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Quality of Irrigation Water and Soil Amendment Effects on Leaching a Saline-Sodic Soil

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ABSTRACT

Field and laboratory experiments were conducted to determine the effects of three qualities of irrigation water and their interaction with gypsum ($CaSO_4 \cdot 2H_2O$) or sulfuric acid (H_2SO_4) on infiltration rates and time and water requirement to leach a calcareous saline-sodic soil. In both field and laboratory experiments city water (lowest salt) reduced infiltration rates, while use of well water (highest salt) resulted in higher infiltration rates. Sulfuric acid improved the infiltration rates significantly with all sources of irrigation water. Gypsum improved infiltration rates only with well water. Equations were developed to predict time and amount of water required to leach soil columns to a given salt content for the three water qualities, and kind and rate of amendment applied.

The poorest quality irrigation water required the least time and amount of water to leach the soil, until the EC of the leachate was equal that of the irrigation water. Both (H_2SO_4 and $CaSO_4 \cdot 2H_2O$) reduced the time of leaching but required more water when compared with untreated columns.

INTRODUCTION

All irrigation waters carry dissolved salt (TDS—total dissolved salts) in solution. The kind and amount of salts vary from one source of water to another and from time to time. If irrigation agriculture is to remain productive, the salt residues derived from irrigation water must be carried beyond the root zone by leaching. Once soils are reclaimed, the leaching process must be rapid enough to be compatible with good plant yields. On the other hand, if excessive quantities of water are passed through the root zone, water is wasted, soluble nutrients are carried away and a serious drainage problem may develop. The time and amount of water required to accomplish a leaching operation depends to a large extent on the rate of water infiltration into the soil.

The soluble salt content (EC_e) and the exchangeable sodium percentage (ESP) of the soil affect infiltration rates and are generally in equilibrium with the salt and sodium in the irrigation water. Infiltration rates can be improved by using chemical amendments of high-salt water when reclaiming sodium-affected soils as shown by many investigators. Fireman and Bodman (3) obtained a high and constant permeability with a sodic soil when $CaCl_2$ was used in the percolating solution while, when distilled water was used, the permeability decreased drastically. Other studies (2,7) have shown that permeability increases with increasing electrolyte concentration of the percolating water even when the ESP is high.

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Sulfur and sulfur compounds have been used to improve infiltration (Eq. 4, 5, 11) and sulfuric acid has been shown to be an effective material on calcareous saline-sodic soils. Yahia, Miyamoto and Stroehlein (12) found evidence that sulfuric acid improved water penetration into some Arizona soils Salt leaching experiments in Utah and California (8,9) have indicated that salt removal from soil follows a general pattern. In order to reduce the salt concentration of soil to about 20% of its original content, 1 cm of water is required for every 1 cm of soil considered. The permeability of sodic soils is a major barrier to successful reclamation. A solution to the problem was offered as mentioned previously by the use of high-salt water or the application of chemical amendments. This paper evaluates the effect of H_2SO_4, gypsum, and water quality on soil infiltration rates and time and water requirement for leaching a calcareous saline-sodic soil.

MATERIALS AND METHODS

A field study was conducted on a Pima silty clay loam (Typic Torrifluvent), saline-sodic phase (6), on the University of Arizona Safford Experiment Farm. Three sources of irrigation water of different qualities were used: well (EC = 3.2), river (EC = 1.6), and city (EC = 0.5) waters. Characteristics of the soils and the waters were given by Alawi, *et al.*, (1). The field experiment was a randomized split plot design with 9 main plots, and 27 subplots, including 3 replications. The main plots had been irrigated with the designated source of water for 3 years before the amendment application. Additional information on the field trial and soil analyses and sudangrass (*Sorghum sudanese*) yields for 1975 and 1976 have been published elsewhere (1). Infiltration rates were recorded in March 1975 before amendment application. One rate of gypsum (3.85 tonnes/ha.) and one rate of sulfuric acid (2.4 tonnes/ha.) were used in the field study. Irrigation of main plots continued with the designated source of water through the 1975 and 1976 growing seasons. Infiltration rates of each subplot were measured nine and fifteen months after amendment application.

A laboratory study of infiltration rates and leaching was conducted using soil columns. Soil was obtained from untreated subplots in the field and air dried, passed through a 2 mm sieve and 100 g were placed into soil columns, each being 30 cm in length and 2.5 cm in diameter. The outlet consisted of a rubber stopper through which a rigid plastic tube passed. A layer of glass wool was placed over the stopper to protect the drain from the overlying soil. The outlet tube drained into beakers. Each column was compacted until the bulk density of all were within the range of 1.23 to 1.28 g/cm^3. Reagent grades of $CaSO_4 \cdot 2H_2O$ and 93% H_2SO_4 were added to the soil columns as follows: 3.85 or 19.35 tonnes/ha. $CaSO_4 \cdot 2H_2O$ and 2.24 or 11.25 tonnes/ha. H_2SO_4. Each treatment was replicated three times. Gypsum was mixed with the upper 2 cm while H_2SO_4 was surface applied. Characteristics of soil columns are shown in Table 1. Columns were left overnight to let CO_2 escape and reduce its effect on infiltration rates. The same sources of irrigation water used in the field were added to the columns by a constant head device. Infiltration rates were recorded. Leachate from each pore volume was taken separately and the EC was measured. The leaching process continued until the EC of the leachate equalled that of the irrigation water.

$$Y = b_0 + b_1 T + b_{b_2} T^2$$

Y = infiltration rate in cm/hour.

b_0, b_1, and b_2 = regression coefficients

T = time

Multiple regression was used to evaluate the collected leaching data.

Table 1 Infiltration rates from a field study using three water qualities and two chemical amendments, average of three replications.

Amendment	Well		River		City	
	ini.[a]	fin.	ini.	fin.	ini.	fin.
			mm/hr			
Untreated	22.3	0.7	19.3	0.5	0.5	0.1
			1975			
Gypsum	29.7	13.2	29.7	11.2	15.2	3.8
Sulfuric Acid	40.6	13.7	36.1	12.7	27.9	6.6
Control	23.9	9.1	19.1	6.4	3.3	1.3
			1976			
Gypsum	39.4	13.7	33.0	11.7	21.6	5.1
Sulfuric Acid	48.3	17.5	41.1	15.0	33.0	9.1
Control	26.9	9.1	22.1	6.4	6.1	1.5

[a]Ini. refers to first reading, fin. refers to steady-state final reading taken eight hours after water application.

RESULTS AND DISCUSSION

The quality of irrigation water had a considerable effect on the infiltration rates in the field (Table 1). Water with the highest electrolyte concentration (well water) maintained good infiltration rates in spite of its high sodium content. Statistical analysis of the infiltration data indicated that city water (lowest salt content) reduced infiltration rates. Reduced infiltration was due to washing of salt from the soil surface and increasing the ESP.

Table 1 also shows the field infiltration rates of subplots treated with city, river and well waters, respectively, 9 and 15 months after amendment application. These data indicated that sulfuric acid increased the infiltration rates significantly over the controls with the three water treatments and, over gypsum, only with city water treatment. Gypsum increased the infiltration rates significantly only with well water, due to the effect of electrolyte concentration on the solubility of gypsum (1). Sulfuric acid increased infiltration rates due to its solubilizing effect on the relatively insoluble calcium compounds in the soil.

Comparison of infiltration rates of the subplots 15 months after amendment application indicated that there were considerably residual effects. Sulfuric acid treated subplots had the highest infiltration rates, control subplots the lowest. The 1976 measurements, however, were higher than those of 1975. This increase may have been due to seasonal effects or increased soil organic matter and improved soil structure resulting from the 1975 crop of sudangrass.

Table 2 shows the laboratory infiltration rates for the three waters. For each water the high rate of sulfuric acid had the highest infiltration rate followed by the low rate of sulfuric acid, the high rate of gypsum, the low rate of gypsum and then the control, respectively. Statistically, the high rate of sulfuric acid produced higher soil infiltration with all water qualities. No significant difference between the effect of the low rate of acid and the high rate of gypsum on the infiltration rates was found. The low rate of gypsum increased infiltration rates significantly above the control only with well water due to the electrolyte effect on the solubility of gypsum.

The quality of irrigation water controlled, to a certain extent, the time and amount of water required to leach the soil. Table 3 shows that, the poorer the quality irrigation water with respect to EC, the less time and water were required to leaching the

Table 2 Laboratory infiltration rates using three water qualities and two chemical amendments, average of three replications

Amendment	Rate	Well		River		City	
	T/ha.	ini.[a]	fin.	ini.	fin.	ini.	fin.
Gypsum	19.35	208.3	41.9	170.2	21.6	129.7	15.2
Gypsum	3.85	181.6	22.9	152.4	10.2	110.5	7.6
Sulfuric Acid	11.25	236.2	53.3	185.4	35.6	158.8	27.9
	2.24	182.9	27.9	165.1	15.2	138.7	12.7
Control		139.7	8.9	95.3	6.4	57.2	2.5

[a]Ini. refers to initial reading, fin. refers to final reading taken after steady-state infiltration had been reached.

untreated soil column until the EC of the leachate was equal to that of the irrigation water.

Table 3 shows the time and depth of water required to leach a column of Pima soil 30 cm deep until the EC of irrigation water equalled that of leachate. These data indicate that application of soil amendments had a positive effect on the reduction of the leaching time and an adverse effect on the required amount of water independent of water quality. The high rate of H_2SO_4 with well, river and city waters reduced the leaching time by 20, 21, and 26-fold compared to controls and used two-fold more water than the control. The increased water requirement when amendments were used would not be a problem in reclamation under field conditions since the EC of the soil is not reduced to the extent as in this study.

The other treatments influenced time and depth of water required depending on the type and rate of the chemical amendment. Table 4 shows that the change in the EC of the soil when the two rates of H_2SO_4 and the high high rate of $CaSO_4 \cdot 2H_2O$ were

Table 3 The depth of water and time required to leach Pima soil columns 30 cm deep until the EC of the leaching water equalled the EC of the leachate.

Source of water	Amendment rate		Time	Depth of water
	tonnes/ha.		days	cm
Well	Control		2.44	25.6
	Gypsum	19.35	2.17	45.8
	Gypsum	3.85	2.07	71.3
	H_2SO_4	11.25	0.68	30.6
	H_2SO_4	2.24	0.12	50.9
River	Control		4.23	30.5
	Gypsum	19.35	3.88	50.9
	Gypsum	3.85	3.39	81.5
	H_2SO_4	11.25	2.85	40.7
	H_2SO_4	2.24	1.44	56.0
City	Control		57.00	40.7
	Gypsum	19.35	8.88	71.3
	Gypsum	3.85	5.98	71.3
	H_2SO_4	11.25	2.42	45.8
	H_2SO_4	2.24	2.16	71.3

Table 4 Electrical conductivity (EC) of leachate vs time model to predict the time required to leach 30 cm of Pima soil to a specific EC with a given quality of water.

Treatment	Regression equations
Control	$EC = 1.942 + 0.245\ (t/1{,}000) + 1.446\ WQ - 0.511\ (T/1{,}000)\ WQ$
2.24 T/ha. H_2SO_4	$EC = 5.192 - 2.717\ (t/1{,}000) + 0.262\ (t/1{,}000)^2$
11.25 T/ha. H_2SO_4	$EC = 8.316 - 7.228\ (t/1{,}000) + 1.668\ (t/1{,}000)^2$
3.85 T/ha. gypsum	$EC = 3.358 - 0.669\ (t/1{,}000) + 0.031\ (t/1{,}000)^2 + 0.736\ WQ$
19.35 T/ha. gypsum	$EC = 1.569 - 0.395\ (t/1{,}000) + 0.292\ (t/1{,}000)^2$

T = Time in minutes
WQ = EC of irrigation water
EC = Desirable soil EC

Table 5 Electrical conductivity of leachate vs. depth of water model to predict the depth of irrigation water required to leach 30 cm of Pima soil to a specific EC.

Treatment	Regression equations
Control	$EC = 4.911 - 0.354D + 1.027WQ + 0.608D^2$
2.24 T/ha. H_2SO_4	$EC = 6.902 - 0.446D + 0.390D^2 + 1.046WQ$
11.25 T/ha. H_2SO_4	$EC = 7.399 - 0.302D + 0.317D^2 + 2.052WQ - 0.282WQD$
3.85 T/ha. gypsum	$EC = 4.576 - 0.167D + 0.161D^2 + 0.826WQ$
19.35 T/ha. gypsum	$EC = 4.545 - 0.151D + 0.235D^2 + 1.535WQ - 0.97DWQ$

D = Depth of water requirement in cm
WQ = EC $\times$ 10^3 of irrigation water
EC = Desirable soil EC

used was dependent on time, but it was independent of water quality. The independence was considered to be related to the effects of sulfuric acid and the high rate of $CaSO_4 \cdot 2H_2O$ on the increased concentration of ions in the soil solution. At a low rate of gypsum, the change in soil EC_e was dependent on both time and water quality, but it did not depend on their interaction due to a low contribution of ions to the soil solution. The main source of ions for the control was from the irrigation water, which caused the change of the soil EC_e to be dependent on time, water quality, and their interaction.

Table 5 shows that only with high rates of sulfuric acid and gypsum the changes in the soil EC_e was a function of both amount and quality of water and their interaction due to the supply of ions from these two sources. The low rates of amendments and the control indicates that the change in EC_e of the soil was affected by depth and quality of water separately due to their low contribution to total ionic concentration.

CONCLUSIONS

This study showed that irrigation water quality controlled infiltration properties of a saline-sodic soil regardless of the effect of soil amendments. Sulfuric acid was more beneficial than gypsum when applied at equal S levels. Increasing the rate of amendments improved soil infiltration rates for the 3 irrigation waters studied. One equivalent of sulfuric acid had an effect similar to 5 equivalents of gypsum on the soil infiltration rate. With regard to leaching, it was found that the poorest quality of irrigation water (highest salt) required the least time and amount of water to leach the soil column until the EC of the leachate equalled that of the irrigation water. The use of H_2SO_4 at high rates reduced the time required for leaching by 20, 21 and 26 times with well, river, and city water, respectively, but required almost two-fold more water than the controls. In general, more water was required to leach soil columns treated with gypsum than those treated with the H_2SO_4 and untreated soil. More water was required to leach soil columns treated with gypsum when well water was used for leaching than for river or city waters.

The change in the EC_e of the soil was found to be dependent on time only when 2 rates of H_2SO_4 and the high rate of $CaSO_4 \cdot 2H_2O$ were used as chemical amendments, but it was dependent on both time and quality of water and their interaction with the low rate of $CaSO_4 \cdot 2H_2O$ and control. Also, the change in the EC_e of the soil depended on both quality and amount of water and their interaction when high rates of H_2SO_4 and $CaSO_4 \cdot 2H_2O$ were used, while it was affected by these 2 variables separately when low rates of H_2SO_4 and $CaSO_4 \cdot H_2O$ or when amendments were not used.

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