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CORRELATION OF BRACKISH WATER AND PHYSICAL PROPERTIES OF SILTY CLAY LOAM SOIL

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This experiment was conducted at University of Agriculture, Faisalabad to evaluate the effect of brackish water on r,hr:sical properties of silty clay loam soil [Bhalwal series, pH_s = 7.70, EC_e = 3.20 dS m" and SAR = 3.70 (mmol L-) 1 2]. Forty disturbed and undisturbed soil columns (20 in each case, 76 cm long and 30 cm diameter) were used. The synthetic brackish waters having different EC (0.64, 2.0, 4.0, 6.0 and 7.35 dS rn"), SAR [3.95, 9.65, 18.0, 26.35 and 32.0 (mmol L-) 1/2] and RSC {0.64, 2.0, 4.0, 6.0 and 7.35 rnrnol, L-1} were applied to these soil columns for three years. Synthetic brackish waters were prepared by dissolvinq the required amount of salts (NaCl, Na_2SO_4, $NaHCO_3$, $CaCl_2.6H_2O$, $MgSO_4.7H_2O$ and NH_4HCO_3) in canal/distilled water. Soil samples were obtained from these soil columns for various physical determinations after three years. The Central Composite Rotatable Second Order Incomplete Factorial design with three variables each at five levels was followed to analyze the data. Saturated hydraulic conductivity and saturation percentage of soil was increased with the increase in EC_{iw} in disturbed as well as undisturbed soil columns. Correlation of SAR_{iw} and RSC with hydraulic conductivity and saturation percentage was found to be negative. Bulk density of soil was not affected with EC_{iw} under both soil conditions but it significantly increased with the increase in either SAR_{iw} or RSC. The effect of EC_{iw}, SAR_{iw} and RSC of water on soil porosity was exactly similar as in case of bulk density because it was calculated from the latter.

INTRODUCTION

Brackish water has been regarded the major cause of accelerated salinity in Pakistan. Thus, a prosper future in agriculture can be guaranteed only if we discover how to use brackish ground water for crop production. Most of the literature available regarding use of brackish water is on disturbed soil but unfortunately a little is known about the long term effect of saline ground water under undisturbed soil conditions. The disturbed soil samples are not good representative of in-situ soil conditions. Therefore, it appears a pressing need for developing a rationale about brackish water use to irrigate soils both under disturbed and undisturbed conditions. It might be possible to predict the effects of different quality waters under field conditions from the data collected under undisturbed soil conditions. Keeping in view these considerations, the present study was undertaken to investigate the effect of brackish water on a silty clay loam (Bhalwal series) soil with the following objectives:

- To monitor the effects of brackish water on physical properties of a silty clay loam soil.
- To evaluate the differences between disturbed and undisturbed soil conditions regarding effects of brackish water irrigation on soil physical properties.

MATERIALS AND METHODS

A silty clay loam soil was selected for this experiment. Twenty undisturbed soil columns (76 cm long and 30 cm internal diameter) were filled in-situ, where as for disturbed soil columns, soil was collected from the same site, brought to wire house, sieved, well mixed and then filled in similar metallic columns.

Experimental design and statistical methods

For the selection of treatment combinations, Central Composite Rotatable Second Order Incomplete Factorial design (Box and Draper, 1987) with three variables each at five levels was followed. These levels were coded as -1.682, -1, 0, +1 and +1.682. This design permits on the basis of coded values, the calculations of quadratic regression equations, which can be used to characterize the response surface (Y) of physical and chemical characteristics of soil as affected by the interaction between any two variables. This type of design is especially important in exploratory experiments because it eliminates the need for a large number of treatments. The treatment in which all the variables were set at the third coded ("0" level) value of the five designed levels was repeated six times and the variation within this replicated treatment was used to estimate the experimental error. Quadratic multiple regression equation was used for predicting the values of hydraulic conductivity, bulk density, percent pore space and saturation percentage to characterize the response surface of these parameters as affected by interactions between any two variables. A generalized form of this is given as under

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3$$

where

Y	=	Quadratic factor to be measured
b_0	=	Regression coefficient for treatment effect
b_1, b_2, b_3	=	Regression coefficient for X_1, X_2, X_3, respectively.

b_{11}, b_{22}, b_{33} = Repression coefficient for X_1^2, X_2^2, X_3^2, respectively.
X_1, X_2, X_3 = Coded level of EC, SAR and RSC, respectively.

Coded scale and variable levels: Three treatments, i.e. EC, SAR and RSC each at five levels were studied and the levels were coded as shown in Table 1.

Table 1. Designed and coded values of EC_{iw}, SAR_{iw} and RSC variables

Coded Value	EC (dS m⁻¹)	SAR $(mmol\ L^{-1})^{1/2}$	RSC $(mmol_c\ L^{-1})$
-1.682	0.64	3.95	0.64
-1	2.0	9.65	2.0
0	4.0	18.00	4.0
+1	6.0	26.35	6.0
+1.682	7.35	32.04	7.35

samples were obtained from each column and analyzed for various soil parameters at the end of three years. Saturated hydraulic conductivity was determined by. Falling Head Permeameter method (Jury *et al.,* 1991) while bulk density, percent pore space and saturation percentage of soil were determined according to the methods of U.S. Salinity Lab. Staff (1954). The crop data was published separately.

* = Coded scales of EC, SAR and RSC of irrigation waters according to the design.

** = Original treatment levels according to the design.

RESULTS AND DISCUSSION

In this study, significant regression coefficient for the three variables involved (EC, SAR and RSC) will indicate the overall effect on physical properties of the soil. A positive sign of the regression coefficient

Table 2: Treatment combinations in relation with coded scales and original variable levels.

Treatment No.	* X_1	* X_2	* X_3	**EC (dSm^{-1})	**SAR $(mmol\ L^{-1})^{1/2}$	**RSC $(mmol_c\ L^{-1})$
1	-1	-1	-1	2.0	9.65	2.0
2	+1	-1	-1	6.0	9.65	2.0
3	-1	+1	-1	2.0	26.35	2.0
4	+1	+1	-1	6.0	26.35	2.0
5	-1	-1	+1	2.0	9.65	6.0
6	+1	-1	+1	6.0	9.65	6.0
7	-1	+1	+1	2.0	26.35	6.0
8	+1	+1	+1	6.0	26.35	6.0
9	-1.682	0	0	0.64	18.00	4.0
10	+1.682	0	0	7.35	18.00	4.0
11	0	-1.682	0	4.0	3.95	4.0
12	0	+1.682	0	4.0	32.04	4.0
13	0	0	-1.682	4.0	18.00	0.64
14	0	0	+1.682	4.0	18.00	7.35
15	0	0	0	4.0	18.00	4.0
16	0	0	0	4.0	18.00	4.0
17	0	0	0	4.0	18.00	4.0
18	0	0	0	4.0	18.00	4.0
19	0	0	0	4.0	18.00	4.0
20	0	0	0	4.0	18.00	4.0

According to this design, twenty treatment combinations were made using EC_{iw}, SAR_{iw} and RSC each at five levels (Table 2). Calculation of salts for developing the above mentioned levels of EC_{iw}, SAR_{iw} and RSC in canal/distilled water was done with the help of quadratic equation using the salts of NaCl, Na_2SO_4, $NaHCO_3$, $CaCl_2.6H_2O$, $MgSO_4.7H_2O$ and NH_4HCO_3. The designed brackish waters were applied in these soil columns continuously for three years. Soil

denotes the positive effect of the respective variable while a negative sign indicates a depressing effect of the parameter involved. The magnitude of the regression coefficient of the squared term of each variable (EC, SAR and RSC) determines the rate of increasing or decreasing effect of the particular parameter as the level of application increased. The regression coefficients of the interaction term indicate the amount of interaction between the two variables involved. The term significant will be used for an effect with probability of 5 percent and highly significant will be used for a probability of 1 percent. Effects that have regression values greater than the standard error may be discussed as being probably real.

undisturbed soil. However, SAR^2_{iw} was highly significant while RSC^2 was non-significant under both the soil conditions. None of the interaction was found to be significant.

Table 3. **Regression coefficient (b) and standard error (SE) for saturated hydraulic conductivity (Cm hr') of disturbed and undisturbed soils as affected by various combinations of EC, SAR and RSC of applied brackish water.**

Parameters	Coefficient	Disturbed soil		Undisturbed soil	
		b	SE	b	SE
Constant	b_0	0.0841 **	± 0.0025	0.1033 **	± 0.0045 **
EC	b_1	0.0051 **	± 0.0016	0.0054 NS	± 0.0030 NS
SAR	b_2	-0.0114 **	± 0.0016	-0.0099 **	± 0.0030 **
RSC	b_3	-0.0125 **	± 0.0016	-0.0133 **	± 0.0030 **
EC^2	b_{11}	0.0101 **	± 0.0016	-0.0016 NS	± 0.0029 NS
SAR^2	b_{22}	0.0163 **	± 0.0016	0.0099 **	± 0.0029 **
RSC^2	b_{33}	0.0023NS	± 0.0016	0.0004 NS	± 0.0029 NS
EC x SAR	b_{12}	~0.0019NS	± 0.0021	-0.0024 NS	± 0.0039 NS
EC x RSC	b_{13}	0.0006 NS	± 0.0021	0.0014 NS	± 0.0039 NS
SAR x RSC	b_{23}	0.0044 NS	± 0.0021	0.0051 NS	± 00039 NS
R2		96.3 %		82.8 %	

* = Significant at 5 % level of probability

** = Significant at 1 % level of probability

NS = Non-significant

Saturated Hydraulic Conductivity (K_s): The data indicated that an increase in EC_{iw} caused increase in the hydraulic conductivity of disturbed as well as undisturbed soil (Figure 1). In general, values for this parameter were slightly higher under the disturbed soil condition, However, higher SAR_{iw} and RSC of water decreased K_s. The correlation between EC_{iw} and K_s was highly significant in the disturbed soil but non-significant in case of undisturbed soil (Table 3), which was positive for both the soil types. The negative correlation between K_s and SAR_{iw} as well as RSC was found to be highly significant under both soil conditions. The square term of EC_{iw} was highly significant in disturbed while non-significant in

It might be possible that irrigation water having higher content of Na increased replacement of Ca by Na on exchange sites. The replacement of divalent ion (Ca) by the larger hydrated size monovalent (Na) ion could not neutralize negative charge on soil colloids, which probably caused dispersion. This dispersion decreased the porosity of the soil and as a result hydraulic conductivity decreased. Rhoades and Ingvalson (1969) reported the importance of dispersion and its impact in the reduction of soil permeability. Dane and Klute (1977) claimed that higher the value of SAR_{iw}, greater was the decrease in hydraulic conductivity. Similar results were obtained by Chaudhry et al. (1985) and Farooq (1992).

Table 4. Regression coefficient (b) and standard error (SE) for bulk density (Mg m^{-3}) of disturbed and undisturbed soils as affected by various combinations of EC, SAR and RSC of applied brackish water.

Parameters	Coefficient	Disturbed soil		Undisturbed soil	
		b	SE	b	SE
Constant	b_0	1.5253 **	± 0.0121	1.5252 **	± 0.0169
EC	b_1	-0.0124 NS	± 0.0080	-0.0195 NS	± 0.0112
SAR	b_2	0.0505 **	± 0.0080	0.0536 **	± 0.0112
RSC	b_3	0.0363 **	± 0.0080	0.0387 **	± 0.0112
EC^2	b_{11}	0.0087 NS	± 0.0078	0.0148 NS	± 00109
SAR^2	b_{22}	-0.0178 *	± 0.0078	-0.0082 NS	± 0.0109
RSC^2	b_{33}	-0.0001 NS	± 0.0078	-0.0078 NS	± 0.0109
EC x SAR	b_{12}	0.0125 NS	± 0.0105	0.0200 NS	± 0.0147
EC x RSC	b_{13}	0.0025 NS	± 0.0105	0.0025 NS	± 0.0147
SAR x RSC	b_{23}	-0.0075 NS	± 0.0105	-0.0000 NS	± 0.0147
R2		87.7 %		81.0 %	

* = Significant at 5 % level of probability

** = Significant at 1 % level of probability

NS = Non-significant

Table 5. Regression coefficient (b) and standard error (SE) for percent pore space of disturbed and undisturbed soils as affected by various combinations of EC, SAR and RSC of applied brackish water.

Parameters	Coefficient	Disturbed soil		Undisturbed soil	
		b	SE	b	SE
Constant	b_0	42.439 **	± 0.457	41.813 **	± 0.449
EC	b_1	0.470 NS	± 0.303	0.737 *	± 0.298
SAR	b_2	-1.905 **	± 0.303	-2.023 **	± 0.298
RSC	b_3	-1.370 **	± 0.303	-1.462 **	± 0.298
EC^2	b_{11}	-0.329 NS	± 0.295	-0.344 NS	± 0.290
SAR^2	b_{22}	0.673 *	± 0.295	0.524 NS	± 0.290
RSC^2	b_{33}	0.007 NS	± 0.295	-0.077 NS	± 0.290
EC x SAR	b_{12}	-0.473 NS	± 0.396	-0.756 NS	± 0.390
EC x RSC	b_{13}	-0.093 NS	± 0.396	-0.094 NS	± 0.390
SAR x RSC	b_{23}	0.285 NS	± 0.396	0.001 NS	± 0.390
R2		87.8 %		89.5 %	

* = Significant at 5 % level of probability

** = Significant at 1 % level of probability

NS = Non-significant

Table 6. Regression coefficient (b) and standard error (SE) for saturation percentage of disturbed and undisturbed soils as affected by various combinations of EC, SAR and RSC of applied brackish water.

Parameters	Coefficient	Disturbed soil		Undisturbed soil	
		b	SE	b	SE
Constant	b_0	44.40 **	± 0.45	45.02 **	± 0.68
EC	b_1	0.96 **	± 0.30	0.46 NS	± 0.45
SAR	b_z	-1.35 **	± 0.30	-0.28 NS	± 0.45
RSC	b_3	-0.73 *	± 0.30	-0.33 NS	± 0.45
EC^z	b_{11}	0.61^{NS}	± 0.29	0.80 NS	± 0.44
SAR^z	b_{zz}	-0.77 *	± 0.29	-0.37 NS	± 0.44
RSC^z	b_{33}	-0.38 NS	± 0.29	-0.63 NS	± 0.44
EC x SAR	b_{1z}	-0.14 NS	± 0.39	0.71 NS	± 0.59
EC x RSC	b_{13}	0.80 NS	± 0.39	-0.62 NS	± 0.59
SAR x RSC	b_{z3}	0.94 *	± 0.39	1.62 *	± 0.59
R2		86.0 %		65.0%	

* = Significant at 5 % level of probability
** = Significant at 1 % level of probability
NS = Non-siqnificant

Bulk Density: Bulk density is an important physical property that expresses the compactness or looseness of a soil. The lesser values indicate the ease of water, air and root penetration while more numerical values reveal decreased permeability to air and water. It was observed that increase in the levels of ECiw generally, decreased the bulk density in disturbed as well as undisturbed soils (Figure 2). However, an increase in SAR_{iw} and RSC increased the bulk density under both soil conditions. This may be due to the deterioration of soil structure. The recorded values were slightly higher in undisturbed soil as compared to disturbed one. The correlation between EC_{iw} and soil bulk density was inverse but non-significant under both soil conditions (Table 4). The correlation of SAR_{iw} as well as RSC with bulk density was positive and highly significant indicating that increase in anyone of the two parameters resulted in highly significant increase in the bulk density. The only significant square term was SAR^z_{iw} in the case of disturbed soil. None of the interaction among these parameters was found to be significant.

Increase in the solute content of the soil solution might have decreased the bulk density because soluble salts increase the flocculation of the soil particles. Costa et al. (1991) recorded decreased bulk density when water of high EC_{iw} combined with relatively low SARiw was used for crop production. Irrigation water having higher values of SAR;w and RSC increase the sodium ions in soil solution. The reactions like cation exchange and precipitation of $CaCO_3$ might be operative which would have ended into an increase in exchangeable sodium percentage. Resultantly, the clay dispersion would have occurred and decrease in soil porosity contributed towards an increase in bulk density. Dane and Klute (1977) reported that higher the SAR value, greater was decrease in hydraulic conductivity. Increase in bulk density occurred simultaneously. Shakir et al. (2002) also found that bulk density increased with increase in TSS and ESP but ESP effect was more in increasing soil bulk density.

Percent Pore Space: Porosity is an important physical property and expresses the relative volume of total pores in a soil. It was observed from the data that increase in EC_{iw} caused a proportionate increase in porosity under both types of soil conditions. In general, a little difference was found among the disturbed and undisturbed soils, the recorded values were slightly lower for the latter soil type (Figure 3). However, increase in the levels of SAR_{iw} and RSC exerted a corresponding decrease in the soil porosity. For example 39.62 % pore spaces were found when the SAR of the water was 26.35 as against 44.91 % that of SAR 9.65 in disturbed soil. The values for the same treatments were 38.11 compared with 43.39, respectively under undisturbed soil condition.

The values of regression coefficient indicated that the correlation between EC_{iw} and porosity of soil was statistically non-significant in the disturbed but significant in case of undisturbed soil (Table 5). The pore space values under both the soil conditions were positive, i.e. an increase in EC_{iw} caused an increase in the porosity. The negative correlation between SARiw as well as RSC and porosity was found to be highly significant in both types of soils. None of the square terms as well as interactions were found to be significant except SAR^z_{iw} in disturbed soil which was statistically significant. Soil porosity has always an inverse relationship with bulk density. Clay dispersion probably occurred due to excessive accumulation of Na on exchange sites clogged the pores and decreased the porosity of the soil (Abu Sharar et al. 1987). Shakir (1996) and Skakir et al. (2002) also concluded that porosity of soil was influenced negatively by ESP and TSS in silty clay loam and clay loam soils but effect was more severe due to ESP.

Figure 1: Hydraulic conductivity of disturbed and undisturbed soils as affected by various combinations of EC, SAR and RSC of applied brackish water.

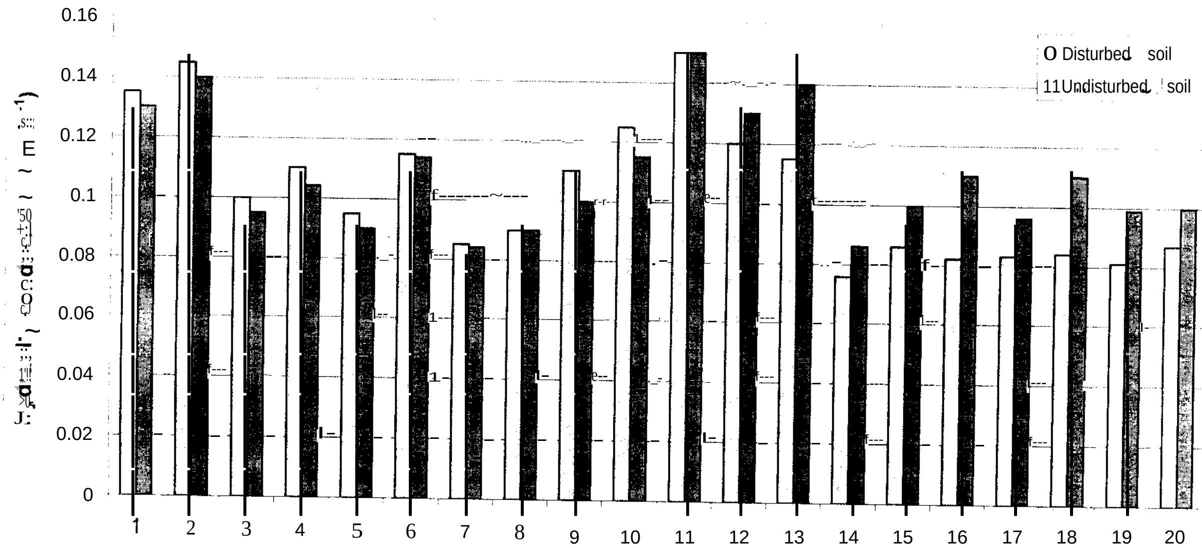


Figure 2: Bulk density of disturbed and undisturbed soils as affected by various combinations of EC, SAR and RSC of applied brackish water.

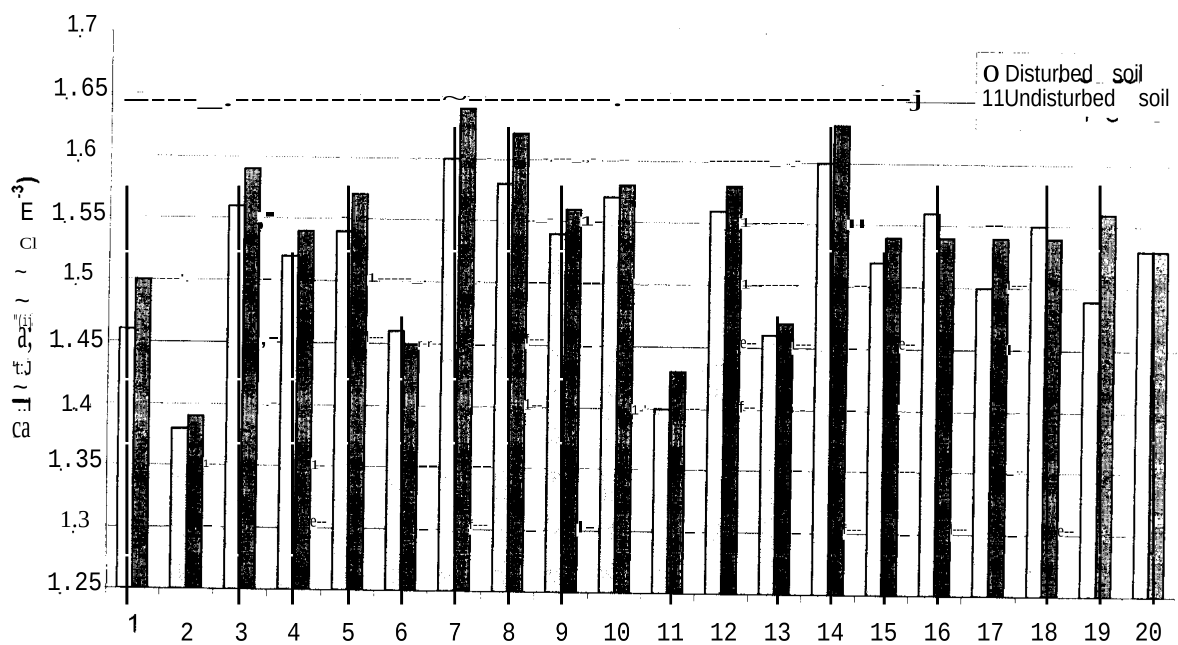


Figure 3: Percent pore space of disturbed and undisturbed soils as affected by various combinations of EC, SAR and RSC of applied brackish water.

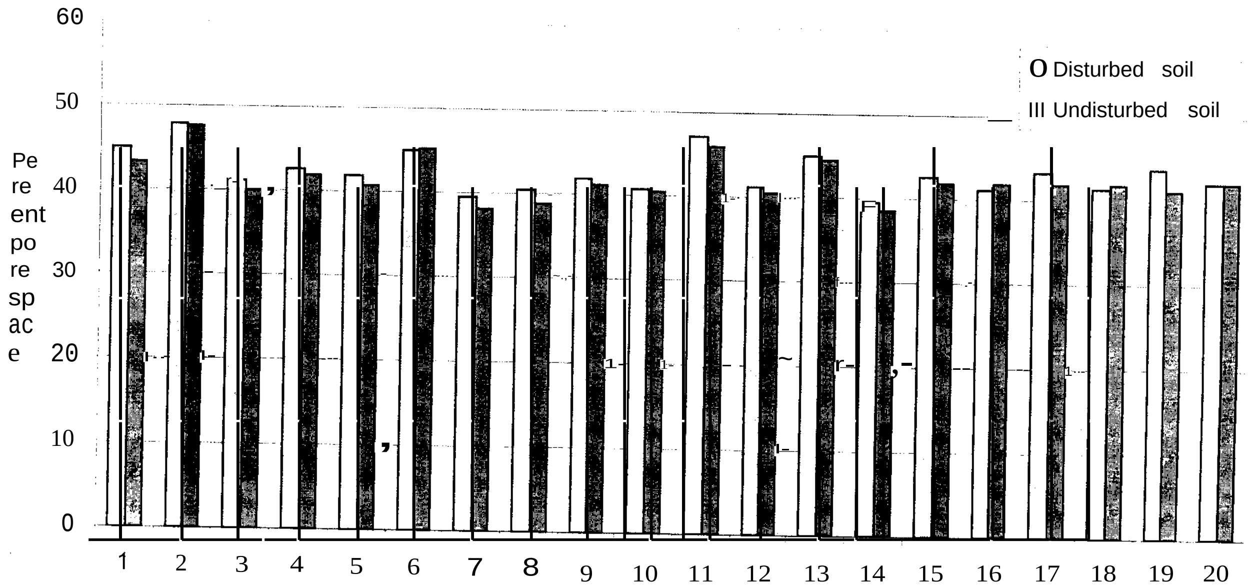
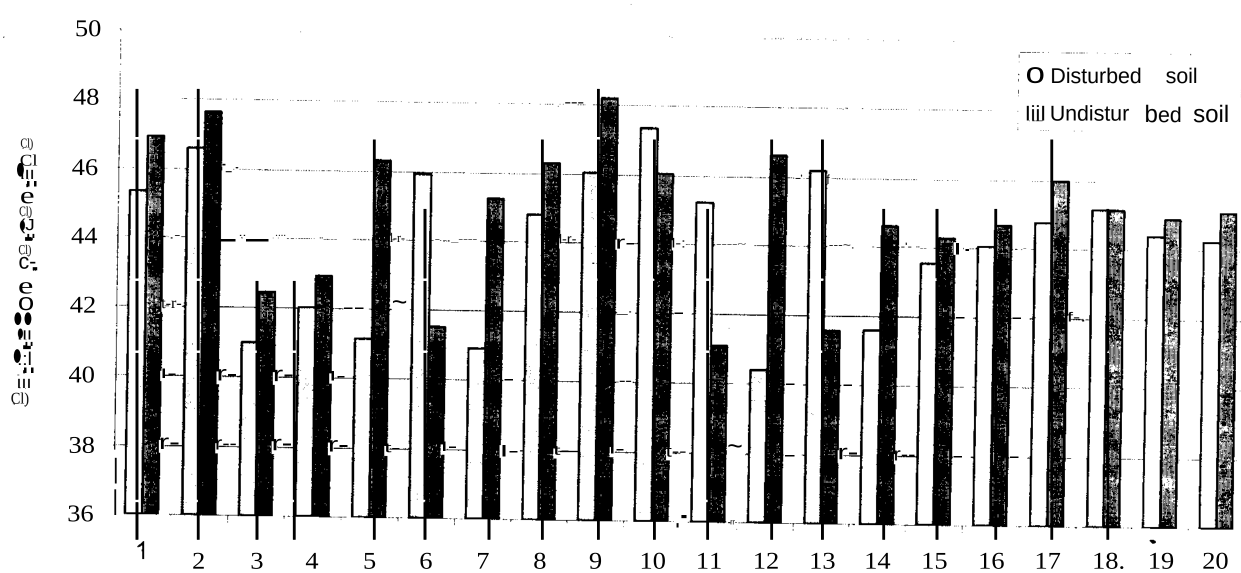


Figure 4: Saturation percentage of disturbed and undisturbed soils as affected by various combinations of EC, SAR and RSC of applied brackish water.



Saturation Percentage (SP): Saturation percentage is affected by many soil properties, some of which may be chemical and the others are of physical nature. It was revealed from the data that as EC_{iw} increased, the SP slightly increased under both disturbed and undisturbed soil conditions (Figure 4). The correlation coefficient between EC_{iw} and SP was, however, statistically non-significant in undisturbed soil but it was found to be highly significant in case of disturbed soil (Table 6). The square term of this parameter was non-significant under both the soil conditions. All the interactions were also non-significant. Costa et al. (1991) observed that irrigation water having combination of low EC and high SAR decreased aggregate percentage than water having high salinity and low SAR Soil bulk density decreased a little and porosity increased when EC_{iw} increased as discussed earlier. All these parameters might have contributed towards an increase in the saturation percentage.

An increase in either of SAR_{iw} and RSC or in combination decreased the SP under both soil conditions (Figure 4). As regard the regression coefficients, it was observed that SAR_{iw} was highly significant in case of disturbed soil but for undisturbed soil, this correlation was non-significant (Table 6). The correlation between RSC and SP was significant only in disturbed soil. Among these two parameters, the only square term of SAR_{iw} was found to be significant in disturbed soil. Generally, the interactions of various parameters were also non-significant except for SAR_{iw} x RSC for both disturbed and undisturbed soils. As noticed earlier, an increase in SAR_{iw} or RSC caused an increase in bulk density and decrease in porosity, which in return might have decreased the SP under these treatments. Yadav et al. (1989) also reported that water retention decreased with the increase in Na content.

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