

LEACHING OF CHLORIDE IN SOIL COLUMNS*

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Leaching of Cl^- was studied in Chicot sandy loam soil in columns under laboratory conditions. The leaching patterns were influenced by the initial moisture content in the soil. In initially saturated column Cl^- band tended to spread and it appeared in the effluent when only 0.66 pore volume water was eluted and the leaching pattern resembled normal distribution curve which was due to Cl^- exclusion and presence of large fast conducting pores. Theoretical values calculated using Day and Forsythe equation were higher than those observed experimentally until 1.5 pore volume water was eluted. Thereafter tailing was much pronounced in the experimental values which was the manifestation of soil-solute interaction. The soil-solute interaction should be taken into account while applying this equation in specific problems.

Key words: Chloride leaching, Dispersion index, Hydrodynamic dispersion.

INTRODUCTION

As a result of municipal waste dumping, chemical spills, nuclear waste burial, agricultural practices and weathering, seeping of salts occurs in the soil. Interest in the simultaneous movement of salts and water has grown significantly in recent years due to under ground water pollution, because of downward movement of salts [1-4].

Soil salinity is a serious problem confronting agriculture in arid and semi arid regions of the world. Leaching of salts from the surface layer below the root zone is a prerequisite for the management and use of such soils. Planning and execution of reclamation of salt affected soils may be facilitated if information on salt movement and distribution in soil is available. Numerous approaches to predict leaching have been devised [5-7]. Using Schedeggar's Statistical Model, Day [8], and Day and Forsythe [9] explained the experimentally measured spreading of salt water boundary moving through sand and exchange resins. Day and Forsythe [9] developed the following equation:-

$$C/C_o = \frac{X_o}{(2\pi\beta\bar{X})^{1/2}} e^{-(X-\bar{X})^2/2\beta\bar{X}} \dots\dots (1)$$

Where,

C = concentration of solution at depth X,

C_o = initial concentration of solution,

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X_o = depth of added solution,
 X = depth where peak concentration occurs,
 \bar{X} = any depth of interest,
 β = index of dispersion.

The objective of this study was to test critically by laboratory experiments the validity of the equation of Day and Forsythe [9] for describing and predicting the leaching of chloride in soil columns.

MATERIALS AND METHODS

The soil used in this study was Chicot sandy loam having pH 6.5, O.M. 2.5 % CEC 11 me/100 g, clay 10.2 %, silt 11.0 % and sand 76.3 %. Leaching of Cl^- was studied with soil packed in columns of 2.2. cm I.D. glass tubes. The columns were packed by compressing with known weights of soil to predetermined heights.

1. *Effect of initial water content of soil on Cl^- leaching.* For this experiment soil samples with initial water contents of air dry, 5 %, 10 %, 15 %, 20 % and saturation point were prepared,

(a). *Air dry.* The soil brought from field was air dried, crushed with wooden hammer and sieved with 2 mm sieve.

(b). *5 % - 20 % water content.* Air dry soil samples were spread thinly in a narrow band on plastic sheet and sprayed with a calculated weight of water. The samples were then mixed thoroughly and kept in double walled plastic bags for 24 hours.

(c). *Saturated water content.* For obtaining saturated water content the air dry soil was packed in the columns,

then distilled water was applied on top of the column until the water drained out at the bottom.

The prepared soil was packed in glass columns. One g. CaCl_2 was mixed in 2.5 cm layer 2.5 cm below the surface of the column, (Table 1). The columns were leached with distilled water under a constant head. The leachate was collected in 1 ml fractions and titrated against standard AgNO_3 using K_2CrO_4 indicator.

2. *Index of dispersion.* Index of dispersion was determined by two methods.

a. Saturated soil column was prepared and 4.6 ml of 3.5 N CaCl_2 solution was applied on top of the column

(column No. 25; Table 2). When the solution disappeared from the top of the column it was cut into sections of 1 cm. The soil from each section was analyzed for Cl^- and its distribution in the column.

b. Different lengths of columns below the salt layer were obtained by positioning the salt layer at different depths in the columns. One gramme CaCl_2 was mixed in 2.5 cm layer (column Nos. 5-9 Table 1). The columns were leached under a constant head. The leachate was collected in 1 ml fractions and analyzed for Cl^- . The concentration of Cl^- in first leachate was used for calculating index of dispersion.

Table 1. Description of columns used for Cl^- movement studies (one g. CaCl_2 used in all columns).

Column No.	Initial water content % by wt.	Position of salt	Total length of column cm	Bulk density g/cm^3	Flow rate $\text{cm}^3/\text{cm}^2 \text{ min}$	Water movement
1.	Air dry	2.5 cm-layer, 2.5 cm from top	30.0	1.26	—	downward
2.	" "	" " " "	30.0	1.30	—	"
3.	" "	" " " " botton	30.0	1.30	—	up word
4.	" "	" " " "	15.0	1.20	—	"
5.	" "	" " " " top	30.0	1.31	0.087	downward
6.	" "	" " " "	23.5	1.28	0.087	"
7.	" "	" " " "	16.4	1.23	0.087	"
8.	" "	" " " "	13.6	1.27	0.087	"
9.	" "	" " 3.6 " "	13.2	1.32	0.087	"
16.	Saturated (42)	" " 2.5 " "	30.0	1.30	0.087	"
17.	Air dry	mixed uniformly	14.4	1.28	0.104	"
18.	5	" "	14.8	1.20	0.104	"
19.	10	" "	14.8	1.20	0.104	"
20.	15	" "	15.7	0.98	0.104	"
21.	20	" "	15.4	0.99	0.104	"
22.	Air dry	" "	9.4	1.12	0.104	"
23.	" "	" "	25.0	1.20	0.104	"
24.	" "	" "	9.6	1.08	0.104	"

Table 2. Description of columns used for comparison of experimental and calculated values by using equation of Day and Forsythe (eq. 1).

Column No.	Length of column cm	Salt solution added	Equivalent length of salt solution layer cm	Pore volume filled with water	Average flow velocity cm/min	Bulk density g/cm^3
25	25	4.6 ml (3.5N)	2.61	0.478	—	1.26
26	5	4.8 ml (2N)	2.74	0.456	0.144	1.20
27	15	4.8 ml (2N)	2.74	0.456	0.144	1.20

3. *Use of Day and Forsythe equation in describing the leaching pattern.* To eliminate the effect of solubility the salt was added in solution form on top of the saturated columns, (column No. 26, 27; Table 2), prepared by leaching with distilled water before the addition of salt solution (4.8 ml 2 N CaCl_2). As soon as the salt solution disappeared from the surface of column, distilled water was added and the column was leached under a constant head. The leachate was collected in fractions of 1 ml each and analyzed for Cl^- .

4. *Soil-solute interaction.* The soil required for 25 cm and 9.6 cm columns was weighed separately. One g. CaCl_2 was mixed in each lot and soil packed in columns (column No. 23, 24; Table 1). The columns were leached with distilled water under a constant head. The leachate was collected in fractions of 1 ml each and analysed for Cl^- . From these data the amount of salt remaining in column was determined.

RESULTS AND DISCUSSION

Leaching of Cl^- is a function of water movement in the soil and the leaching patterns are greatly influenced by the initial water content of the soil (Fig. 1; column Nos. 17, 18, 20 and 21). When the soil below the salt layer was

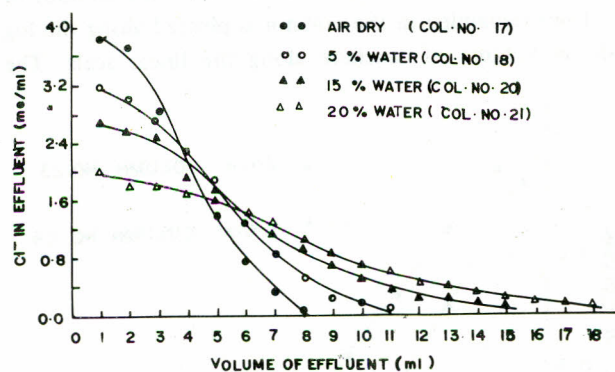


Fig. 1. Effect of water content on leaching of Cl^- in soil columns.

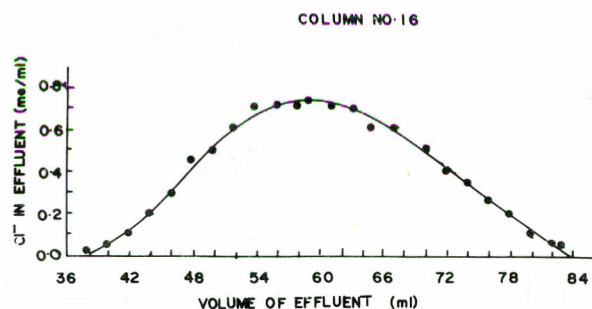


Fig. 2. Concentration of Cl^- in effluent from soil column initially saturated with water.

saturated with water the leaching pattern resembled normal distribution curve (Fig. 2; column No. 16). In this case Cl^- appeared in the effluent when only 0.66 pore volume water was eluted and more than 2 pore volume water was used for leaching Cl^- completely. This spreading of Cl^- band and early appearance of Cl^- in the effluent could be due to the presence of large fast conducting pores, and Cl^- exclusion. Anion exclusion has also been observed under different conditions by other workers [10-14]. Due to presence of clay and ionizable O.M. soil particles exhibit negatively charged surfaces. In the presence of a soil solution, the negative charge extends from the surfaces of particles into the solution thus forming the diffuse double layer. The negative charge results in the repulsion of anions from this region. The resulting concentration gradient causes the anion concentration to near zero at the soil particle surface and increases with distance. At the limit of the diffuse double layer, it is equal to that in the bulk soil solution. By excluding anions from the diffuse double layer where water is almost immobile the system restricts the anions to the faster moving pore water, resulting in an average rate of transport that is greater than the average pore water velocity. Thus for a given duration of leaching, anions will move further in soil or porous material in presence of anion exclusion than in its absence.

Index of dispersion. To use the Day and Forsythe [9] equation to describe the leaching pattern through a column initially saturated with water, dispersion index (β) was determined using the experimental data in Fig. 3

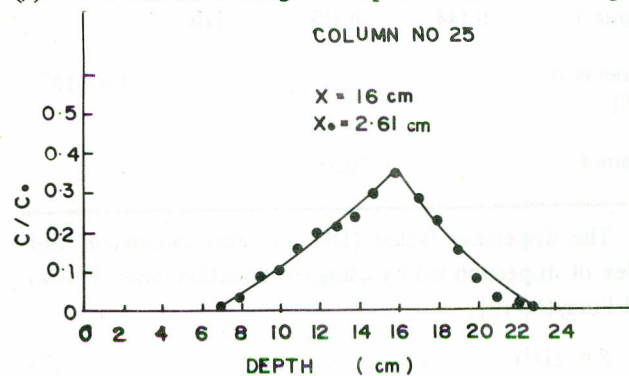


Fig. 3. Distribution of Cl^- in soil column.

(column No. 25). The depth of interest (X) and the depth of peak concentration occurred (\bar{X}) were taken equal, 16 cm. The experimental data were substituted in the equation of Day and Forsythe and solved for β . The dispersion index (β) thus determined was 0.556 cm.

A second calculation was carried out by plotting the concentration of the first 1 ml fraction of the leachate from columns of various lengths vs. square root of the

length below the salt layer (Fig. 4; column Nos. 5-9). The slope of the line of best fit, in absolute value, gave the dispersion index. The values of the dispersion index calculated by different methods are given in Table 3.

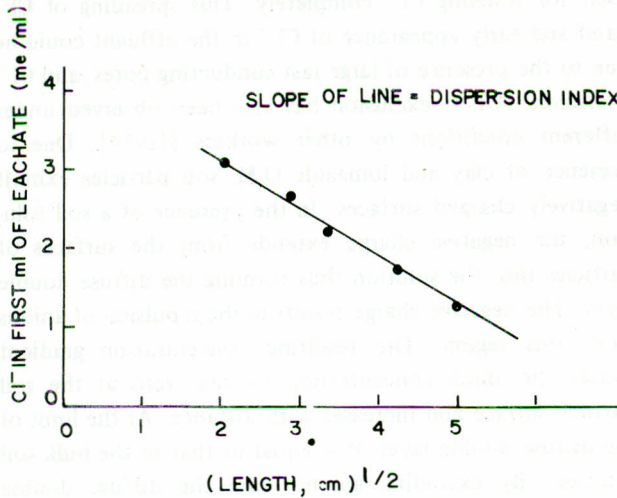


Fig. 4. Concentration of Cl⁻ in first ml of effluent vs. (length of column)^{1/2}.

Table 3. Index of dispersion (β), factor of dispersion (D_f), and coefficient of diffusion (D_e) of Cl⁻.

Source of experimental data	Average velocity (V) (cm/min)	Index of dispersion β (cm)	Factor of dispersion D_f (cm ² /min.)	Coefficient of diffusion D_e (cm ² /min.)
Figure 3	0.144	0.556	0.04	-
Porter <i>et al.</i> [15]	-	-	-	1.8×10^{-4}
Figure 4	-	0.55	-	-

The dispersion factor (D_f) was also calculated from index of dispersion (β) by using the equation, given by Day and Forsythe [9].

$$\beta = 2D/V \dots\dots\dots (2)$$

Where,

β = index of dispersion; D = factor of dispersion; V = average velocity.

The factor of dispersion calculated was 0.04 cm/min.

Theoretical and experimental leaching curves. Theoretical values calculated from the Day and Forsythe [9] equation, using $\beta = 0.556$ cm for two columns 5 cm and 15 cm long are plotted alongwith experimental data in Fig. 5 (column Nos. 26 and 27). The equation gave approximate-

ly the correct spread, and a maximum value of C/C_0 was equal to the maximum value observed experimentally. The experimental points generally fell below the theoretical curves on rising end and the intersected tailing end of the curves when approximately 1.5 pore volume water was eluted. The tailing effect was much more pronounced than that observed by others under different experimental conditions [16-19]. The discrepancy between the experimental and calculated values could be due experimental methodology but is most probably due to soil-solute interaction.

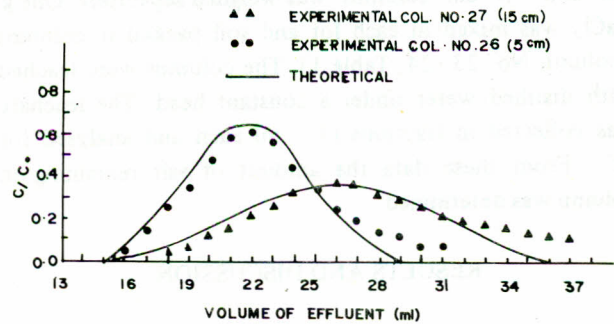


Fig. 5. Theoretical and experimental leaching patterns from soil columns initially saturated with water.

The evidence for soil-solute interaction is provided in Fig. 6 (column Nos. 23 and 24) in which the amount of Cl⁻ (me) remaining in the column is plotted along the log scale vs volume of leachate along the linear scale. The

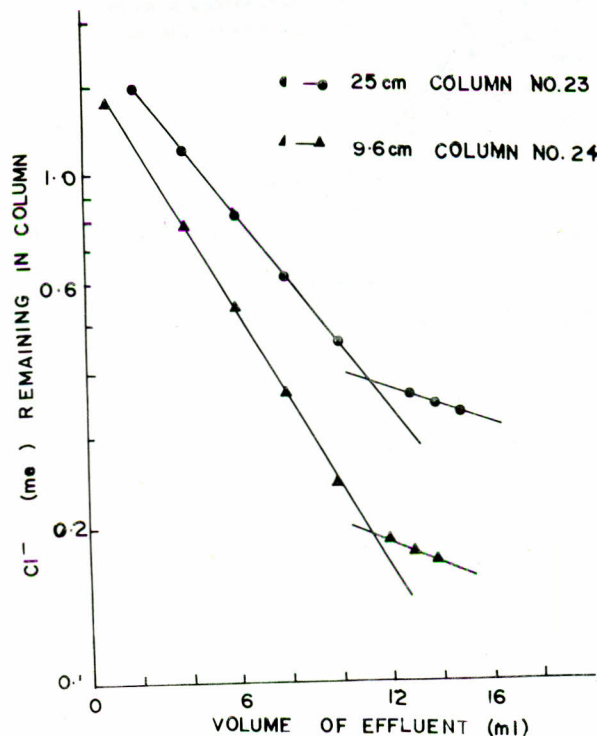


Fig. 6. Rate of leaching of Cl⁻ from soil columns.

curves showed a sharp change in slope. The two lines corresponding to the two slopes show that two reactions are simultaneous in the column during leaching, that is fast removal of salt and the second is slow removal. The second slow reaction causes the change in slope of the leaching curve. This is the manifestation of soil-solute interaction. On a microscopic scale, a film of water containing salt may be left behind on the soil particles while most of the water is swept forward. According to Day and Forsythe [9] hydrodynamic dispersion is responsible for the leaching pattern.

The mechanism of hydrodynamic dispersion is distinctly different from diffusion. It is a fluid transfer phenomenon and does not depend on the random thermal motion of molecules. The velocity of water on a microscopic scale, in the soil varies in magnitude and direction from place to place because of the complicated pore geometry. This heterogeneous character of the velocity is the fundamental cause of hydrodynamic dispersion. In soil diffusion and soil-solute interaction are superimposed on hydrodynamic dispersion. As the dispersion factor (D_f) is 200 times greater than the diffusion coefficient of Cl^- (Table 3) the role played by diffusion in transportation of Cl^- during leaching is negligible.

The results of the present study suggest the need of reformulating the equation of Day and Forsythe to include soil-solute interaction while applying the equation to specific practical problems.

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