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BRACKISH WATER FOR IRRIGATION: IV. EFFECTS ON YIELD OF MAIZE (*ZEA MAYS* L.) AND SATURATED HYDRAULIC CONDUCTIVITY OF SOIL

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Abstract: The experiment was conducted to investigate the effect of brackish water irrigation on fresh biomass yield of maize variety Agati-72 and saturated hydraulic conductivity (HC) of silty clay loam soil. Total 20 treatment combinations having different EC_{iw} (0.65, 2.0, 4.0, 6.0 and 7.35 dS m^{-1}), SAR_{iw} [3.95, 9.65, 18.0, 26.35 and 32.04 $(mmol\ L^{-1})^{1/2}$] and RSC (0.65, 2.0, 4.0, 6.0 and 7.35 $mmol_c\ L^{-1}$) were applied to 30 cm x 68 cm undisturbed and disturbed soil columns. Results indicated that biomass yield of maize decreased with an increase in EC_{iw} from 0.65 to 7.35 dS m^{-1} at coded "0" levels of SAR_{iw} and RSC in undisturbed soil. The maize tolerated EC_{iw} up to 2.0 dS m^{-1} at coded "0" levels of SAR_{iw} and RSC in disturbed soil. The SAR_{iw} up to 18.0 did not affect the yield of crop at coded "0" levels of EC_{iw} (4.0 dS m^{-1}) and RSC (4.0 $mmol_c\ L^{-1}$) in both soil conditions. The RSC up to 2.0 and 4.0 $mmol_c\ L^{-1}$ did not affect the yield at coded "0" levels of SAR_{iw} and EC_{iw} for the undisturbed and disturbed soils, respectively. The increase in HC was 48% in undisturbed and 54% in disturbed soils with EC_{iw} 7.35 dS m^{-1} over EC_{iw} 0.65 dS m^{-1} coded "0" levels of EC_{iw} and RSC. The HC decreased with SAR_{iw} and RSC at coded "0" levels of EC_{iw} and RSC; EC_{iw} and SAR_{iw} in both the soil columns.

Keywords: Brackish water, maize, saturated hydraulic conductivity.

INTRODUCTION

For successful irrigated agriculture, both quality and quantity of water are of significant importance. Canal water is gradually becoming short to meet the crop water requirement. The canal water supplies are being supplemented by using groundwater, in spite of its questionable quality [Khan *et al*. 1990]. The use of groundwater is likely to affect the health and productivity of the soil adversely.

Continuous use of brackish water has resulted in deterioration of soil health and reduced crop yield [Saleem *et al*. 1993, Singh *et al*. 1992]. High concentration of salts in soil solution reduces the water availability to plants. Magistad [1965] observed that in saline soil the principal factor depressing the crop growth was the decrease in available water due to high osmotic pressure of the soil solution, by the dehydration of cell contents and inference of ions.

Sufficient work does not seem to have been done in the past to predict the rate at which yield and saturated hydraulic conductivity started declining with EC_{iw}, SAR_{iw} and/or RSC under the undisturbed soil conditions. Most of the research work has been done previously using limited number of combinations of EC_{iw}, SAR_{iw} and/or RSC. The present study 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 biomass yield of maize and saturated hydraulic conductivity of soil.

MATERIALS AND METHODS

The experiment was conducted in a net-house, University of Agriculture, Faisalabad during 1994. The physico-chemical properties of the soil were: sand 35%; silt 50%; clay 15% (silty clay loam); pH_s 7.7; EC_e 2.2 dS m^{-1}; SAR 3.3 (mmol $L^{-1})^{1/2}$; $CaCO_3$ 6.8% ; CEC 10.4 $cmol_c$ 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) was placed on the upper edge of the cylinder. Cylinder was 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. 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 details of procedure have been discussed earlier [Abid *et al*. 2002].

IRRIGATION WATER QUALITY

Twenty treatment combinations having different EC_{iw}, SAR_{iw} and RSC levels were selected following Central Composite Rotatable Second Order Design [Montgomery 1997]. 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 relationships between coded levels and actual levels for EC_{iw}, SAR_{iw} and RSC are given by Eqs. (1 – 3) at the foot of Table 1.

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 were applied to the respective soil columns. After the harvest of wheat 1993-94 crop, eight seeds of maize variety Agati-72 were sown in both the undisturbed and disturbed soil columns on August 17, 1994. The plants were thinned out to four in each column 10-days after germination. The N, P and K were applied @ 100, 60, 50 kg ha^{-1} as urea, triple super phosphate and potassium sulphate, respectively. All the P, K and half of the N were applied at the time of sowing. The remaining N was applied 25-days after germination. The plants were irrigated with brackish water (Table 1) and were harvested 50 days after germination. After harvesting the crop, saturated hydraulic conductivity was determined with falling head method [Jury *et al*. 1991].

Table 1: Treatment combinations used in experiment.

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

Where: x_1, x_2 and x_3 are the coded scales for EC_{iw}, SAR_{iw} and RSC.

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

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

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

DATA ANALYSIS

The coefficients presented in Table 2 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:

$$\log \hat{y}_i = \beta_0 + \beta_I x_i + \beta_{II} x_i^2$$

Table 2: Regression coefficients (b) and coefficient of determination (R^2) for fresh biomass yield of maize (g pot^{-1}) and saturated hydraulic conductivity of soil 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
Fresh biomass yield of maize											
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**
Saturated hydraulic conductivity											
Undisturbed	-1.222**	0.217**	-0.077**	-0.077*	-0.051ns	-0.039ns	-0.035ns	0.002ns	0.001ns	0.006ns	0.870**
Disturbed	-1.280**	0.230**	-0.083**	-0.087*	-0.041ns	-0.041ns	-0.029ns	0.001ns	-0.002ns	0.007ns	0.854**

* = Significant at 0.01 level of probability; ** = Significant at 0.05 level of probability; ns = Non-significant

To predict 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.

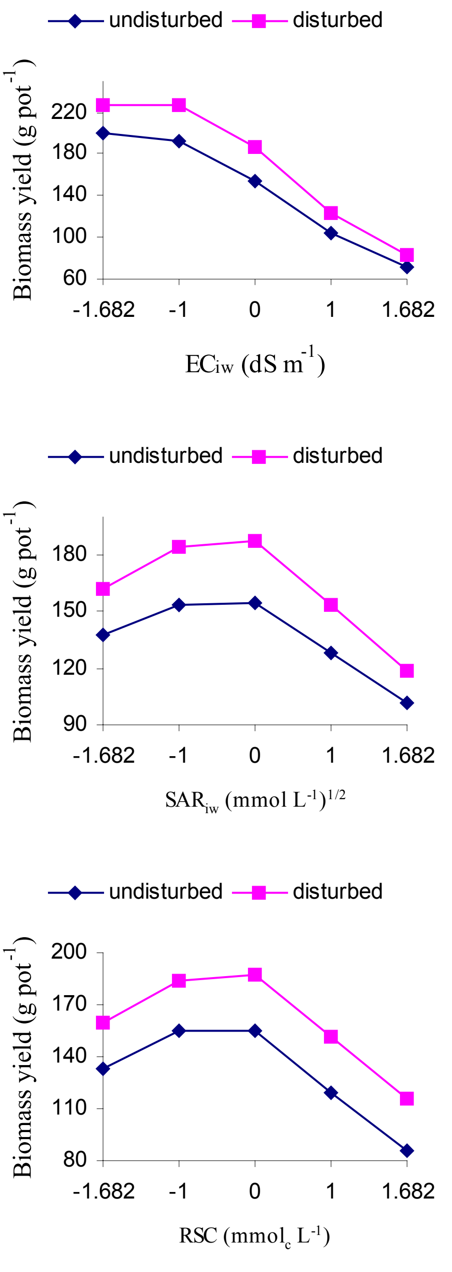

Fig. 1. Effect of EC_{iw}/SAR_{iw}/RSC on biomass yield of maize.

RESULTS AND DISCUSSION

FRESH BIOMASS YIELD OF MAIZE

Results presented in Table 2 indicated that fresh biomass yield of maize decreased with EC_{iw} at coded "0" levels of SAR_{iw} [18.0 (mmol $L^{-1})^{1/2}$] and RSC [4.0 mmol$_c$ L^{-1}] in both the undisturbed and disturbed soils. At given levels of SAR_{iw} and RSC, the reduction in yield was more with EC_{iw} for undisturbed soil than that for disturbed one. For instance, the reduction in yield was 64% for undisturbed and 56% for disturbed soil with EC_{iw} 7.35 dS m^{-1} at coded "0" levels of SAR_{iw} and RSC. About 50% reduction in yield occurred with EC_{iw} 6.0 dS m^{-1} at coded "0" levels of SAR_{iw} and RSC (Fig. 1). Similar results were reported by Abid *et al*. [2002] and Shirazi *et al*. [1971]. The decrease in yield was even more pronounced with EC_{iw} 7.35 dS m^{-1} at coded "1 and 1.682" than at coded "-1.682 and -1" levels of SAR_{iw} and RSC (Table 2). The rate of decrease in yield was 74 and 50% with EC_{iw} 7.35 dS m^{-1} over EC_{iw} 0.65 dS m^{-1} at higher coded "1.682" than that at lower coded "-1.682" levels of SAR_{iw} and RSC. Moreover, greater biomass yield was predicted with the same EC_{iw} from the disturbed than that from the undisturbed soils at given levels of SAR_{iw} and RSC. Pasternak *et al*. [1985] reported that maize yield decreased by 50 % with EC_{iw} 7.0 dS m^{-1}. At coded "-1.682" levels of SAR_{iw} and RSC, the yield increased with EC_{iw} up to 2.0 dS m^{-1}, thereafter it decreased with further increase in EC_{iw} from 2.0 to 7.35 dS m^{-1} in both the undisturbed and disturbed soil conditions.

It is evident from Fig. 1 that maize yield increased with SAR_{iw} up to 18.0 in the undisturbed and disturbed soil columns at coded "0" levels of EC_{iw} (4.0 dS m^{-1}) and RSC (4.0 mmol$_c$ L^{-1}). The rate of yield reduction with SAR_{iw} was the same for both the soils at coded "0" levels of EC_{iw} and RSC. However, the rate of decrease in maize yield was more with SAR_{iw} in the undisturbed particularly at coded"1 and 1.682" levels of EC_{iw} and RSC. For instance, the reduction in yield with SAR_{iw} 32.04 was 29 and 25%; 31 and 23% for the undisturbed and disturbed soil, respectively over SAR_{iw} 3.95 at coded "1 and 1.682" levels of EC_{iw} and RSC. At higher coded "1 and 1.682" levels of EC_{iw} and RSC, the yield of maize increased with SAR_{iw} up to 9.65 in both the undisturbed and disturbed soils. Contrary to this, the yield increased with SAR_{iw} up to 18.0 at coded "1 and 1.682" levels of EC_{iw} and RSC in the disturbed soils (Table 2). Comparatively more yield was predicted with similar SAR_{iw} from the disturbed than that from the undisturbed soils at coded "0" levels of EC_{iw} and RSC. Reduction in biomass yield of maize variety Sultan with sodic water was reported by Qayyum [2000]. The adverse effect of SAR_{iw} was even more severe on yield at higher EC_{iw} and RSC than that at lover levels of EC_{iw} and RSC in the present studies. It might be due to that higher levels of SAR_{iw} increased exchangeable sodium percentage and pH_s of soils and this environment probably resulted in nutritional imbalance and consequently decreased the crop yields [Khandelwal and

Lal 1991]. Pearson [1960] reported that accumulation of exchangeable Na might cause the mechanical impedance to roots penetration to poor soil structure prevailing to the root zone.

Fig. 1 indicated that yield increased with RSC up to 2.0 $mmol_c\ L^{-1}$ at coded "0" levels of EC_{iw} and SAR_{iw} in undisturbed soil, thereafter it decreased with further increase in the RSC. Contrary to this, the yield increased with RSC up to 4.0 $mmol_c\ L^{-1}$ for the disturbed soil (Fig. 1). The rate of reduction in the yield was more (35%) with RSC 7.35 $mmol_c\ L^{-1}$ in the undisturbed than that of disturbed (27%) over RSC 0.65 $mmol_c\ L^{-1}$. This indicated that high RSC water is more injurious to yield particularly to the undisturbed soils. Similar trend in yield with RSC waters was noted at coded "-1.682, -1, 0, 1 and 1.682" levels of EC_{iw} and SAR_{iw} (Table 2). Low yield with high RSC waters may be due to toxic effect of bicarbonate ions [Muhammed and Rauf 1983]. Excessive bicarbonate ions in irrigation water may have adverse effect on nutrition of plants and tend to cause chlorosis [Miller 1959].

SATURATED HYDRAULIC CONDUCTIVITY (HC)

The HC increased with electrolyte concentration in irrigation water at given levels of SAR_{iw} and RSC for both the soil conditions (Fig. 2). At coded "0" levels of SAR_{iw} and RSC, the increase in HC was 54% more in the disturbed than that in the undisturbed (48%) soil columns. Higher HC was observed with similar EC_{iw} at lower coded "-1.682 and –1" than higher coded"1 and 1.682" levels of SAR_{iw} and RSC (Table 2). For instance, the HC values with EC_{iw} 7.35 dS m^{-1} were 0.20 and 0.23 cm h^{-1}; 0.19 and 0.23 cm h^{-1} at coded "-1.682 and 1.682" levels of SAR_{iw} and RSC. Suarez and Lebron [1993] reported that high saline water tended to flocculate the soil particles, which in turn increased the HC of the soils.

In general, the SAR_{iw} and/or RSC waters at given levels of EC_{iw} and RSC; EC_{iw} and SAR_{iw} have resulted decrease in HC for both the soil conditions. It was noted that HC for both the soils increased with SAR_{iw} up to 9.65, decreased with further increase in SAR_{iw} from 9.65 to 32.04 (Fig. 2). Decrease in HC was more (25%) with SAR_{iw} 32.04 in the undisturbed than that in the disturbed soils (23%) over SAR_{iw} 3.95 at coded "0" levels of EC_{iw} and RSC. Reduction in HC was more with similar SAR_{iw} at lower coded "-1.682 and -1" than that at higher coded "1 and 1.682" levels of EC_{iw} and RSC (Table 2). This decrease was 57 and 62%; 23 and 27% with SAR_{iw} 32.04 over SAR 3.95, respectively at coded "-1.682 and 1.682" levels of EC_{iw} and RSC. Similar trend in HC was noted with RSC waters at given levels of EC_{iw} and SAR_{iw}. There was an increase in HC with RSC waters up to 2.0 $mmol_c\ L^{-1}$ for both the soil conditions (Fig. 2) at coded "0" levels of EC_{iw} (4.0 dS m^{-1}) and SAR_{iw} (18.0), thereafter it decreased with further increase in RSC from 2.0 to 7.35 $mmol_c\ L^{-1}$. However, this increase in HC with RSC 2.0 $mmol_c\ L^{-1}$ was more in the undisturbed than that in the disturbed soils. It is apparent from Table 2 that there was more reduction in HC with RSC 7.35 $mmol_c\ L^{-1}$ in the undisturbed soil (56% and 54%) than that in the disturbed soil (25.11% and 23.12 %) over RSC 0.65 $mmol_c\ L^{-1}$. Irrigation water having higher concentration of Na^+ increased replaced Ca^{2+} from exchange sites. Replacement of Ca^{2+} by high hydrated size Na^+ could not neutralize net negative charge on soil colloids (Bohn *et al*. 1985), which caused dispersion, hence decreased in soil porosity and hydraulic conductivity.

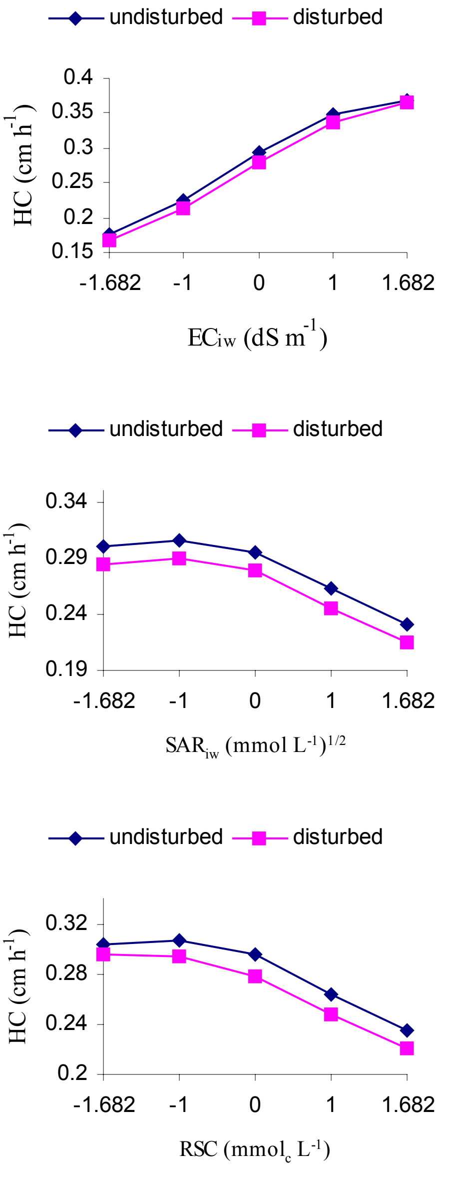

Fig. 2. Effect of EC_{iw}, SAR_{iw} and RSC on hydraulic conductivity ($cm\ h^{-1}$).

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