

LABORATORY TESTS ON THE USE OF SODIUM CARBONATE FOR REDUCING PERMEABILITY IN SOIL COLUMNS

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INTRODUCTION

Earthen water impoundments are often the only solution to water shortage in areas of insufficient natural supply. Soils of potential sites should be examined for such physical characteristics as deposition and texture. This precaution improves the chance of selecting a satisfactory site; however, the chemical characteristics of the soil often have more influence on permeability than does texture, and the impoundment fails to hold water for the required length of time.

Reginato *et al.* (3) describe a method of using sodium carbonate to reduce water loss and give an equation for determining the amount of chemical required based on cation exchange capacity of the soil.

$$\text{Na}_2\text{CO}_3 = 0.004 \text{ DA (0.15 CEC-ES)} \dots (1)$$

where:

Na_2CO_3 = pounds of sodium carbonate;
D = depth of soil to be treated (inches);
A = area to be treated (ft^2);
CEC = cation exchange capacity (meq/100 g);
ES = exchangeable sodium (meq/100 g).

This formula facilitates calculation of the quantity of sodium carbonate required to raise the exchangeable sodium percentage (ESP) from the original value to 15 (designated by the factor 0.15), assuming complete replacement by the sodium.

The extremely low permeability to water of high-sodium soils is well known and much research has been done on ameliorating this condition to improve the environment for plant growth.

McNeal *et al.* (2) suggest that the reduction of hydraulic conductivity in high-sodium soil may be the result of a two-step process: swelling, which aids the second, dispersion, resulting in clogged pores. van Schaik (5) reported that in the absence of gypsum, the permeability of montmorillonitic till soils was negligible when the ESP exceeded 15-20. The same condition occurred at an ESP of 30-35 if gypsum was present.

Eaton (1) was one of the first to recognize that carbonate would increase the ESP of soil. This occurs through the removal of calcium and magnesium as insoluble carbonates, resulting in an increased proportion of sodium in the soil solution. This phenomenon makes sodium carbonate most appropriate for raising the ESP and thus causing a sealing effect.

The work described in this paper was conducted to check and possibly improve on equation (1) and to develop a method of increasing the adsorption of the applied sodium on the exchange complex.

MATERIALS AND METHODS

A moderately coarse textured soil was selected to ensure that effluent could be collected for analysis. It was air-dried and passed through a 2-mm sieve. Table I gives the physical and chemical characteristics of the soil and a chemical analysis of the water. The experiment was conducted in three parts.

(I) Leachate Composition

This part of the experiment was performed using plastic tubes 4.4 cm in diam and 20 cm high containing soil columns 12.7 cm high. The bottoms of the tubes were equipped with fine metallic screens that were covered with a thin layer of fine gravel.

Treatments, replicated four times,

were as follows: (a) dry soil alone; (b) dry soil plus sodium carbonate; (c) soil plus sodium carbonate wetted to approximate field capacity for 1 d; and (d) soil plus sodium carbonate wetted to approximate field capacity for 3 d. The amount of sodium carbonate added in each case was sufficient to raise the ESP to 15 (factor 0.15) assuming complete cation exchange. Sufficient tap water was applied to the top of each soil column so that 350 ml of leachate could be collected in 25- and 50-ml increments.

(II) Changes in Hydraulic Conductivity

The same mechanical apparatus was used as described in part I except for the addition of a constant head regulator for hydraulic conductivity measurements.

Treatments consisted of mixing various amounts of salt with the soil, plus a check. The amounts used were determined by solving equation (1) with the following coefficients for the CEC term: (a) 0.15; (b) 0.20; (c) 0.25; and (d) 0.30.

Treatments were run in duplicate and were wetted 3 d prior to applying a constant head of tap water. Two hundred ml of water were passed through the columns and the resulting leachate was collected in 50-ml increments for analysis.

(III) Redistribution on Ions in Columns

This part of the experiment consisted of placing 12.7 cm of sodium carbonate-treated soil over 12.7 cm of nontreated soil in a plastic column 4.4 cm in diam and 30 cm high. The amount of sodium carbonate mixed with the soil was determined by solving equation (1) using 0.25 as the CEC coefficient. The soil was wetted to a depth of 12 cm for 3 d before water was applied to the surface. Sufficient tap water was applied to collect 50 ml of leachate from each column. The column was disassembled and the soil core sampled in 5-cm increments, then

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TABLE I CHARACTERISTICS OF SOIL AND WATER (ANALYSIS OF SOIL DONE ON SATURATION EXTRACT)

	pH	EC	Ca ⁺⁺	Mg ⁺⁺	Na ⁺	HCO ₃ ⁻	%S	%Si	%C	CEC	
		mmhos/cm	mg/liter			mg/100 g				ESP	
Soil	8.2	0.61	170	28	8.3	24.4	56	27	17	13.6	1.4
Tap water	8.1	0.38	56	19	15.4	21.3					

TABLE II WEIGHT OF IONS IN LEACHATE AND RESULTANT ESP OF SOIL

Treatment†	Na ⁺	Ca ⁺⁺	Mg ⁺⁺	HCO ₃ ⁻	ESP
	mg				
a	2.8	27.1	4.4	67.6	0.8
b	62.8	9.4	2.4	170.1	2.2
c	52.4	9.4	1.3	129.9	2.5
d	47.7	10.2	0.9	113.9	2.8
Added	113.0	-	-	147.0	

† Treatment (a) soil alone; (b) dry soil + Na₂CO₃; (c) soil + Na₂CO₃ wet 1 d; and (d) soil + Na₂CO₃ wet 3 d.

TABLE III WEIGHT OF IONS IN LEACHATE AND RESULTANT ESP OF SOIL

CEC Coef.	Na ⁺	Ca ⁺⁺	Mg ⁺⁺	CO ₃ ⁼	HCO ₃ ⁻	ESP
	mg					
Check	.9	13.5	2.7	.4	28.6	.9
.15	36.3	4.2	.6	2.4	75.7	6.1
.20	50.2	5.9	.7	3.4	105.0	10.4
.25	61.1	6.5	.6	4.2	149.8	14.5
.30	81.3	8.2	.4	6.9	175.6	17.7

dried and analyzed for exchangeable sodium. This experiment was done in triplicate.

Chemical analyses for all three parts were performed where required as follows: sodium by flame emission; magnesium by flame absorption; calcium plus magnesium by versenate titration; and carbonate and bicarbonate by titration with an automatic titrimeter. Methods described in the United States Department of Agriculture Handbook 60 (4) were used to determine CEC, ES, and hydraulic conductivity. The hydrometer method was used for mechanical analysis.

RESULTS AND DISCUSSION

(I) Leachate Composition

The addition of sodium carbonate to the soil increased the amount of sodium and bicarbonate (Table II) removed in the leachate but reduced the amount of calcium and magnesium. The sodium and bicarbonate removed in the leachate decreased when the soil was wetted prior to inundation. Wetting the mixture for 3 d raised the ESP to 2.8 from 2.2 for the dry

mixture, for an increase in sodium absorption of 27%. The bicarbonate was likely precipitated out as calcium and magnesium carbonate.

The most rapid removal of sodium took place from the soil that was not wetted during the early stages of saturated flow (Figure 1). This was prior to swelling and dispersion of the soil particles and the reduction in pore size. Wetting allowed the sodium carbonate to move into the small pores by viscous flow and diffusion and allowed time for swelling and dispersion to take place before inundation.

(II) Changes in Hydraulic Conductivity

Increased application of sodium carbonate increased the amounts of sodium, calcium, carbonate, and bicarbonate removed in the leachate and also increased the resultant ESP of the soil (Table III).

Leaching resulted in a greater removal of calcium from the untreated soil than from the soil receiving the largest application of sodium carbonate. It appears that only one-half of the applied sodium remained on the exchange complex after

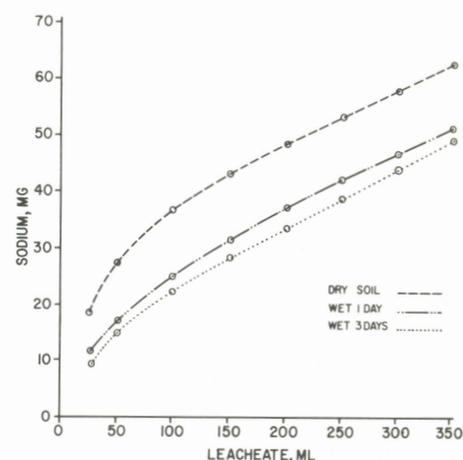


Figure 1. Accumulated sodium leached from soil columns.

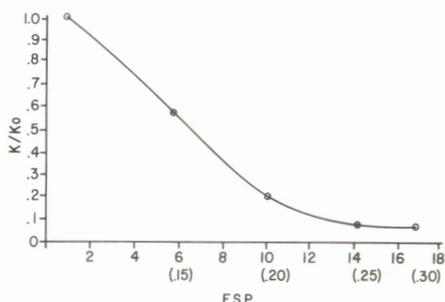


Figure 2. Effects of ESP on hydraulic conductivity ratios. Numbers in parentheses indicate the factor in equation to attain ESP. Note: K, hydraulic conductivity of treated sample; K₀, hydraulic conductivity of untreated sample.

13 cm of tap water were applied. Adding larger amounts of sodium carbonate to the soil columns continuously decreased the hydraulic conductivity (Figure 2) down to an ESP of about 15, where the effect levelled off. It was necessary to use a formula coefficient of 0.25 to reach this level of sealing.

(III) Redistribution of Ions in Columns

The exchangeable sodium appears to have moved down from the surface 5 cm into the next 10 cm (Table IV). The ESP of the lower portion was not raised appreciably. There was a statistically significant difference in ESP between each 5-cm increment.

TABLE IV DISTRIBUTION OF ESP IN COLUMNS

Depth (cm)	ESP
0 - 5	9.0
5 - 10	18.8
10 - 15	13.8
15 - 20	7.3
20 - 25	2.7
Original	1.4

SUMMARY

A laboratory experiment was conducted to evaluate an equation suggested for determining the application rate of sodium carbonate for sealing soils against water movement. Pretreatment effects on sodium retention on the exchange complex and resultant changes on hydraulic conductivity with different application rates of sodium carbonate were studied. The distribution of sodium in soil columns after inundation was also measured.

It was shown that the addition of sodium carbonate to soil resulted in an increase in the amount of sodium appearing in leachate but a decrease in the amount of calcium and magnesium. Pre-wetting resulted in a smaller loss of sodium and thus more retention in the soil. The adsorption of applied sodium on the exchange complex was increased by approximately 25 percent if the soil was wetted 3 days prior to inundation. This can be accomplished in the field by either irrigation or natural precipitation.

Increasing application rates of sodium carbonate resulted in a decrease in hydraulic conductivity to a levelling off point that coincided with an actual exchangeable sodium percentage of 15. This point was achieved by using a coefficient of 0.25 in the application rate equation.

Analysis to determine the distribution of adsorbed sodium in the soil column after inundation showed a movement of sodium from the surface 5 centimeters into the lower 10 centimeters.

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