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Effects of Water Quality on Soil Structure and Permeability

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Abstract

Uncertainty involved in estimating water quality effects on soil permeability is an obstacle in appraising water quality for irrigation. This study examined salinity, sodicity and turbidity effects on hydraulic conductivity (HC) of three Torrifluvents ; Gila silt loam, Saneli clay loam and Glendale silty clay. HC was measured in laboratory columns containing initially dry aggregates (<2 mm) at two bulk densities using ten saline solutions (electrical conductivity, EC of 0.4 to 4.8 dSm^{-1}, and sodium adsorption ratio, SAR of 0 to 20) with and without soil suspension. Hydraulic gradients, suspended solid concentrations of outflow, and aggregate size distributions were also measured. HC decreased at SAR less than 5 in all the tested soils, and the reduction followed an exponential form involving SAR/EC. Gila and Saneli soils developed surface seal, while Glendale silty clay that has shown swelling did not. The introduction of soil suspension into the saline solutions at a rate to form a depositional layer of less than 3 mm thick caused 4 to 7-fold reduction in HC of Gila and Saneli soils, but did not accentuate water quality effects on HC. The depositional layer did not reduce HC of Glendale soil. Increasing sodicity and/or reducing salinity of saline solutions increased destruction of soil aggregates having a peak diameter of 0.18 mm, and HC was quantitatively related to the reduction in soil aggregates. Water intake into newly plowed and thoroughly disked soils may decrease at much lower SAR than commonly recognized, partly because of destruction of weak soil aggregates. The extent of reduction depends strongly on soil types. This results suggests that the soil permeabilty management requires the consideration of both soil properties and water quality.

Key words : Water Quality, Permeability, Salinily, Soil Colum Experiment

1. Introduction

Salt leaching is an important management practice for irrigated agriculture in arid region. The available water for leaching is also limited and contains various dissolved salts in it. Effective use of the water for leaching demands the knowledge of soil permeability when those water is applied.

Quality of water used for irrigation, especially salinity and sodicity, affects soil structure and permeability. This phenomenon was identified at as early as the turn of this century (e.g., Scofield and Headley, 1921), but the mechanisms involved are still being studied. Identified mechanisms include clay swelling (McNeal *et al.*, 1966), clay particle dispersion and subsequent pore plugging (Frenkel *et al.*, 1978), destruction of soil aggregates (Abu-Sharar *et. al.*, 1987), combination of the above mechanisms (Koga K, 1989) and soil crust formation (Shainberg and Singer, 1986). The quantitative description of salinity and sodicity effects on soil hydraulic conductivity and water intake rates has also been attempted (McNeal, 1968 ; Oster and Schroer, 1978 ; Cass and Sumner, 1982 ; Minhas and Sharma, 1986). Also, there is an attempt to explain the soil pore clogging by the rheological behavior of percolating suspension flow. (Mihara and Yasutomi, 1992).

Many of these equations were developed based on laboratory hydraulic conductivity measurements, and their applicability to different soils and field situations have not been fully tested. This uncertainty needs to be resolved before improved assessment of irrigation water quality can be made.

This study was conducted mainly to obtain quantitative information on salinity, sodicity and turbidity effects on permeability of Torrifluvents (the soils developed from alluvial sediments). The identification of the main mechanism or processes involved was also included as a subobjective. In studying those objectives, special attention was placed on the prevailing characteristics of surface-irrigated soils ; slaking of aggregates and the effect of depositional crusts. The interactive effect of soil cracks and water quality on permeability is beyond the scope of this study.

2. Materials and Methods

Three Torrifluvents ; Gila silty loam, Saneli clay loam and Glendale silty clay, which widely found in southwestern US, were used for this study. Glendale silty clay is noted for low permeability. Clay minerals of these soils are mixtures of montmollironite, vermiculite and mica. All the samples came from the surface 0.15 m of the A-horizon in the fields irrigated with water from the Rio Grande river, which has electrical conductivity (EC) of 1.1 dSm^{-1} and the sodium adsorption ratio (SAR) of 3.5. The soil samples were air-dried, crushed, and passed through a 2 mm opening sieve. Subsamples were analyzed for selected properties (Table 1) by the methods of the US Salinity Laboratory (Salinity Lab Staff 1954).

Eleven saline solutions were prepared by adding salts to deionized water (Table 2). Solution 1 contained $CaCl_2$ only, and was used as a reference. Salinities of solutions 2 through 8 are comparable to that of irrigation waters used in the Southwestern USA. Sodicities of those solutions are generally higher than that of most irrigation waters, although it is not out of the range. Solutions 9 and 10 were prepared to evaluate bicarbonate effects. Solution 11 was used to initialize the soil column to avoid the effects of previous irrigation at different sampling locations.

1) Soil Column Experiments

Two separate column experiments were conducted in a laboratory at 23±2℃. In the first experiment, hydraulic conductivity was measured under ponding with the above saline solutions. Ninety two grams of Glendale, 120 g of Saneli and 155 g of Gila soils were placed in permeameters (54 mm ID) 30, 38 and 50 mm deep at the bulk density of 1.34, 1.38, and 1.35 Mg/m^3, respectively, and were leached with 2.2 L (equivalent to 40 to 65 pore volumes) of solution 11. The 50 permeameters were regrouped into 10

Table 1 Some properties of three Torrifluvents used for the experiments

Soil type	Classification	Saturation extract analysis						Cation exchange capacity	Soil	Sat. water content
		pH	EC	SAR	Na	Ca	Mg		$CaCO_3$	
			dsm^{-1}		mmol (+) L^{-1}			mmol (+) kg^{-1}	g kg^{-1}	%
Gila silt loam	Mixed, thermic Typic Torrifluevent	8.3	1.9	5.1	10.4	6.1	2.2	139	66	32
Saneli clay loam	Montmorillonitic, thermic Vertic Torrifluevent	8.2	1.9	5.8	12.2	6.5	2.3	165	61	38
Glendale silty clay	Mixed, thermic Typic Torrifluevent	8.3	2.2	8.9	16.5	5.0	1.8	274	98	60

Table 2 The composition of saline solutions used for the experiments

Treatment	EC	TDC1)	SAR	SARs1)	Na	Ca	Mg	HCO_3	Cl
No.	dsm^{-1}	mmol (+) L^{-1}			mmol (+) L^{-1}			mmol (−) L^{-1}	
1	4.8	40.0	0	0.0	0.0	40.0	0.0	0.0	40.0
2	0.37	2.5	5	1.8	2.14	0.24	0.12	0.0	2.5
3	0.69	5.0	5	2.9	3.83	0.78	0.39	0.0	5.0
4	0.71	5.0	15	4.1	4.80	0.13	0.07	0.0	5.0
5	1.2	10.0	10	6.1	8.60	0.93	0.47	0.0	10.0
6	1.3	10.0	20	7.7	9.55	0.30	0.15	0.0	10.0
7	2.5	20.0	15	10.8	17.33	1.78	0.98	0.0	20.0
8	4.8	40.0	20	16.9	34.17	3.88	1.95	0.0	40.0
9	0.65	5.0	5	3.3	3.83	0.78	0.39	1.17	3.83
10	0.62	5.0	5	3.8	3.83	0.78	0.39	2.34	2.66
11	13.2	120.0	1	1.0	8.00	75.00	37.00	0.00	120.00

1) EC : electrical conductivity at 25℃, TDC : Total dissolved cation or anion. SARs : sodium adsorption ratio of soil solution estimated by a computer model of Miyamoto *et al.*, (1975).

groups, based on the flow rate of solution 11, to form randomized complete block design. The average flow rate of each gorup has statistically same value. (Table 3, shown as an initial value). Hydraulic conductivity (HC) was monitored under a constant head difference of 200 mm, until the readings approached constant values after the passage of 50 to 240 pore volumes (PV, 1PV = soil vol. x porosity) for a period of 3 days in Gila, Saneli, and 15 days in Glendale soils. Thereafter, soil suspensions (of which preparation is given in the next paragraph) was introduced to the saline solutions, and hydraulic conductivity was determined with a falling head method. As soon as the sediment containing saline solutions had infiltrated, the falling-head conductivity measurement was repeated with 150 mm of deionized water, then again with the saline solutions. The entire drainage from each column was collected to analyze the electrical conductivity (EC), and the concentration of suspended solids by a filtration method.

The soil suspension introduced to the ponded saline solutions was prepared by adding 10 g of the soils (pretreated with saline solution 11, then with each of the 10 solutions) to 50 mL of each solution, then by shaking them with a wrist-action shaker for 30 min. Ten grams of the soils make up a soil layer of approximately 3 mm in the permeameter columns or 6 to 12 g of clay content per L of the saline solutions.

The second laboratory experiment was to determine the depth of the maximum resistance to water flow through soil columns. The soil samples were packed into PVC (polyvinyl chloride) pipes (30 mm ID) to a depth of 300 mm at the same bulk density as used in the first experiment. Piezometers were inserted at 10, 20, 30, 50, 100, and 150 mm deep. Selected saline solutions (1, 3 and 6 of Table 2) to represent the range of HC change characteristics observed in the first experiment, then deionized water were applied following pretreatment with solution 11 in the same amount per cross-sectional area as those of the first experiment, and flow rates and hydraulic heads were monitored under a constant ponding depth of 145 mm. This experiment was conducted in 3 replicates for each soil.

The analysis of variance was performed by the methods described in Little and Hills (1975) ; a randomized block design for evaluating water quality effects on HC of each soil tested ; and a split-block design analysis for evaluating the hydraulic gradient distributions over depths.

Table 3 Hydraulic conductivity (HC) of uncompacted three Torrifluvents following application of various saline solutions

soil	Saline solution		Saline suspension		Distilled water	
Sol. #	HC	%	HC	%	HC	%
	mm/hr		mm/hr		mm/hr	
Gila (Initial 19.5 mm/hr)						
1	35 a	100	15.2 a	100	7.9 a	100
2	20 de	57	2.3 d	15	2.5 c	32
3	25 c	71	3.6 d	24	2.8 bc	35
4	18 ef	51	3.5 d	23	3.0 bc	38
5	25 c	71	7.4 bc	49	3.2 bc	41
6	17 f	49	4.9 cd	32	3.0 bc	38
7	25 c	71	3.6 d	24	2.5 c	32
8	31 b	88	9.8 b	65	0.7 d	9
9	21 d	60	3.7 d	24	3.2 bc	40
10	18 ef	51	5.0 cd	33	3.8 b	48
Saneli (Initial 17.5 mm/hr)						
1	32 a	100	5.7 a	100	5.0 a	100
2	15 d	47	3.6 b	63	2.3 b	46
3	17 c	53	3.0 cde	53	1.5 c	30
4	9.5 f	30	2.7 f	47	1.4 c	28
5	14 d	44	2.9 def	51	1.1 cd	22
6	9.1 f	28	2.5 f	44	0.8 de	16
7	18 c	56	3.2 bcd	56	0.4 ef	8
8	22 b	60	3.4 bc	60	0.07 f	2
9	12 e	36	2.8 def	49	1.6 c	32
10	10 f	31	2.8 def	49	2.1 b	42
Glendale (Initial 2.4 mm/hr)						
1	1.90 a	100	1.46 a	100	0.73 a	100
2	0.31 de	16	0.27 de	18	0.22 bcd	30
3	0.45 c	24	0.45 c	31	0.26 b	36
4	0.26 de	14	0.25 de	17	0.19 d	26
5	0.35 cd	18	0.32 cd	22	0.19 d	26
6	0.18 e	9	0.17 e	12	0.12 e	16
7	0.71 b	37	0.67 b	46	0.14 e	19
8	0.64 b	34	0.61 b	42	0.04 f	6
9	0.33 cd	17	0.32 cd	22	0.25 bc	34
10	0.26 de	14	0.32 cd	22	0.21 cd	29
Gila						
F	39**	—	20**	—	23**	—
LSD. 05	2.7	—	2.5	—	1.1	—
Saneli						
F	270**	—	37**	—	98**	—
LSD. 05	1.2	—	0.43	—	0.48	—
Glendale						
F	150**	—	91**	—	110**	—
LSD. 05	0.13	—	0.13	—	0.05	—

[1] The numbers followed by the same letter are not significantly different at the 5% level by the Duncan's Multiple Range Test in each soil and each column. The listed LSD is for comparison between different treatments at the 5% level for a randomized block design.

[2] **,* F values significant at the 1 and 5% levels, respectively.

The relationship between hydraulic conductivity and salinity or sodicity was fitted after several trials to the following equation :

$$\frac{HC}{HC_0}=\mathrm{EXP}\left(a-b\frac{SAR_s}{EC}\right) \qquad (1)$$

and when deionized water was used,

$$\frac{HC}{HC_0}=1-a\,(SAR_s)^b \qquad (2)$$

where HC is the hydraulic conductivity of a saline solution, HCo the reference conductivity, such as those obtained with $CaCl_2$ solutions, EC the electrical conductivity of saline solutions, and SARs the sodium adsorption ratio of soil solutions estimated by a computer model of Miyamoto *et al.* (1975). The computed SARs is corrected for $CaCO_3$ dissolution and, when present, sulfate ion pairs.

2) Soil Aggregate Analysis

Air-dry samples of Gila, Saneli, and Glendale soil (75, 75 and 50 g each, respectively) were leached with solution 11, then with solution 1, 3, or 6, using the solution to soil ratios comparable to those used in the first experiment. The half of leached soil samples were transferred to 1 L cylinders containing each of the saline solutions, and the rest of sample to the cylinders containing deionized water. They were analyzed for apparent particle size distribution using the hydrometer method (Day, 1975). A set of original soil samples was also analyzed after a dispersion treatment with H_2O_2 and calgon (Day, 1975). All the measurements were made in triplicate. The percentage of aggregated particles (AGP) was estimated as

$$AGP=\frac{P\,(\mathrm{Dispersed})-P\,(\mathrm{Apparent})}{P\,(\mathrm{Dispersed})}\times 100 \qquad (3)$$

where P stands for the cumulative frequency of particle size distribution with or without the dispersion treatment. The measurements were made in triplicate, and the analysis of variance performed for a randomized block design. The percent of aggregated particles less than 0.01 mm was then correlated to the relative hydraulic conductivity using a linear regression.

3. Results

1) Hydraulic Conductivity

Hydraulic conductivity (HC) of Gila, Saneli and Glendale soils is plotted as a function of the cumulative depth of the passed solutions in Fig. 1. The data points shown are the arithmetic mean of the five replicates, and the coefficient of variability (CV) averaged 7%. HC after application of solution 11 (shown as an initial value in Table 3) increased over a time, except for Gila soil. The introduction of solution 1 (marked by the arrow numbered 1 in Fig. 1) caused further increases in HC in Gila and Saneli soils. Application of all other saline solutions caused substantial reduction in HC as illustrated by the data from solutions 3 and 6 in Fig. 1. The reduction was especially rapid and large in Glendale silty clay.

The saline solution treatments had highly significant effects on HC in all soils (Table 3). Increasing concentration of HCO_3 (solutions 9 and 10 as compared to solution 3) resulted in small, but a significant reduction in HC. Hydraulic conductivity normalized by the conductivity using a 0.04 N $CaCl_2$ solution (solution 1 of Table 2), hereafter referred to as relative hydraulic conductivity (RHC), was lowest in silty clay, and highest in silty loam. This trend was also observed when the HC obtained at the onset of the experiments (referred to as the initial conductivity in Table 3) was used as a reference to compute RHC.

Introduction of soil suspension into solution 1 (marked by arrows 2 in Fig. 1) reduced the HC to 57, 82 and 23% for Gila, Saneli, and Glendale soils, whereas in other solutions HC reduced to average of 77, 79 and 3%, respectively. Application of deionized water following solution 1 (marked by arrow 3) caused a reduction of 48, 12 and 50% in HC (Table 3) in Gila, Saneli and Glendale, respectively, whereas application following other saline solutions caused respective reductions of 45, 57, and 52%. The largest reduction in HC occurred in the soils previously

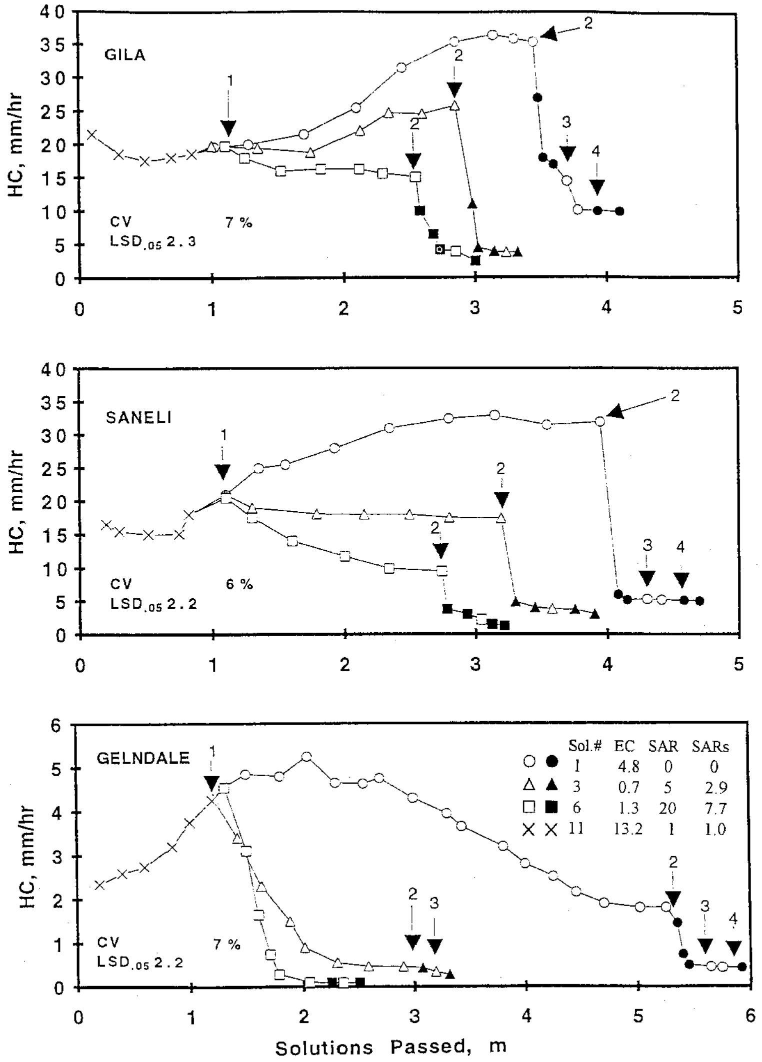

Fig. 1 Hydraulic conductivity (HC) of three Torrifluvents measured with three solutions (1, 3, and 6) ; the first arrow indicates the introduction of saline treatment solutions, the second arrow the introduction of soil suspension, the third the conversion to deionized water, and the fourth the reintroduction of saline water.

treated with the solution 8 having high SAR and EC. The reintroduction of saline solutions after distilled water did not substantially change HC.

The relationship between RHC of soils and SARs/EC conformed to Eq (1) with the standard error of estimates less than 0.05 in HC/HCo (Fig. 2 A and Table 4). However, the intercept did not converge to unity. The application of soil suspension caused the coefficient of regression to decline and some became insignificant at the 5% level (Table 4). The empirical coefficient b also declined with application of soil suspension indicating that RHC became less dependent upon a ratio of SARs to EC. The conversion to deionized water increased the dependence of RHC on SARs, and the relationship conformed to Eq. (2). (Fig. 2 B and Table

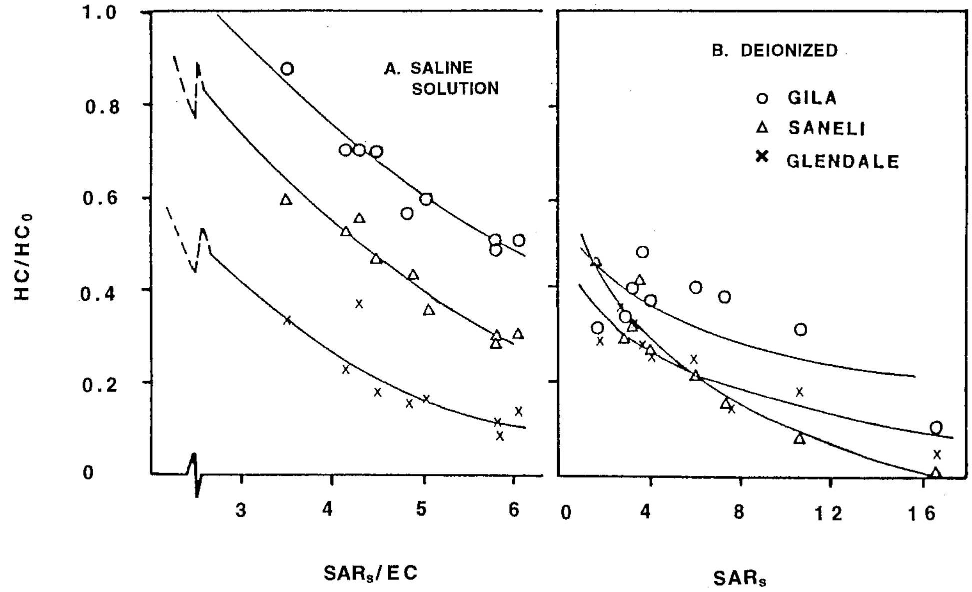

Fig. 2 Hydraulic conductivity (HC) of three Torrifluvents normalized by that of 0.04 N $CaCl_2$ solution (HC_0) as related to SARs/EC, (Fig. 2 A), and HC normalized by that of deionized water (Fig. 2 B) following 0.04 N $CaCl_2$ solution application as related to SARs, the sodium adsorption ratio of percolating solutions. Refer to Table 4 for regression analyses.

4)

2) Hydraulic Gradient Distribution

The hydraulic gradient measured upon completion of pretreatment with saline solution 11 (shown by the long dashed lines in Fig. 3) was fairly uniform throughout the depth in Gila and Saneli soils. The average gradient was about 1.4, a theoretical overall gradient of the flow system employed. In Glendale soil, the gradient near the soil surface was initially close to unity, then decreased with increasing amounts of saline solution application. The gradient at the time of completing pretreatment was greater with depth as illustrated in Fig. 3.

After the application of solutions 1, 3 and 6, the gradient increased rapidly at the soil surface in Gila and Saneli soils, and peaked right at the soil surface (solid lines in Fig. 3). Application of deionized water further accentuated the development of high gradients at the soil surface. The water level in piezometer disappeard except the one close to the surface, which shows the hydraulic head below the surface became negative. The hydraulic gradient distribution in Glendale soil remained higher at deeper depths from the inception of solution application through the 1.0 to 1.3 m equivalent depth of solution applied. Thereafter, the gradient distribution pattern has gradually shifted toward having higher values at the soil surface.

3) Suspended Solids and Aggregate Size Distribution

The outflow from the soil columns used for hydraulic conductivity measurements with saline solutions was free from suspension. Application of deionized water caused the suspended solids to appear in the outflow from Gila and Saneli soils which were previously leached with solutions having SARs greater than about 5 (Fig. 4). At the highest SARs (16.9), the outflow from the columns was muddy (48 and 36 mg/L in Gila and Saneli soil, Fig. 4). The suspended solids in the outflow from Glendale soil were, however, minimal.

Table 4 Empirical coefficients and statistical parameters for the relationship between relative hydraulic conductivity (HC/HC_o) and the sodium adsorption ratio of percolating solutions (SARs) or its ratio to the electrical conductivity (EC). Hydraulic conductivity of 0.04 N $CaCl_2$ solution or distilled water following 0.04 N $CaCl_2$ application is taken as a reference value.

SALINE SOLUTIONS ; $HC/HC_o = \mathrm{Exp}\,[a - b\,(SARs/EC)]$			
	Gila	Saneli	Glendale
a	0.63	0.66	0.59
e intercept H/H_o	1.87	1.94	1.80
b	0.22	0.32	0.47
r coeff. of correlation	−0.99**	−0.95**	−0.87**
SE standard error	0.023	0.042	0.055
SALINE SUSPENSIONS ; the equation same as above			
a	−0.34	−0.095	0.48
e intercept H/H_o	0.71	0.91	1.61
b	0.18	0.19	0.39
r coeff. of correlation	−0.36	−0.71	−0.79*
SE standard error	0.15	0.05	0.10
DISTILLED WATER ; $HC/HC_o = 1 - a\,(SARs)^b$			
a	0.53	0.48	0.58
b	0.12	0.27	0.16
r coeff. of correlation	0.54	0.93**	0.89**
SE standard error	0.02	0.051	0.043

**,* Significant at the 1 and 5% levels.

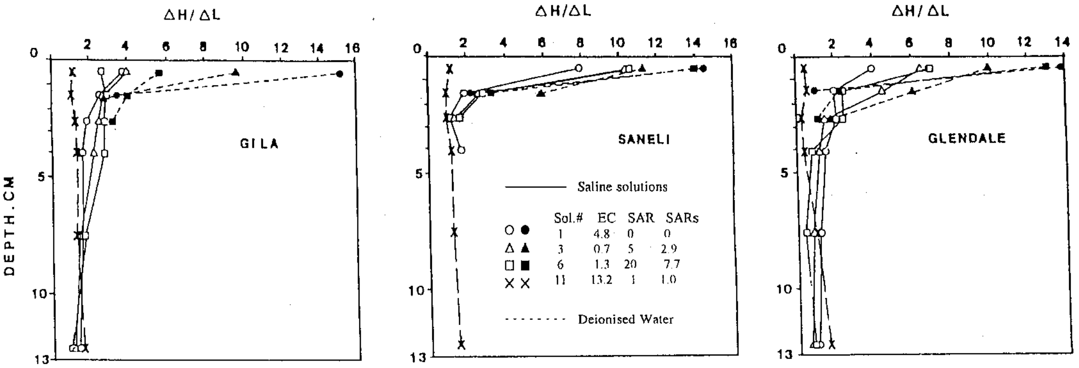

Fig. 3 Hydraulic gradient distribution in soil column leached with high saline solution (X symbol with long dash lines), after application of three different saline solution (open symbols) and deionized water (dotted lines with closed symbols).

The EC of the outflow from the above soil columns was higher by 0.15 to 0.2 dSm^{-1} than those of the inflow. The EC of the outflow when deionized water was used in excess of several pore volumes was also in the same range, 0.15 to 0.2 dSm^{-1}.

Results of the particle size analysis indicated that silt and clay particles remained mostly aggregated after the treatments with various saline solutions (the cumulative frequency

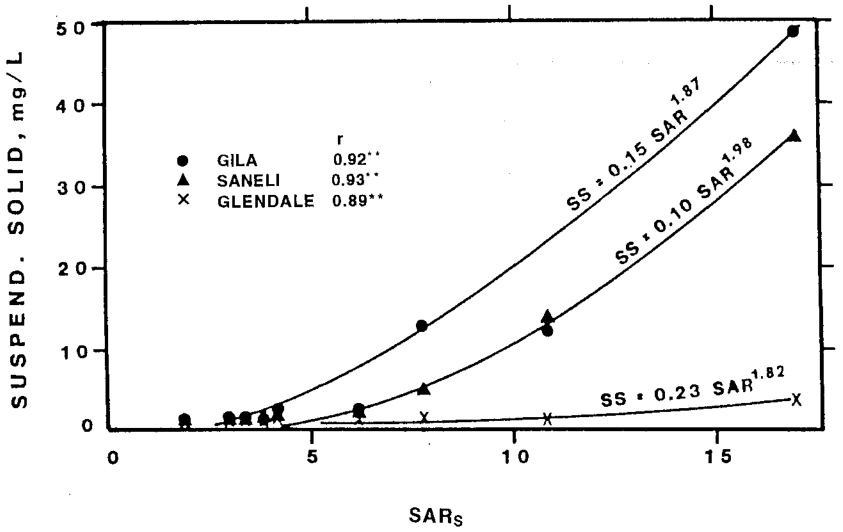

Fig. 4 The concentration of suspended solids in the outflow from soil columns previously treated with saline solutions having various sodium adsorption ratios then leached with deionized water.

curves of Fig. 5). The size distribution in solution 11 was similar to that in solution 1 and the data from solution 3 are not shown in Fig. 5 for simplicity. The aggregated percentage of particles less than 0.002 mm (clay fraction), estimated by Eq(3) using the data shown in the upper cases of Fig. 5, ranged from 72 to 85%, independently of the saline treatments. The percent of aggregated silt and clay particles (< 0.05 mm) ranged from 25 to 50%, irrespective of the saline treatments. The highly significant effects of water quality on the percentage aggregation occurred in size fraction less than 0.01 mm (Table 5).

The differential form of size distribution (the lower cases of Fig. 5) indicates that "apparent" particle size in solution 1 (and solution 11) centered around about 0.018 mm in all the tested soils. This size peak has shifted to about 0.008 mm in solution 6. In all other cases, the size distribution curves shifted toward the pattern observed in the dispersed samples. This shifting occurred even in solution 1 having SAR of zero through reducing electrolyte concentration by dilution with deionized water.

4) Relationship between aggregation and hydraulic conductivity

A highly significant correlation was obtained between the percentage of aggregated particles less than 0.01 mm and the relative hydraulic conductivity (Fig. 6). The plots are inclusive of three experimental soils. The data from soil suspension and deionized water application after the suspension application were excluded, because these data included the effect of depositional layer on HC. The relative hydraulic conductivity decreased as the percentage of aggregates less than 0.01 mm decreased. No significant correlation was obtained from the other size fractions.

4. Discussion

Breakdown of soil clods and aggregates and formation of depositional crusts are common features of surface-irrigated soils. Simulating these features in laboratory columns is a difficult task, but the conditions of the present experiment were meant to simulate the steady water flow through the soils plowed and thoroughly disked.

Results of the first column study suggests

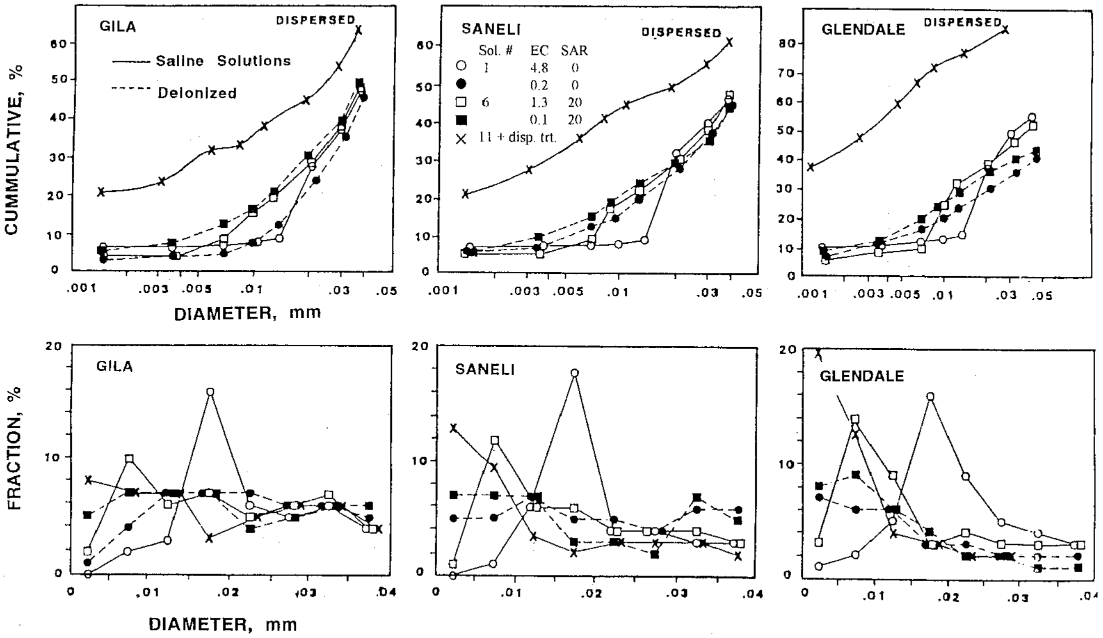

Fig. 5 The particle size distribution of three Torrifluvents measured after H_2O_2-Calgon dispersion treatment (dispersed), with saline solutions 11, 1 and 6 (solid lines), then with deionized water (dashed lines). The upper figures are for cumulative and the lower figures the differential distribution.

that the steady intake rate into such soils is likely to be reduced at lower sodicity than previously believed, such as, FAO sodicity hazard criterion states the SAR=5 cause no significant reduction of soil permeability. In fact, hydraulic conductivity (HC) of these soils declined as much as half at SAR of zero by reducing salinity from 4.8 to 0.2 dSm^{-1} (Table 3). At SAR of 5 in water (or SAR 1.8 to 2.9 in soil solution), the reduction in HC ranged from 50 to 80% at EC of 0.37 to 0.69 dSm^{-1}. These findings are contrary to most earlier reports where a significant reduction in HC was observed only at considerably higher SAR in water, e.g., 10 to 15 (e.g., McNeal *et al.*, 1966 ; Frenkel *et al.*, 1978 ; Felhendler *et al.*, 1974). Our data are in agreement with the later work conducted by Abu-Sharar *et al.* (1987) using three California soils ; Haplic Durixeralfs, Typic Haploxeralfs and Mollic Durixeralfs. HC in our study also declined when high saline solutions, e.g., solution 8 having EC of 4.8 dSm^{-1} were used. This finding also contradicts earlier observations that high salinity can adequately counteract the adverse effect of sodicity.

The reason for this sharp reduction in HC at low SAR is probably related to aggregate destruction as postulated earlier by Abu-Sharar *et al.* (1987), and supported by the highly significant correlation between aggregate stability and water quality (Table 5) and between HC and aggregate stability (Fig. 6). However, this interpretation can not explain why HC of Glendale soil but not of Gila or Saneli soil declined so abruptly following application of solutions 3 and 6 (Fig. 1). Neither does it explain why HC has actually increased in some cases with increasing application of saline solutions such as shown in Fig. 1. These points are discussed below.

The hydraulic gradient data (in Fig. 3) indicate that the soil surface became a flow-limiting layer with increasing application of the

Table 5 The percentage of the specified size fractions that are estimated to be aggregated by Eq (3)

Soils Soln	Saline solutions			Deionized water		
	<.002	<.01	<.04 mm	<.002	<.01	<.04 mm
			%			
GILA						
12	76 b[1]	79 a	24 a	—	—	—
1	76 b	74 a	21 a	78 a	71 a	24 a
3	79 a	67 b	23 a	76 a	56 b	22 a
6	78 ab	53 c	19 a	76 a	47 c	23 a
SANELI						
12	78 a	86 a	23 a	—	—	—
1	72 b	81 b	22 a	78 a	61 a	23 a
3	73 b	65 c	25 a	74 a	59 a	25 a
6	73 b	57 d	23 a	74 a	48 b	23 a
GLENDALE						
12	86 a	90 a	41 a	—	—	—
1	80 b	82 b	37 a	82 a	72 a	54 a
3	81 b	72 c	38 a	81 a	62 b	48 b
6	83 ab	64 d	38 a	80 a	65 b	49 b
Gila						
F	3.0	34[2]**	.48	1.5	106**	1.8
LSD.05	2.7	6.5	10.8	4.7	4.4	4.4
Saneli						
F	4.1	212**	.52	2.7	16**	0.19
LSD.05	3.3	3.1	9.5	7.3	5.6	6.7
Glendale						
F	5.0*	45**	.84	0.03	9.6*	5.1
LSD.05	3.6	5.0	8.6	3.8	3.5	5.2

[1] Numbers followed by the same letter are not significantly different at the 5% level within the same soil and column.

[2] **, * Significant at the 1 and 5% levels.

saline solutions, especially in Gila and Saneli soils. Soil aggregates were probably destroyed preferentially at and near the soil surface, since aggregates there are exposed to the maximum hydraulic pressure as well as unavoidable disturbance during solution application. The hydraulic pressure below the surface decreased with the development of surface seal in Gila and Saneli soils. This low pressure might have permitted the shrinkage of Gila and Saneli below the soil surface, leading to some boundary flow along permeameter walls. The initial increase in HC observed with solution 11 may also have been caused by soil shrinkage induced by the high electrolyte concentration of the solution and subsequent development of boundary flow. The removal of entrapped air is another possibility.

The hydraulic gradient measured in Glendale soil during the pretreatment period increased with depth. This soil was high in clay content, and vertically expanded its volume upon solution application. The vertical expansion of the soil may have lowered the bulk density and the hydraulic gradient near the soil surface, and probably have contributed to the increased flow rate during the pretreatment period. The rapid reduction in HC fol-

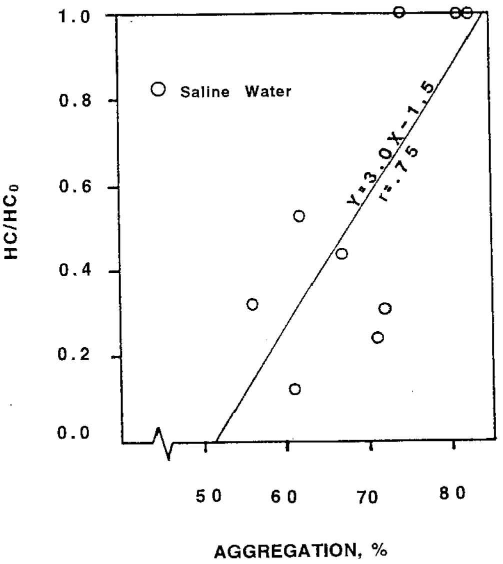

Fig. 6 The relationship between the relative hydraulic conductivity (HC/HC_0) and the aggregated fraction of particles less than 0.01 mm in three Torrifluvents.

lowing application of solutions 3 and 6 (Fig. 1) has occurred when the hydraulic gradient was fairly uniform throughout the depth. The surface-seal which is caused by the introduction of soil suspension was not the cause of flow reduction in Glendale soils, but aggregate destruction was. Slaking of soil aggregates, which causes the loss of large pores once existed among aggregates, would bring about a rapid reduction in flow, especially which occurs throughout the flow path length of clayey soils. The swelling of clay particles is probably not involved in this process, because it does not usually occur unless the exchangeable Na percentage (which would be approximately equal to SARs) exceeds about 15 (e.g., McNeal *et al.*, 1966), which is larger than the present cases, except for solution 8.

Surface irrigation methods usually causes soil erosion, especially at a point of water check-in, and increases the concentration of suspended solids in water. As the sediment laden water infiltrates, a thin depositional layer is formed at soil surface, typically 1 to 3 mm thick. This depositional layer, in spite of its limited thickness, is known to substantially reduce HC (e.g., Shainberg and Singer, 1986). The present study shows that this assessment is correct in silt loam and clay loam, but not in silty clay, coinciding with the earlier discussion on the flow limiting process. The surface seal was the dominant process in Gila and Saneli soils, but not in Glendale soil. The large reduction in HC occurred after sediment application to Gila and Saneli soils may have included plugging of some boundary flow spaces along the permeameter walls by the sediments.

In conclusion, the present study indicates that permeability of plowed and thoroughly disked soils can be affected greatly by such factors as aggregate slaking and the formation of depositional layers. Reducing salinity and/or increasing sodicity of irrigation waters causes the destruction of weak soil aggregates and can reduce permeability even at zero SAR. The extent of permeability reduction is, however, strongly dependent of soil types, and is likely to be most extensive and damaging in clayey soils. The maintenance of adequate infiltration of saline irrigation water as well as rain water requires the consideration of the relationships between soil properties and irrigation water quality.

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水質が土壌構造と透水性に与える影響

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要　約

米国の3土壌（Gila silf loam, Saneliciay loam と Glendale silty clay）について，浸透水中の塩類濃度，成分（電気伝導度 EC 0.4〜4.8 $\mathrm{dSm^{-1}}$, SAR 0〜20），懸濁土粒子の有無が透水係数（HC）に及ぼす影響を室内土壌カラムを使い実験的に考察した。

浸透水 SAR 値が0以外の場合，全3土壌で HC が減少し，減少量は SAR/EC の指数関数で表現された。浸透水に懸濁土粒子を加えた時，Gila と Saneli では HC が 1/4〜1/7 に減少したが，Glendale では顕著な減少はなかった。高 SAR と低 EC の組み合わせが土壌団粒の直径 0.18 mm 付近の崩壊を引き起こし HC の減少をまねいていた。

以上の結果から，播種前リーチングで重要な耕起直後の圃場透水性管理は土壌と水質の両面から行われる必要がある事がわかった。

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