A Quantitative Study of the Salinization and Desalinization of Soil Columns

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The problems related to the use of irrigation water have received considerable attention by several investigators. When water is added to the soil, several processes take place; cation exchange reaction [2, 4, 6, 9, 11], dissolution or precipitation of salts [1, 3, 12], and accumulation in, or leaching from the soil of soluble salts with the water movement through the soil. The U. S. Salinity Laboratory Staff [10], BRYSSINE [5], DARAB [6] and VAN DER MOLEN [11] established mathematical equations to calculate the salt concentration in the soil upon irrigation. Other investigators [4, 7] attempted to calculate the salt concentration in the soil layers after irrigation.

This report is a study of the variations in the soluble salt content of soil column upon addition of water containing different salt concentrations. A mathematical relationship describing the salinization and desalinization processes is suggested.

Experimental

Four hundred g of soil were packed in glass percolators, 5 cm. in diameter and 35 cm. long with a glass wool layer on the bottom and a filter paper on the surface. Two hundred ml. of $CaCl_2$ solution of a known concentration were added to the soil column. The percent salt in the soil before and after leaching, the volume and salt content of the filtrate were determined and the salt balance was calculated for each soil column. In soils nos. 4—11, inclusive, percolators of 3 cm. in diameter and 22 cm. long were used, the soil was 100 g. and the volume of $CaCl_2$ stock solution was 6 ml. From the soils used, samples with different salt contents were prepared by passing $CaCl_2$ solution of a known concentration through a column of the selected soil. The columns were then unpacked, the salt content determined, dried, ground and reused. The $CaCl_2$-solution was preferred to avoid the unfavorable properties of the sodium soils when NaCl was used.

The following treatments were carried out in duplicates:
a) Soil samples with different soluble salt content;
b) Solutions of different concentrations;
c) Different amounts of the added solution;
d) Number of irrigations;
e) Soils with different textures.

Table

Effect of adding solutions of different concentrations

Init. soil salt cont. g./kg.	Filtrate conc. g./l.	Salt retain g./kg.	Salt leach. g./kg.	Final soil salt cont. Det.	Calc. A *	Calc. B **	Filtr. conc. g./l.	Salt retain g./kg.	Salt leach. g./kg.
	Soln. Conc. = 0.555 g./l.						Soln. conc. =		
0.48	2.61	0.19	0.28	0.40	0.44	0.54	3.29	0.63	0.19
0.90	4.62	0.19	0.59	0.39	0.44	0.78	5.80	0.61	0.55
1.60	8.60	0.18	1.39	0.40	0.43	1.26	10.32	0.57	1.30
2.20	11.72	0.18	1.86	0.45	0.44	1.65	13.32	0.58	1.72
2.90	18.10	0.19	2.70	0.40	0.45	2.20	17.92	0.57	2.57
4.30	26.81	0.15	4.00	0.38	0.42	3.14	26.98	0.58	3.87
5.00	31.06	0.19	4.79	0.35	0.46	3.55	33.06	0.59	4.61
6.10	37.34	0.19	5.79	0.40	0.47	4.29	47.37	0.64	5.44
7.00	45.05	0.19	6.72	0.41	0.47	5.08	44.55	0.58	6.39

The percent salt in the soil was estimated by determining the electric resistence of the soil paste. The salt concentration of the filtrates (in me./l.) was considered equal to the electrical conductivity of the filtrate in mmhos./cm. multiplied by 10. In cases where the soils were leached with $CaCl_2$ solution more than once, the Ca^{2+}-concentration was determined in the filtrates by the EDTA method and considered as the total salt concentration.

The least square-method was used in establishing equations 2, 3 and 4.

Results and discussions

I. Two major factors are involved in the salinization and desalinization processes when a solution is added to a soil column:

1. The soil column will retain a part of this solution. Hence the soil salt content increases according to the amount of salt in the retained solution. The ability of the soil to retain portions of the added solution had been studied by several workers.

2. The other part of the solution which passes through the soil column may leach a part of the soils original salt content. Considering these two factors, BRYSSINE [5] established the following equation:

$$X_1 = S \frac{R}{Q} + CR \tag{1}$$

where

X_1: the amount of salt in the soil after one irrigation expressed in g. salts per kg. of soil,

S: the initial salt content of the soil in g./kg. of soil,

C: the salt concentration of the added water in g./l., *1.*

to soil "A" columns with different salt content

Final soil salt cont.			Filtr. conc. g./l.	Salt retain g./kg.	Salt leach. g./kg.	Final soil salt cont.		
Det.	Calc. A *	Calc. B **				Det.	Calc. A *	Calc. B **
1.67 g./l.					Soln. conc. = 3.25 g./l.			
0.87	0.94	1.00	4.11	1.15	0.14	1.50	1.49	1.56
0.82	0.94	1.22	6.05	1.16	0.40	1.62	1.54	1.78
0.90	0.92	1.68	10.50	1.13	1.15	1.59	1.58	2.22
0.90	0.96	2.05	13.69	1.12	1.62	1.65	1.63	2.64
0.90	0.98	2.55	18.14	1.11	2.45	1.60	1.69	3.09
0.98	1.04	3.50	28.29	1.14	3.77	1.70	1.86	4.15
1.00	1.08	4.00	40.86	1.26	4.25	1.90	2.05	5.19
1.30	1.18	5.28	36.14	1.13	5.00	2.00	2.03	5.38
1.20	1.15	5.50	32.97	1.02	5.50	2.40	—	—

* Calc. A = calculated by using equation (5).
** Calc. B = calculated by using equation (1).

Q: the amount of added water in l./kg. soil per one irrigation and

R: the amount of water retained by the soil in l./kg. soil per one irrigation.

The results obtained in this study showed that the effect of variations in the soil initial content of salt upon the composition of the filtrate is governed by several factors:

a) By using soil columns of one soil type differing in salt content and leached with one solution, the amount of salt leached from the soil column per kg. soil increased with the increase of the initial soil salt content.

b) For one soil, the leached amount of salt tended to decrease with the increase in the salt concentration of the added solution.

c) Soils without — or with very low — initial salt content may retain an additional amount of salt from the solution, other than the amount RC, as seen in Tables 1. and 2. This is especially clear with solutions of higher concentrations.

d) The soil texture also affects the variation in the soil initial salt content. Table 2. shows that the clay soil had lost less salt than the loam soil, and the latter lost less than the sandy soils. Also the additional amount of salt retained by the nonsaline, clay soil is greater than that retained by the lighter soils.

From these results it became clear that $\frac{S}{R}$ in the BRYSSINE equation (1) does not represent the change in the soil salt content upon being leached. An evaluation of this change in the soil salt content will help to establish a mathematical relationship correctly describing the salinization or desalinization process. Plotting the leached amount of salt in g./kg. of soil from Table 1. Fig. 1. was obtained. It will be seen that the relationship between the two variables can be considered rectilinear up to 7.0 g. salt/kg. soil. After this point, the rate of increase in the amount of salt in the leachate slows down, especially with more concentrated solutions, and a bend in the curve appeared. A mathe-

Table

Effect of leaching columns of soils different in texture and salt content

Soil			Filtr. conc. g./l.	Water retain CR g./kg.	Salt retain CR g./kg.	Salt leach or added g./kg.	Final soil salt cont.		
No.	Text.	Init. salt cont. g./kg.					Det. g./kg.	Calc. A g./kg. *	Calc. B g./kg. **
			Soln. conc. = 1.67 g./l.						
8 – O	S	0.0	1.35	0.25	0.418	+0.130	0.50	0.71	0.42
9 – O	S	0.0	1.00	0.28	0.467	+0.257	0.70	0.76	0.47
5 – O	L	0.1	1.43	0.38	0.630	+0.060	1.00	0.92	0.69
3 – O	S	0.3	1.79	0.28	0.467	0.047	0.70	0.77	0.59
4 – O	L	0.4							
6 – O	HL	0.6	2.31	0.37	0.620	0.190	1.10	0.93	0.95
2 – O	SL	0.6	1.95	0.31	0.518	0.103	1.00	0.83	0.81
3 – T	S	1.2	5.68	0.23	0.390	1.070	0.50	0.73	0.46
1 – O	C	1.1	2.50	0.41	0.679	0.210	1.50	1.01	1.36
2 – T	SL	1.6	7.74	0.31	0.510	1.170	0.90	0.86	1.47
3 – T	S	1.9							
8 – T	S	2.0							
4 – T	L	2.1							
4 – T	L	3.0	9.40	0.39	0.650	2.16	1.30	1.06	2.40
2 – T	SL	3.7	10.10	0.27	0.450	3.36	0.80	0.89	1.93

NB.: O = original soil
T = treated (previously leached)

* Calc. A = Equation (5) was used
** Calc. B = Equation (1) was used

matical relationship for the rectilinear part was established for solutions with concentrations of 0.555, 1.67 and 3.25 g./l. as follows:

a) For the solution 0.555 g./l.: $S_1 = 0.995\,S - 0.244$ (2)
b) For the solution 1.67 g./l.: $S_1 = 0.960\,S - 0.290$ (3)
c) For the solution 3.25 g./l.: $S_1 = 0.900\,S - 0.298$ (4)

By subtracting the value of S_1 from the value of S and adding the amount of salt retained with the retained solution the following equation is suggested to calculate the final soil column salt content upon irrigation with a saline solution:

$$X_1 = S - S_1 + CR \tag{5}$$

where the significance of the terms of the equation are as previously stated in equations (1), (2), (3) and (4).

It should be pointed out that the constants of equations (2), (3) and (4) were calculated from the results of Table 1., where soil "A" was used. Hence it is expected that the application of equations (2), (3), (4) and (5) is limited to light textued soils with salt content not exceeding 7.0 g./kg. For equation (4) the maximum soil salt content was 6.1 g./kg. Applying equation (5) for light textured soils when irrigated with solution of concentrations 0.555, 1.67 and 3.25 g./l., the calculated values were in close agreement with the experimental values (Table 1). It is also seen in Table 2., that values calculated for clay soils were not in agreement with the experimental values.

2.

with solutions of different salt concentrations

Filtr. conc. g./l.	Water retain CR g./kg.	Salt retain CR g./kg.	Salt leach or added g./kg.	Final soil salt cont. Det. g./kg.	Calc. A g./kg. *	Calc. B g./kg. **
			Soln. conc. = 3.25 g./l.			
2.68	0.26	0.850	+0.230	1.30	1.14	0.85
2.30	0.29	0.942	+0.358	1.40	1.23	0.94
3.26	0.27	0.893	0.005	1.30	1.22	1.00
2.68	0.40	1.300	+0.153	2.10	1.64	1.57
1.63	0.36	1.170	+0.502	2.30	1.52	1.49
3.36	0.30	0.975	0.040	1.65	1.33	1.26
5.02	0.24	0.790	0.750	1.18	1.20	1.23
3.66	0.42	1.355	0.103	2.30	1.76	2.04
6.10	0.32	1.027	1.000	1.60	1.68	1.78
8.57	0.23	0.770	1.400	1.15	1.25	1.67
6.80	0.24	0.780	1.530	1.20	1.27	1.50
8.80	0.40	1.300	1.520	1.65	1.80	2.55
10.33	0.40	1.300	1.910	2.26	1.89	3.09
10.95	0.27	0.877	3.080	1.35	1.54	2.35

S = sand
L = loam

SL = sandy loam
HL = heavy loam
C = clay

Table 3.

Effect of several irrigations on salt content of saline soils in tubes

Soil	Volume of water added l./kg.	No. of irrig.	Soil salt cont. Initial g./kg.	Soil salt cont. Final g./kg.	Vol. of filtrate l./kg.	Conc. of filtrate g./l.	Salt leach from soil g./kg.	Salt ret. RC g./kg.
			Soln. Conc. = 3.25 g./l.					
A	0.500	1st	0.48	1.56	0.130	4.11	0.125	1.20
	0.500	2nd	1.56	1.59	0.171	9.48	1.066	1.07
	0.500	3rd	1.59	1.65	0.145	10.55	1.060	1.15
	0.500	4th	1.65	1.60	0.155	10.79	1.170	1.12
			Soln. Conc. = 4.58 g./l.					
A	0.500	1st	0.48	2.30	0.138	4.94	0.04	1.66
	0.500	2nd	2.30	2.40	0.158	14.51	1.57	1.56
	0.500	3rd	2.40	2.40	0.147	14.97	1.52	1.62
	0.500	4th	2.40	2.30	0.159	15.27	1.70	1.56

Table 4.

Effect of increasing the volume of the added solution (Q) on salt content of soils in tubes

Soil	Soil salt cont.		Vol. of soln. and No. of addn. l./kg.	Water retains R l./kg.	No. Vol. and concentration of filtrates									
					1		2		3		4		5	
	Initial g./kg.	Final g./kg.			Vol. l./kg.	Conc. g./l.	Vol. l./kg.	Conc. g./l.	Vol. l./kg.	Conc. g./l.	Vol. l./kg.	Conc. g./l.	Vol. l./kg.	Conc. g./l.
					Conc. of added soln. = 1.67 g./l.									
A	0.48	0.85	$1\times0.5 = 0.5$	0.370	0.130	3.17								
	0.48	0.90	$2\times0.5 = 1.0$	0.370	0.130	3.04	0.497	1.72						
	0.48	0.83	$3\times0.5 = 1.5$	0.360	0.140	3.10	0.497	1.61	0.502	1.61				
	0.48	0.90	$4\times0.5 = 2.0$	0.351	0.149	3.07	0.495	1.72	0.500	1.72	0.495	1.72		
	0.48	0.90	$5\times0.5 = 2.5$	0.351	0.149	3.07	0.502	1.75	0.493	1.72	0.493	1.72	0.501	1.74
					Conc. of added soln. = 6–7 g./l.									
1*	1.10	5.40	$1\times1.0 = 1.0$	0.467	0.533	4.88								
	1.10	5.00	$0.67+1.0 = 1.67$	0.417	0.250	2.37	0.993	6.80						

* a clay soil

II. The amount of water and number of irrigations: Table 3. shows that when the soil column was irrigated with different amounts of the saline solution, the final salt content in the soil column did not materially vary with the amount of the added solution. Dividing the added solution into 500 ml portions and collecting each filtrate separately, it was found that the salt concentration in the filtrate portions after the first were almost equal to each other and to the initial concentration of the added solution.

In studying the effect of several irrigations, the soil column was unpacked, dried, ground and repacked. The same amount of the same solution was used each time. This was repeated for every irrigation. It was found, as seen in Table 4., that the final soil salt concentration after one irrigation is almost the same after 2 or more irrigations. It seems that an equilibrium between the salt concentration of the added solution and the soil takes place upon the first irrigation. The calculation of the salt balance of the soil column and leachate revealed that when the soil was irrigated with the same solution, the amount of salt leached from the soil S_1 was equal to the amount added to the soil in the retained portion of the added solution, or $S_1 = CR$.

In this regard the writer points out that the experiments reported herein dealt mainly with the salinization process and desalinization of soils with low salt content. Desalinization of highly saline soils may act in a different manner [8].

III. Effect of soil texture. — The results in Table 2. show that the application of a saline solution to the soils resulted in a greater increase in the salinity of the clay soils than in the loam soils. The increase in the sandy soils was the lowest. The study of the salt balance of the soil columns showed that 3 factors are responsible of the greater increase in the final salt content in the clay soils.

a) The clay soils possess a greater ability to retain water, and hence the amount of salt retained with the retained portion of the solution, CR is greater.

b) The amount of salt leached with the passing portion of the added solution decreases with the increase of the fine soil particles.

c) In nonsaline soils the amount of salt retained—in addition to RC — increases with the increase of the fine particles. This is especially clear with solutions of high salt concentrations. The mechanism with which this amount of salt is retained still needs further investigation.

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Summary

Columns of soils different in their salt content and texture were leached with salt solutions of different concentrations. The soil salt content before and after leaching, the volume and salt concentration of the added solutions and the filtrates were determined. The study showed that the final soil salt content is affected by the amount of the retained solution, the amount of salt leached from or added to the soil. A mathematical relationship was suggested for the calculation of the final salt content of light soils. The effect of the amount of added water, the number of irrigations, and the soil texture on the final soil salt content were also studied.

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Количественные исследования изменения содержания солей в почвенных колонках

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Резюме

Проводилось выщелачивание колонок почв различного механического состава и с различным уровнем содержания солей растворами солей меняющейся концентрации. Определяли содержание солей в почве до и после промывания, а также количества использованных для промывания растворов и фильтратов и концентрацию. Результаты исследований показали, что на конечное содержание солей в почве влияние оказывают содержание солей в почвенном растворе и в фильтрате, полученном при промывке, а также количество солей в растворе, использованном для промывки. Выведена математическая формула для расчета конечного содержания солей для легких почв. Кроме того, изучали влияние количества использованной для промывки воды, числа поливов и механического состава на остаточное содержание солей в почве.