{iw}$  and RSC for both the undisturbed and disturbed soils, respectively (Fig. 4). Reduction in bulk density of both the soil conditions was more with  $EC_{iw}$  at low coded -1 and -1.682 than that at high coded 1 and 1.682 levels of  $SAR_{iw}$  and RSC. Both the soil conditions behaved almost similarly to  $EC_{iw}$  at given levels of  $SAR_{iw}$  and RSC. It has been reported that bulk density was reduced from 0.04 to 0.06  $Mg\ m^{-3}$  with  $EC_{iw}$  2.98  $dS\ m^{-1}$  and SAR 8.0 for 0-15 cm depth (Coasta *et al.*, 1991). This decrease in bulk density was attributed to  $Ca^{2+}_{iw}$  (6.3 to 11.6  $mmol\ L^{-1}$ ) and  $Ca^{2+}_{iw}$  could help flocculation of soil particles, resulting in decreased bulk density (U.S. Salinity Lab. Staff, 1954).

At given  $EC_{iw}$ , RSC and/or  $SAR_{iw}$ , SAR and RSC of waters increased the bulk density. The bulk density increased from 1.40 to 1.56  $Mg\ m^{-3}$  with  $SAR_{iw}$  from 3.95 to 26.35, remained constant with further increase in  $SAR_{iw}$  for the disturbed soil at coded "0" levels of both the  $EC_{iw}$  and RSC (Fig. 4). Contrary to this, bulk density of the undisturbed soil decreased with  $SAR_{iw}$  from 3.95 to 32.04 at coded "0" levels of both the  $EC_{iw}$  and RSC, increase in bulk density with  $SAR_{iw}$  being more pronounced at lower coded than that at higher coded levels of  $EC_{iw}$  and RSC. At coded "0" levels of both the  $EC_{iw}$  and  $SAR_{iw}$ , increase in bulk density with RSC of waters was more in the undisturbed than that in the disturbed (Fig. 4), being more at low coded

**Fig. 4.** Effect of  $EC_{iw}$ ,  $SAR_{iw}$  and RSC on soil bulk density

**Fig.5. Effect of  $EC_{iw}$ ,  $SAR_{iw}$  and RSC on saturated hydraulic conductivity ( $K_s$ ) of soil**



than that at higher coded levels of  $EC_{iw}$  and  $SAR_{iw}$ .

The increase in bulk density with  $SAR_{iw}$  was more at coded -1.682 levels of  $EC_{iw}$  and RSC as compared with similar levels of  $SAR_{iw}$  at coded "-1, 0, 1 and 1.682" levels of  $EC_{iw}$  and RSC in both the types of columns. More increase in bulk density was noted with similar  $SAR_{iw}$  for the undisturbed than that for the disturbed soils. Similar trend in bulk density was recorded for undisturbed and disturbed soil with RSC water at coded "0" levels of  $EC_{iw}$  and  $SAR_{iw}$ . Higher bulk density was recorded for undisturbed than that for disturbed columns with  $SAR_{iw}$  and/or RSC at given levels of  $EC_{iw}$ , RSC and/or  $SAR_{iw}$ . Accumulation of  $Na^+$  ions on exchange sites with high SAR water might have decreased the pore space to affect an increase in bulk density.

**Saturated hydraulic conductivity ( $K_s$ ).** An increased in  $EC_{iw}$  at a given  $SAR_{iw}$  and RSC increased the  $K_s$  of both the soil conditions. At coded "0" levels of  $SAR_{iw}$  and RSC, the  $K_s$  increased from 0.152 to 0.172 and 0.160 to 0.178  $cm\ h^{-1}$  for undisturbed and disturbed soil conditions as  $EC_{iw}$  increased from 0.65 to 7.35  $dS\ m^{-1}$ , respectively. Higher  $K_s$  was recorded with  $EC_{iw}$  at lower coded than that at higher coded levels of  $SAR_{iw}$  and RSC (Table III). The  $K_s$  with  $EC_{iw}$  7.35  $dS\ m^{-1}$ , SAR 32.04 and RSC 7.35  $mmol_c\ L^{-1}$  was, in general, one-half of that with  $EC_{iw}$  7.35  $dS\ m^{-1}$ ,  $SAR_{iw}$  3.95 and RSC 0.65  $mmol_c\ L^{-1}$  for the undisturbed soil columns. The values of  $K_s$  were noted for disturbed than that for undisturbed soil with similar  $EC_{iw}$  and at a given  $SAR_{iw}$  and RSC. At similar  $EC_{iw}$ , higher values of  $K_s$  were noted at low (-1.682 and -1) than that at high (0, 1 and 1.682) coded levels of  $SAR_{iw}$  and RSC which could be due to high  $Na^+$  and  $HCO_3^-$  in water that reduced the porosity of soil.

At given  $EC_{iw}$  and RSC, the  $SAR_{iw}$  affected a decrease in  $K_s$ , magnitude being differed for the undisturbed and disturbed soil columns (Fig. 5). At coded "0" levels of both the  $EC_{iw}$  and RSC, more decrease in  $K_s$  was resulted with  $SAR_{iw}$  in undisturbed than that in the disturbed soil. Similar was the case in  $K_s$  with  $SAR_{iw}$  at all other coded levels of  $EC_{iw}$  and RSC (Table III). The decrease in  $K_s$  was also

noted with RSC of waters at a given levels of  $EC_{iw}$  and  $SAR_{iw}$  (Fig. 4). At coded "0" levels of  $EC_{iw}$  and  $SAR_{iw}$ , decrease in  $K_s$  with RSC waters was more for undisturbed than that in the disturbed soil. Higher  $K_s$  (0.137  $cm\ h^{-1}$ ) resulted with similar RSC of waters (7.35  $mmol_c\ L^{-1}$ ) in the undisturbed than that in disturbed (0.12  $cm\ h^{-1}$ ) soils at coded "0" levels of  $EC_{iw}$  and  $SAR_{iw}$ . A reduction in  $K_s$  with RSC from 0.65 to 7.35  $mmol_c\ L^{-1}$  was more at coded "-1.682 and -1" (lowest levels) than that at coded "1 and 1.682" (highest levels) levels of  $EC_{iw}$  and  $SAR_{iw}$  (Table III).

High SAR and/or RSC of waters affected a decrease in  $K_s$  at given levels of  $EC_{iw}$ , RSC and/or  $SAR_{iw}$  under both the soil conditions (Fig. 5). At coded "0" levels of  $EC_{iw}$  and RSC, reduction in  $K_s$  with  $SAR_{iw}$  was more in the undisturbed than that in the disturbed soil columns. Similar was the case with RSC of waters at given levels of  $EC_{iw}$  and  $SAR_{iw}$ . At similar  $SAR_{iw}$  and/or RSC of waters, higher  $K_s$  was noted at low than that at high coded values of  $EC_{iw}$ , RSC and/or  $SAR_{iw}$ . At a given SAR, dispersion potential of a low  $EC_{iw}$  is greater than that for  $EC_{iw}$  (Suarez & Lebron, 1993). There was positive relationship between soil SAR and  $SAR_{iw}$  (Fig. 3). High  $SAR_{ss}$  or  $SAR_{iw}$  has to defloccule soils and consequently a decrease in  $K_s$ . Irrigation water having higher concentration of  $Na^+$  increased replaced  $Ca^{2+}$  from exchange sites. Replacement  $Ca^{2+}$  by high hydrated size  $Na^+$  could not neutralize net negative charge on soil colloids (Bohn *et al.*, 1985), which caused dispersion, hence decrease in soil porosity and hydraulic conductivity. Translocations of particle into pores are considered important factors to decrease hydraulic conductivity of salt-affected soils (Rengasamy *et al.*, 1984).

## CONCLUSIONS

The wheat yield decreased linearly with an increase in  $EC_{iw}$  at given levels of  $SAR_{iw}$  and RSC. Economic wheat yield could be maintained with  $SAR_{iw}$  up to 18.0 at  $EC_{iw}$  and RSC up to 4.0  $dS\ m^{-1}$  and 4.0  $mmol_c\ L^{-1}$ , respectively for the undisturbed and disturbed soils. The RSC of waters up to 2.0 and 4.0  $mmol_c\ L^{-1}$  were observed safe for wheat at

levels of  $EC_{iw}$  up to  $4.0 \text{ dS m}^{-1}$  and  $SAR_{iw}$  up to 18.0 for the undisturbed and disturbed soils, respectively. It could be concluded that whole of the undisturbed and disturbed soil profile attained  $EC_e > 4.0 \text{ dS m}^{-1}$  and  $SAR > 13.0$  with designed  $EC_{iw}$ ,  $SAR_{iw}$  and/or RSC which are the upper limits for saline-sodic soils. The effect of  $SAR_{iw}$  and/or RSC of waters on bulk density and saturated hydraulic conductivity was more pronounced at coded 0, 1 and 1.682 than that -1.682 and -1 levels of both the  $EC_{iw}$  and RSC;  $EC_{iw}$  and  $SAR_{iw}$ .

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