Evaluation of the Salt and Sodium Retention of Soils

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It was shown earlier [2] that two phases with different velocities and mechanisms may be distinguished in the salt leaching process. It is, however, not possible to apply the suggested reaction-kinetical approach to processes with salt accumulation. Therefore, it was deemed necessary to develop a computation method to evaluate salt movement.

For the numerical characterization of the ability of soils to retain and release salt, a correlation is suggested below, which may be useful not only for drawing theoretical conclusions, but also in solving a number of practical problems.

Under laboratory conditions samples from the A horizons of two chernozems (loam) and one brown forest soil (sand) with both disturbed and original structures were tested. Some characteristic data of the soils are given in Table 1.

In some instances the salt contents of the columns were increased by adding KCl, to facilitate the exact observation of the salt movement. The model experiments were carried out with soil samples (columns) taken with or packed into 10 cm high metal cylinders. The columns were irrigated with waters containing different amounts of sodium salts and with distilled water.

The salt concentration (C_{irr}) and sodium percentage (Na_{irr}) of the irrigation waters were the following: non-saline irrigation: $C_{irr} = 570$ mg/l; $Na_{irr} = 115$ mg/l; Na% = 50.0; saline irrigation: $C_{irr} = 1550$ mg/l; $Na_{irr} =$ $= 414$ mg/l; Na% = 66.6.

Depending on the water permeability of the soils the solutions were applied using the rain simulation method or as 2 cm high water columns. The amount of water was equivalent to 70—80 mm. The salt concentration and Na content of the leachate [1] were tested for each 10 ml, after which the amount of salts removed by the leaching water was computed.

Knowing the initial salt content, the mobile Na content and the moisture content of the soil, and taking into consideration the salt concentration and volume of the leachate and the quality of the irrigation water, it is possible to calculate the changes in the salt content of soil columns with respect to the different stages of leaching.

Table 1

Some characteristic data of the soils tested

Soil: Type	Soil: Origin	K_A	Bulk density g/cm³	Field capacity vol. %	Humus %	Salt %	Mobile Na me/100 g
Chernozem, salty in deeper horizons	Debrecen	43	1.40	40.5	2.3	0.05	1.53
Meadow chernozem	Ebes	39	1.26	35.2	2.6	0.025	0.75
Brown forest soil with alternating thin layers of clay	Józsa	27	1.42	23.8	0.83	0.01	—

K_A = stickiness, approximately 10—15% lower as compared to SP; Mobile Na = soluble + exchangeable.

The decrease in the salt content of the soils due to leaching with distilled water can be expressed as:

$$S_1 = C_0 \cdot V_0 - C_{d_1} \cdot V_{d_1} = S_0 - S_{d_1}$$

where:

C_0 = initial conc. of soil solution (g/l)
V_0 = volume of soil solution (l)
C_{d_1} = conc. of first part of the leachate (g/l)
V_{d_1} = volume of first part of the leachate (l)
S_0 = initial salt content of the soil (g)

$$S_0 = s_0 \cdot m/100$$

s_0 = initial salt content of the soil (%)
m = the mass of soil in the column (g)
S_{d_1} = salt leached out by the first part of the water (g)
S_1 = the calculated salt content of the soil column after leaching with the first part of the water (g).

In general:

$$S_n = S_{n-1} - S_{d_n} \tag{1}$$

where:

S_n = salt content of the soil after leaching with the n-th part of the water (g)
S_{n-1} = salt content of the soil after leaching with the (n — 1)th part of the water (g)
S_{d_n} = the salt quantity removed by the n-th part of the water (g).

It must be taken into consideration when soils are in contact with *waters containing dissolved salts* that, on the one hand, salt has already been added to the soil with the water necessary for field capacity (FC) before the irrigation water is added and, on the other hand, it is supposed that during the additional water dosage the volume of water applied to the soil is equivalent to the leachate.

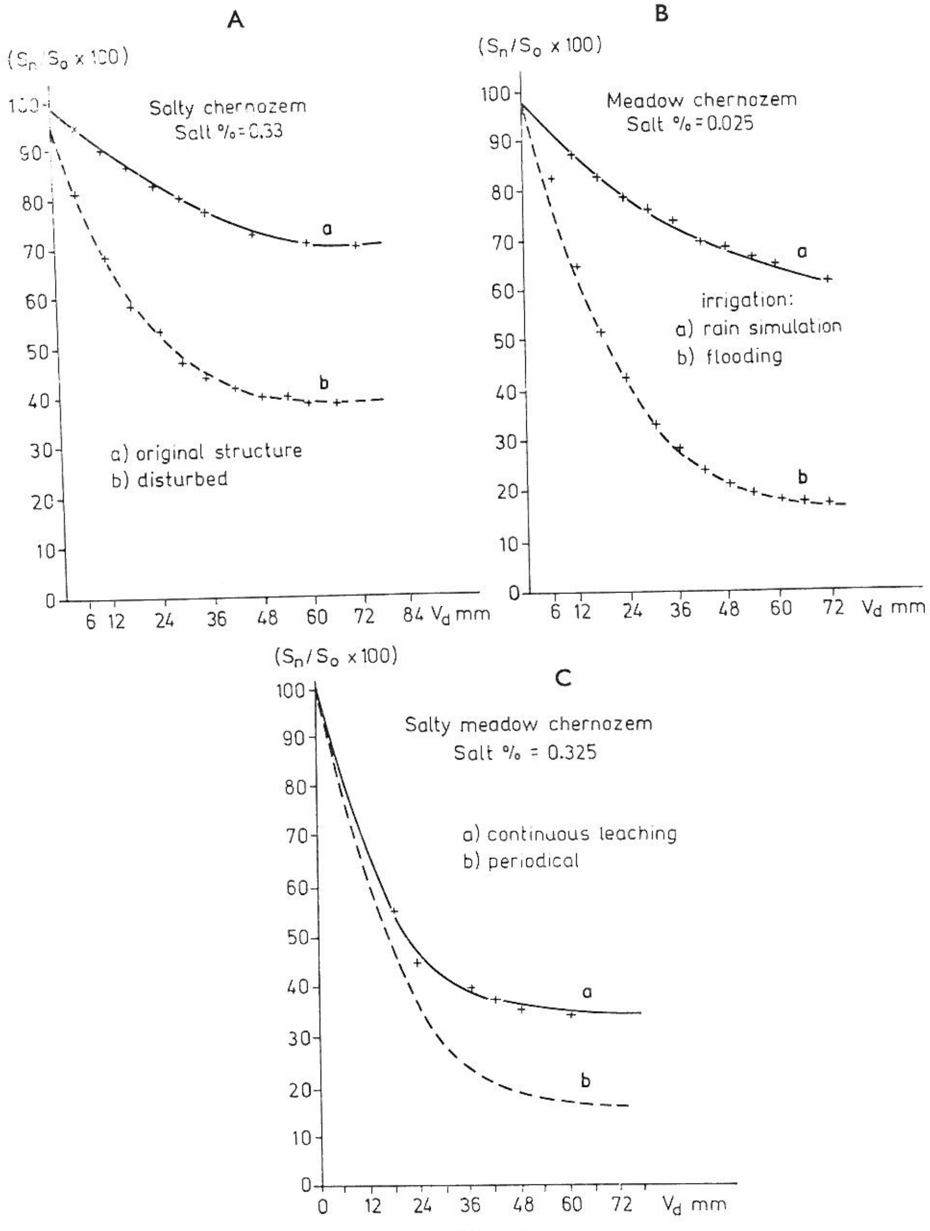


Fig. 1

Relative change in salt content during the leaching of soils with different initial salt contents and structures. A) Irrigation with distilled water. C) Irrigation with non-saline water

The salt conditions of soils receiving saline irrigation water can be expressed as:

$$S_1 = S_0 + C_{irr} \cdot VH + C_{irr} \cdot V_{d_1} - C_{d_1} \cdot V_{d_1} = S_0 + S'_0 + S_{irr_1} - S_{d_1}$$

C_{irr} = salt concentration of irrigation water (g/l)
VH = irrigation water added to reach FC (l)
S'_0 = $C_{irr} \cdot VH$ = salt quantity at the moisture level of FC (g)
S_{irr_1} = salt added with the first part of the irrigation water above FC (g)

In general:

$$S_n = S_{n-1} + S_{irr_n} - S_{d_n} \tag{2}$$

S_{irr_n} = salt added in a single phase of irrigation (g)
S_{d_n} = salts removed with the leachate (g)

To make it easier to demonstrate the intensity of salt movement and to draw comparisons, the momentary salt content (S_n) was expressed as a percentage of the salt quantity (S_0) before appearance of the leachate, then the values were plotted against the relevant leachate volume (V_d). The volume of leachate was given in mm. Graphs showing the change in the salt contents are presented in Fig. 1.

With an increase in the quantity of irrigation water the salt content of the soil gradually decreases, as is demonstrated in Fig. 1.

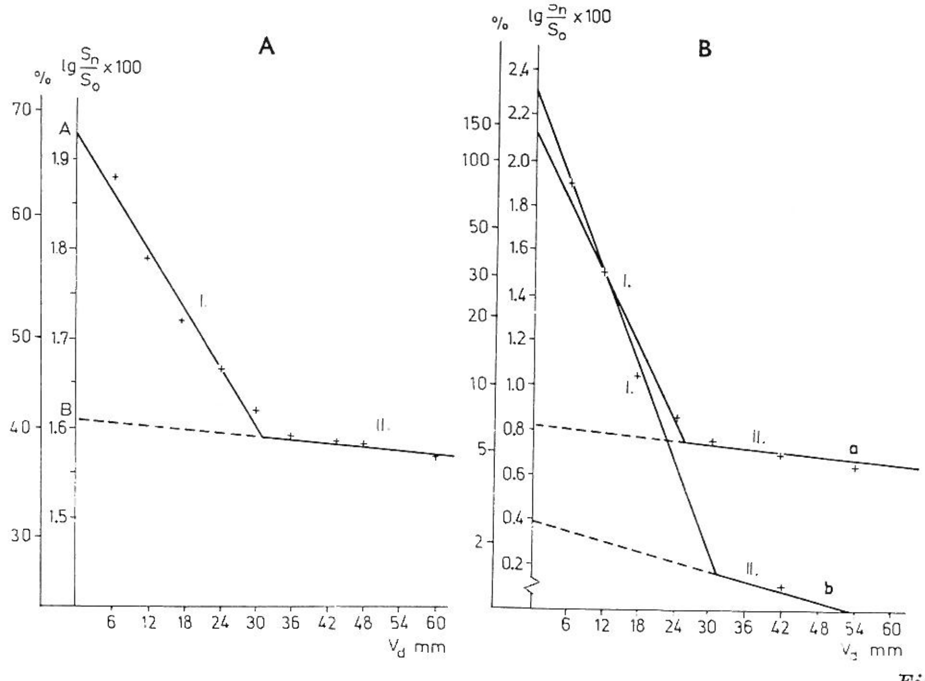


Fig.
Correlation between the velocity of leaching and the volume of the leachate. A) Meadow water; b) non-saline water. C) Chernozem, irrigated with distilled water. D) Meadow

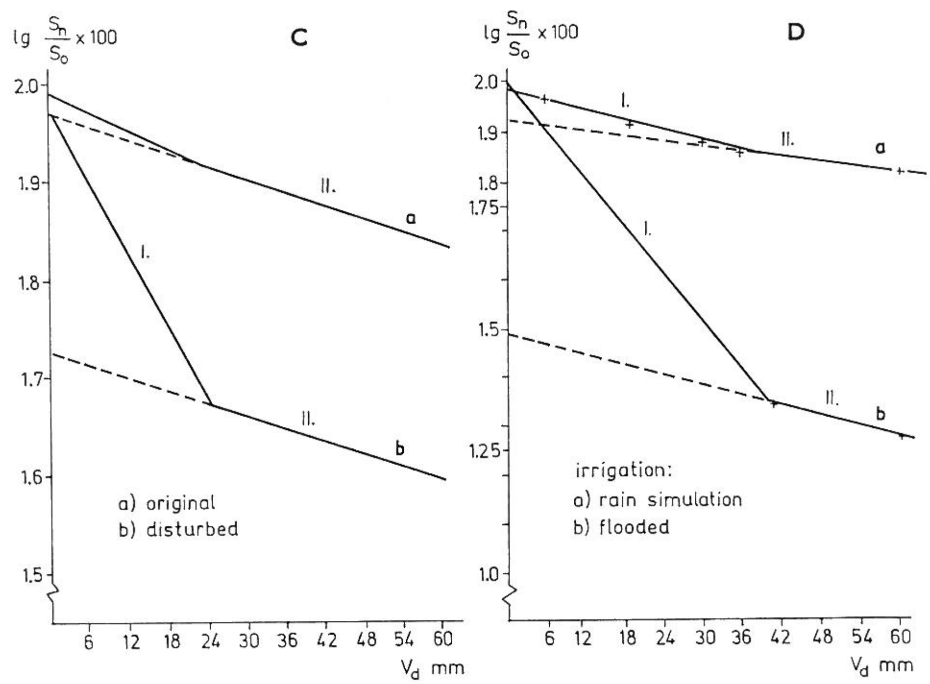
Fig. 1/a—1/c show relative changes in the salt contents of soils due to representative treatments.

Whereas the graphs satisfactorily present the trend in salt content, they are not suitable for a numerical characterization of the efficiency of leaching. On testing the correlation between the logarithm of the percentage values and the leachate volume, straight lines were obtained, suitable for a quantitative evaluation of the process.

Fig. 2/a shows that with this method of approximation the salt movement may be divided into two phases with different velocities. The steepness (tg α) of the straight sectors characterizes the velocity of the process, depending on the soil properties, (Figs. 2/b—c—d).

The $1/\text{tg}\,\alpha = \text{tg}\,\alpha'$ values calculated for phases I and II are summarized in Table 2.

Both the change in the percentage of the salt content and the numerical data for tg α' show that the velocity of the salt movement is determined for a given soil structure by the physical conditions, and in this respect the intensity of water movement is independent from the initial salt content (S_0) of the soil. This is verified by the almost identical values of tg α' for chernozem soils with their original structures at salt contents of 0.05% and 0.33%, and also from another aspect, by the fact that the leaching efficiency and the salt concentration of the leachate fraction are larger at lower permeability (Fig. 1/a).



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chernozem irrigated with distilled water. B) Brown forest soil. Irrigated with: a) distilled chernozem (original structure)

Table 2

The tg α′ values (tg α′ = 1/tg α), characterizing the velocity of change in the salt content

Soil	Salt %	Treatment	tg α′	
			Phase I.	Phase II.
I. Chernozem	0.05	Distilled water, rain simulation	−313.4	−460.3
II. a) Salty chernozem	0.33	Distilled water, rain simulation	−315.8	−466.0
b) Salty chernozem disturbed		Distilled water, rain simulation	−91.1	−460.0
III. a) Brown forest soil	0.3	Distilled water, rain simulation	−18.2	−420.0
b) Brown forest soil		Non-salty irrigation water, rain simulation	−15.4	−145.0
IV. a) Meadow chernozem	0.025	Non-salty irrigation water, rain simulation	−272.7	−571.4
b) Meadow chernozem		Non-salty irrigation water, flooded	−57.27	−284.2
V. Salty meadow cherno-zem	0.345	Salty irrigation water, rain simulation	−90.9	−1500.0
VI. a) Salty meadow chernozem	0.325	Salty irrigation water, continuous rain simulation	−65.75	−594.1
b) Salty meadow chernozem		Salty irrigation water, periodical rain simulation	−57.18	−73.17

With suitable modelling this evaluation system permits the good estimation of:

1. the degree of material transport influenced by the soil and salt solution;

2. the quantity of irrigation water which results in a given change in the salt content of the soil and, consequently,

3. the scale of salt movement which may be caused by a given amount of rain in various soils.

Graphs similar to Fig. 2 are convenient for demonstrating the value of tg α′, the volume of leachate, and the correlation between them in accordance with the relative salt content. On this basis the quantity of leachate associated with a given increase or decrease in the salt content may be calculated.

The quantity of water necessary for decreasing the salt content to the required extent can be expressed as follows:

Phase I

$$V_{dI} = \text{tg}\,\alpha'_I \left(\lg\left(\frac{S_n}{S_0} \cdot 100\right) - A\right) \tag{3a}$$

where:

tg α'_I = the characteristic value for the velocity of leaching in the rapid phase

A = point of intersection of straight line I and the axis of

$$\lg \frac{S_n}{S_0} \cdot 100$$

$$A = \lg \left(\frac{S_n}{S_0} \cdot 100 \right)_0^I$$

$()_0$ for the case when $V_d = 0$
$()^I$ for phase I of leaching

Phase II

$$V_{dII} = \operatorname{tg} \alpha'_{II} \left(\lg \left(\frac{S_n}{S_0} \cdot 100 \right) - B \right) \qquad (3b)$$

where:

$\operatorname{tg} \alpha'_{II}$ = the characteristic value for the velocity of leaching in the slow phase
B = point of intersection of straight line II and the axis of

$$\lg \frac{S_n}{S_0} \cdot 100$$

$$B = \lg \left(\frac{S_n}{S_0} \cdot 100 \right)_0^{II}$$

From the above equations it is possible to calculate the degree of decrease in the salt content of the studied soil after the percolation of a certain quantity of water.

The salt remaining in the soil for a given quantity of water can be calculated as follows:

Phase I

$$\lg \left(\frac{S_n}{S_0} \cdot 100 \right) = \frac{V_d}{\operatorname{tg} \alpha'_I} + A \qquad (4a)$$

Phase II

$$\lg \left(\frac{S_n}{S_0} \cdot 100 \right) = \frac{V_d}{\operatorname{tg} \alpha'_{II}} + B \qquad (4b)$$

The system presented can be successfully applied not only for the total salt content, but also for the evaluation of leaching or accumulation of any mobile components (e.g. Na^+, Mg^{2+}, K^+, NH_4^+). When testing cation retention, the calculation should be done on the basis of total mobile (soluble + exchangeable) quantities.

The system discussed can be utilised:

— to study the interaction between irrigation water and the soil,

— to determine the migration of substances in drained areas and to reveal the parameters which influence it,

— to study the leaching of fertilizers,

— in research on the soil properties which promote the accumulation of certain substances (e.g. Mg^{2+}).

Summary

Under laboratory circumstances the salt release of soil samples (with both disturbed and original structures) treated with different salt solutions and with distilled water was tested.

Based on a knowledge of the original soil characteristics, the actual values of salt contents in the soil columns were computed from the differences between the salt quantities added to the soil column and those transported by the leaching water.

Changes in the tested parameters were expressed as a percentage of the initial (before the addition of irrigation water) salt content in the soil (S_0), then the values were plotted as a function of the relevant leachate volume (V_d). On the basis of the data, the factors which influence water movement, and which have a considerable effect on salt movement, are the following: the structure, bulk density and porosity of the soil, the size of the pores and the method of water application.

The correlation between the logarithm of the change as a percentage and the volume of leaching water was used for the quantitative characterization of the process. This method of approximation made it possible to divide the process into two phases with different velocities.

The steepness of the straight sectors (tgα) characterizes numerically the ability of the soil column at a given water permeability to release or retain salt. For the sake of simplicity, the reciprocal of tgα(:1/tgα = tgα':) was used in the calculation.

The quantity of leaching water (V_d) associated with a given decrease or increase in the salt content may be calculated from the correlation between the equations given above.

References

[1] Diagnosis and improvement of saline and alkali soils. (Ed.: RICHARDS, L. A.) USDA Handbook No. 60. Washington. 1954.

[2] FILEP, G. & KUN, A.: (Studies on the mechanism of the leaching of salts in soil columns. I. Interpretation and characterization of leaching velocity in soils leached with distilled water) (H, e, g, r,) Agrokémia és Talajtan. **25.** 253—264. 1976.

Discussion

GIRDHAR, I. K.

You have reported that leaching efficiency is better under continuous leaching method as compared to intermittent leaching. Please explain why? Because in literature it is reverse, leaching with low flow velocity (intermittent leaching) increased the leaching efficiency over the high flow velocity (continuous leaching). This has been explained on the basis of intermittent displacement theory, i.e. with low flow velocity, water will get the more chance and time to contact with soil particles and will dissolve more salt and further displacement of the salt will also be more.

FILEP, G.

As can be seen in Figs. 1/c. and 2/c. the intermittent leaching has been going on in our experiments with greater velocity and efficiency than in the case of continuous water supply. The interpretation of this phenomenon together with the explanation of the rapid and slow stage of leaching mechanism may be find in our earlier paper.

SINGH, N. T.

For a chernozem the bulk density of 1.4 g/cm^3 when the humus content is 2—3% seems to be high. Was the soil compacted?

FILEP, G.

The structure of our chernozem soil has been damaged considerably by too intensive usage (by machines of high efficiency, fertilizing at high levels, irrigation). In such cases even bulk densities of 1.5 g/cm^3 are not rare. So the given value of 1.4 g/cm^3 cannot be regarded as extreme.