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EVALUATION OF WATER QUALITY GUIDELINES FOR DIFFERENT SOIL SERIES

Muhammad Abid[1], Anwar-ul-Hassan[2], Abdul Ghafoor[2] and Rana Abdul Wajid[3]
[1]University College of Agriculture and [3]Department of Statistics, Bahauddin Zakariya University, Multan, [2]Department of Soil Science, University of Agriculture, Faisalabad, Pakistan.

Abstract: A fixed rating or evaluation is not possible for all the soils when considering the quality of water for irrigation. The recommended approach is to evaluate the water for the specific conditions at the locality where it is to be used. The experiments were conducted to develop the irrigation water quality guidelines for Rasulpur, Bhalike and Bhalwal soil series. Twenty undisturbed soil columns (76 cm long and 30 cm in diameter) were collected in metallic cylinders for the Rasulpur (sandy loam), Bhalike (clay loam) and Bhalwal (silty clay loam) soil series. The same numbers of packed columns in similar cylinders were also prepared for each soil series. The columns were irrigated with 20 brackish waters having EC @ 0.65, 2.0, 4.0, 6.0,7.35 dS m^{-1}, SAR 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, 7.35 $mmol_c\ L^{-1}$. The application of these waters was run for the period of four and a half years. Results indicated that the safe level of EC_{iw} was up to 1.0, 0.8 and 1.0 dS m^{-1}, respectively for the undisturbed Rasulpur, Bhalike and Bhalwal soil series. The safe level of SAR_{iw} was up to 12.0; 8.0; 10.0 for the undisturbed Rasulpur, Bhalike and Bhalwal soils, respectively. Similarly, RSC up to 2.0, 1.25 and 2.0 $mmol_c\ L^{-1}$, respectively was calculated as the safe level for the Rasulpur, Bhalike and Bhalwal soil series. Use of water having values higher than the upper limits of EC_{iw}, SAR_{iw} and RSC for the respective soils mentioned above would be hazardous and their use for irrigation will require some additional management for sustainable use. It was also noted that undisturbed and disturbed soil conditions behaved almost similarly regarding the effect of EC_{iw}, SAR_{iw} and RSC.

Keywords: Evaluation, soil series, water quality guidelines.

INTRODUCTION

Irrigation water is imperative for successful crop production, as most of our agriculturally productive area falls in arid and semi-arid regions. The main source of irrigation water is the network of surface canals. Quality of canal water in the country is excellent for growing agricultural crops as it contains salts far below the critical limits reported in literature [Ahmad 1993]. At present, canal water is not enough to exploit the potential of soils and crops. An alternate source of irrigation for horizontal expansion of agriculture is the groundwater. Although, groundwater is present in abundance, most of it is hazardous for soils and crops health [Malik *et al.* 1984].

Concentration and composition of salts determine the suitability of water for irrigation. A number of schemes are being used to assess quality of irrigation water. Mostly, total soluble solids (TSS), sodium adsorption ratio (SAR) and residual sodium carbonate (RSC) are considered to be useful parameters [Qayyum and Sabir 1975, Yadav 1982]. In the past, these parameters were used individually or in combination for the classification of irrigation water. However, the effects of given water on soil health are not determined solely by such water properties.

Many scientists in the country have proposed irrigation water quality guidelines on the work carried elsewhere or without the support of scientific data. There have been indications that these guidelines do not hold good under local conditions. For instance, Younus [1977] reported that electrical conductivity (EC_{iw}) from 1.5 to 3.0 dS m^{-1}, sodium adsorption ratio (SAR_{iw}) 10 to 18 and RSC 2.5 to 5.0 mml_c L^{-1} could be used without any deleterious effect on soils and crops under the agro-climatic conditions of the Indus Basin. In another study conducted on silt loam soil in the same area of the country, Chaudhry *et al*. [1983] reported that a water having total dissolved solids (TDS) more than 1062 mg L^{-1}, SAR_{iw} > 9.15 and RSC > 1.10 $mmol_c$ L^{-1} could not be used to grow different crops. It is reported that water suitable for irrigating crops in an area cannot be used for growing crops in another area with different agro-climatic conditions. Scientists do not agree to any water suitability guidelines for irrigating crops under all the conditions, i.e. no water is suitable for all situations. Therefore, only generalized guidelines are appropriate because site-specific conditions may alter the suitability of any particular irrigation water. This work will help in successful planning of groundwater development and future salinity related programme for crop production on productive and marginal lands.

MATERIALS AND METHODS

The experiments were conducted in net-house, University of Agriculture, Faisalabad during 1991-1995. Three soil series, i.e. Rasulpur (Coarse-loamy, mixed, calcareous, hyperthermic Typic Camborthids), Bhalike (Coarse-silty, mixed, hyperthermic Mollic Epiaquepts) and Bhalwal (Fine-silty, mixed, hyperthermic Ustollic Calciargids) were investigated. The physico-chemical properties of these soils are presented in Table 1.

SAMPLING AND SOIL COLUMNS PREPARATION

Metallic cylinders (76 cm long and 30 cm in diameter) were used to collect the undisturbed soil samples. A piece of wood (35 cm x 35 cm and 8 cm thick) having circular groove that fitted easily on the upper edge of the cylinder was placed on the top. Cylinder were pushed vertically into the moist soil (at 50% field capacity) by dropping a 20 kg weight on the grooved wooden planks, tied with a strong string and controlled through a pulley, attached to a tripod. When cylinder was inserted up to 68 cm depth, the soil around the cylinder was excavated up to 80 cm and soil columns were removed by titling it. This excavated soil was used for preparing the disturbed soil columns. The extra soil at the bottom of the cylinder was removed with the help of a sharp knife. This procedure was repeated for 60 cylinders (20 for each soil series).

Table 1: Physico-chemical properties of selected soil series.

Determinant	Unit	Rasulpur	Bhalike	Bhalwal
Sand	%	71.00	33.49	35.00
Silt	"	21.50	38.70	50.00
Clay	"	7.50	27.82	15.00
Textural class	-	Sandy loam	Clay loam	Silty clay loam
Saturation	%	26.40	44.80	39.44
pH_s	-	7.65	7.65	7.70
EC_e	dS m^{-1}	2.40	2.41	2.20
TSS	mmol L^{-1}	24.00	24.10	22.0
Ca^{2+}	"	9.40	6.35	8.11
Mg^{2+}	"	10.25	4.03	4.90
Na^{+}	"	4.28	13.19	8.52
CO_3^{2-}	"	3.00	2.00	0.30
HCO_3^{-}	"	7.50	9.35	7.35
Cl^{-}	"	5.20	6.28	8.21
SO_4^{2-}	"	8.30	5.89	6.01
SAR	$(mol\ L^{-1})^{½}$	1.37	5.80	3.34
ESP	%	2.28	6.35	4.98
$CaCO_3$	"	3.42	6.49	6.84
CEC	$Cmol_c\ kg^{-1}$	6.63	11.18	10.42

For the preparation of disturbed soil columns, stainless steel wire gauze (35 cm x 35 cm) was fixed at the bottom of the empty cylinders with the help of a rubber inner tube band. A thin layer of glass wool and sand were spread 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, sieved (2 mm) sieve and thoroughly mixed soils of the Rasulpur, Bhalike and Bhalwal series. The detailed procedure for the preparation of disturbed soils has been discussed earlier [Abid *et al*. 2002]. The soil columns were packed at bulk density of 1.33, 1.36 and 1.38 g cm^{-3}, respectively for the Rasulpur, Bhalike and Bhalwal soil series. A total of 60 disturbed (20 for each soil series) columns were prepared.

LEVEL OF INDEPENDENT VARIABLES

The EC_{iw} (X_1), SAR_{iw} (X_2) and RSC (X_3) levels @ 0.64, 2.0, 4.0, 6.0 and 7.35 dS m^{-1}, 3.95, 9.65, 18.0, 26.35 and 32.04 (mmol $L^{-1})^{1/2}$ and 0.64, 2.0, 4.0, 6.0 and 7.35 $mmol_c$ L^{-1}, respectively were used in the present studies. The levels of EC, SAR and RSC were coded as -1.682, -1, 0, 1 and 1.682, respectively [Montgomery 1997]. The relationship between coded (X) and actual levels of EC_{iw}, SAR_{iw} and RSC are as follows:

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

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

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

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

The 14 + 6 [1 x 6 (central points)] design points/treatment combinations having different EC_{iw}, SAR_{iw} and RSC levels were selected following the Central Composite Rotatable Second Order Statistical Design [Montgomery 1997]. The design matrix and treatment combinations are shown in Table 2.

Table 2: Treatment combinations run during the experiments.

A) Design points/treatment combinations run in the experiment

Coded scale			Original level		
x_1	x_2	x_3	EC_{iw} (dS m^{-1}) X_1	SAR_{iw} (mmol $L^{-1})^{1/2}$ X_2	RSC (mmol$_c$ L^{-1}) X_3
-1	-1	-1	2.00	9.65	2.00
1	-1	-1	6.00	9.65	2.00
-1	1	-1	2.00	26.35	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	9.65	6.00
-1	1	1	2.00	26.35	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

B) Extra treatment combinations used to test the model validity

-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

The choice of complete factorial experiment provides a means of estimating the response surface but the number of treatment combinations required, especially where more than two factors are involved, has often prohibited their use in field and greenhouse research. Therefore, the selection of few treatment combinations should be made in such a way that maximum information regarding the study could be achieved with minimum possible resources. Second-degree polynomial has proved to be more useful to identify the region where optima of the response are present. For estimation a second-degree polynomial, statisticians propose different second order designs. However, central composite designs (CCD) are most useful.

BRACKISH WATER PREPARATION AND APPLICATION

The levels of EC_{iw}, SAR_{iw} and RSC (Table 2) were prepared by dissolving NaCl, $NaHCO_3$, Na_2SO_4, $CaCl_2$. $2H_2O$ and $MgSO_4$. $7H_2O$ salts in canal water. After achieving near chemical steady-state with brackish waters, the cropping patterns, i.e. wheat-sorghum; wheat-rice; wheat-fallow were practiced in both the undisturbed and disturbed columns of the Rasulpur, Bhalike and Bhalwal soil series, respectively. Three wheat crops during1992-93, 1993-94 and 1994-95 were grown in all the columns (except in Bhalwal soil series where only two crops were raised, i.e. 1993-94 and 1994-95 while sorghum during 1993 and 1994 and rice during 1993 and 1994 were grown in columns of the Rasulpur and Bhalike soil series, respectively. At each irrigation, measured quantity of designed waters was applied to the respective columns. Total quantity of brackish water added to each column was 165 and 170; 148 and 140; 139 and 138 liters, respectively in the undisturbed and disturbed Rasulpur, Bhalike and Bhalwal soil series from the startup to the termination of the studies. After termination of the experiments, the soil samples from 0-15, 15-30, 30-45 and 45-60 cm depth were collected from all the three soil series and were analyzed for EC_e, Ca^{2+}, Mg^{2+}, Na^+, CO_3^{2}, HCO_3^-, Cl^-, SO_4^{2-}, SAR and pH_s following the methods as described by U.S. Salinity Lab. Staff [1954]. In this paper water quality guidelines for the above-mentioned soil series are being discussed.

DATA ANALYSIS

Scheme for data analysis was followed as described by Montgomery [1997]. This was accomplished by using "MINITAB" version 7. Data were analyzed following log and exponential forms of the following model equations:

$$\log \hat{y} = \beta_0 + \sum_{i=1}^{3} \beta_i x_i + \sum_{i=1}^{3} \beta_{ii} x_i^2 + \sum_{\substack{i=1 \\ i<j}} \sum_{j} \beta_{ij} x_i x_j \tag{4}$$

$$\hat{y} = e^{\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{33} x_3^2 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3} \tag{5}$$

Where $\hat{y}$ = dependent variable to be measured, e = exponential, β_0 = regression coefficient for treatment effect, β_1= regression coefficient for x_1, β_2 = regression coefficient for x_2, β_3 = regression coefficient for x_3.

The coefficients were determined using multiple regression analyses. From the interpretation point of view, the contour diagrams for each of the fitted model equations have been drawn in “SAS” version 6.21 and attempts were made to select a region of experiment where optimum response could be obtained. Due to space limitation, only values of the

Table 3: Coded values of EC_{iw}, SAR_{w} and RSC recorded from the contours for maximum EC_e, SAR and pH_s.

Soil Series	Set I Effect of EC_{iw}			Set II Effect of SAR_w			Set III Effect of RSC		
	EC_e	SAR	pH_s	EC_e	SAR	pH_s	EC_e	SAR	pH_s
				Rasulpur Soil Series					
Undisturbed	-0.75	-1.5	-0.75	0.96	-0.72	0.24	-1	-1	1.25
	(1.63)	(1.97)	(1.63)	(2.48)	(2.07)	(2.12)	(1.50)	(2.04)	(2.63)
Disturbed	-1.5	-1.5	0.5	-0.96	-0.96	1.198	-1	-1	1.50
	(1.25)	(1.97)	(2.25)	(1.52)	(2.04)	(2.60)	(1.50)	(2.04)	(2.75)
				Bhalike Soil Series					
Undisturbed	-1.5	-1.5	-1.6	-0.96	-0.96	-1.198	-1	-1	-1.375
	(1.25)	(1.97)	(1.20)	(1.52)	(2.04)	(1.40)	(1.50)	(2.04)	(1.31)
Disturbed	-1.5	-1.5	-1.6	-0.96	-0.96	-1.198	-1	-1	-1.375
	(1.25)	(1.97)	(1.20)	(1.52)	(2.04)	(1.40)	(1.50)	(2.04)	(1.31)
				Bhalwal Soil Series					
Undisturbed	-1.5	-1.5	-1.5	-0.96	-0.96	-0.96	-1	-1	-1
	(1.25)	(1.97)	(1.25)	(1.52)	(2.04)	(1.52)	(1.50)	(2.04)	(1.50)
Disturbed	-1.5	-1.5	-1.5	-0.96	-0.96	-0.96	-1	-1	-1
	(1.25)	(1.97)	(1.25)	(1.52)	(2.04)	(1.52)	(1.50)	(2.04)	(1.50)

( ) = Values of EC_e, SAR and pH_s

EC, SAR and RSC of waters were dragged from the contour and are listed at Table 3.

RESULTS AND DISCUSSION

RASULPUR SOIL SERIES

At fixed coded levels of SAR_{iw} and RSC, the EC_{iw} at coded "-1.5" level (Table 3) yielded soil SAR within permissible limit (<13.3), whereas its effect on EC_e and pH_s tended to increase for the undisturbed soil columns. The same coded level of EC_{iw} reflected the similar results for the disturbed soil. Therefore, EC_{iw} at coded "-1.5" coded level was selected as the maximum safe levels. The SAR_{iw} at coded "-0.72" level indicated the soil SAR (Table 3) remained below the critical of 10. The effect of SAR_{iw} on EC_e and pH_s elevated these parameters. Thus the SAR_{iw} at coded "-0.72" was considered critical one for the undisturbed soil condition. Contrary to this, the SAR_{iw} at coded "-0.96" level resulted in soil SAR less than 15 at fixed coded levels of EC_{iw} and RSC for the disturbed soil. The effect of RSC on EC_e and pH_s increased their values beyond the safe level of 4.0 dS m^{-1} and 8.5. Therefore, the RSC at coded "-1" level (Table 3) was selected as the maximum permissible levels for both the undisturbed and disturbed soils.

BHALIKE SOIL SERIES

The EC_{iw} at coded "-1.6" level (Table 3) yielded pH_s below 8.5 for both the undisturbed and disturbed soil. However, the SAR_{iw} at coded "-1.198" level (Table 3) was selected, since it resulted pH_s 8.5 for both under undisturbed and disturbed conditions. Similarly, at fixed coded levels of EC_{iw} and SAR_{iw}, the RSC at coded "-1.375" level resulted pH_s of 8.5 for the undisturbed and disturbed conditions.

BHALWAL SOIL SERIES

The EC_{iw} at coded "-1.5" level at coded fixed levels of SAR_{iw} and RSC was selected since it yielded pH_s of about 8.5 both for the undisturbed and disturbed soil. The SAR_{iw} at coded "-0.96" level resulted in pH_s 8.5. Similarly, the RSC at coded "-1" level was selected since it produced all the three soil characteristics within the maximum safe levels under both the soil conditions. The selected coded levels of these parameters were transformed into actual EC_{iw}, SAR_{iw} and RSC by Equations 1, 2 and 3 and are listed in Table 4.

The proposed maximum permissible levels of EC_{iw}, SAR_{iw} and RSC (Table 4) did not differ for the undisturbed and disturbed Bhalike and Bhalwal soils. However, for the Rasulpur soil series, such safe level of

SAR_{iw} was higher (12.0) for the undisturbed than that for the disturbed (10.0). This observed small difference in the water quality parameter levels might be due to the settling of particles during four and a half years study period after which the soil columns behaved like under the natural soil condition. Results indicate that the safe and hazardous levels of EC_{iw}, SAR_{iw} and RSC for the undisturbed and disturbed Rasulpur soil remained almost similar to those proposed by U.S. Salinity Lab. Staff [1954]. Comparison between soil series revealed that EC_{iw}, SAR_{iw} and RSC safe and hazardous levels were lower for the Bhalike than that of the Rasulpur and Bhalwal soil series most probably owing to the fine texture of the former soil. Finer the texture of soil, lesser will be its permeability and greater cation exchange capacity (CEC) and vice versa. Hence the same quality may be suitable for coarse textured soils with good permeability but becomes hazardous for fine textured soils, particularly having restricted drainage. In field and laboratory studies, it has been reported that EC_e and/or SAR build up was more in fine than that in coarse textured soils at same EC_{iw}, SAR_{iw} and/or RSC irrigation water [Gupta 1990, Oster 1994].

Table 4: Proposed water suitability guidelines for soils.

Category	EC_{iw} (dS m^{-1})	SAR_{iw} (mmol $L^{-1})^{1/2}$	RSC (mmol$_c$ L^{-1})
	Rasulpur soil series		
Undisturbed			
Safe	≤ 1.0	≤ 12.0	≤ 2.0
Hazardous	> 1.0	> 12.0	> 2.0
Disturbed			
Safe	≤ 1.0	≤ 10.0	≤ 2.0
Hazardous	> 1.0	>10.0	> 2.0
	Bhalike soil series		
Undisturbed			
Safe	≤ 0.8	≤ 8.0	≤ 1.25
Hazardous	> 0.8	> 8.0	> 1.25
Disturbed			
Safe	≤ 0.8	≤ 8.0	≤ 1.25
Hazardous	> 0.8	> 8.0	> 1.25
	Bhalwal soil series		
Undisturbed			
Safe	≤ 1.0	≤ 10.0	≤ 2.0
Hazardous	> 1.0	> 10.0	> 2.0
Disturbed			
Safe	≤ 1.0	≤ 10.0	≤ 2.0
Hazardous	> 1.0	> 10.0	> 2.0

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