Salt transport in heavy clay soil

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Abstract

Salt transport in heavy clay soil is analysed, using field data of saline clay soils.

1 Introduction

Salt movement is linked together with water movement which depends on the hydraulic conductivity of the soil profile and its structure. In heavy clay soils one can usually distinguish a top layer with a rather high hydraulic conductivity consisting of the tilled layer in arable land or the turf layer in grassland, below which the hydraulic conductivity is much lower and often decreases with depth. In basin clay soils in river areas and in marine clay soils one may encounter at a depth of about 1 m again a layer having a moderate to high hydraulic conductivity and consisting of clay with iron concretions, organic matter, peat or soil material with a coarser texture.

The discharge of water in such soil profiles depends on the ratio between the rainfall (or irrigation) rate and the infiltration rate of the second layer of low permeability. Under Dutch climatic conditions the rainfal rate during autumn and winter is rather low, ranging between 1 and 2 mm/hour for rainfall amounts up to 10-15 mm/day. Observations in tile-drained fields have shown that most of the water is drained off by infiltration into the heavy clay layer and flows through the permeable subsoil towards the drains (Figure 1a). Horizontal flow through the highly permeable top layer towards the drain trench only occurs during short periods after heavy rainfall (Van Hoorn, 1960).

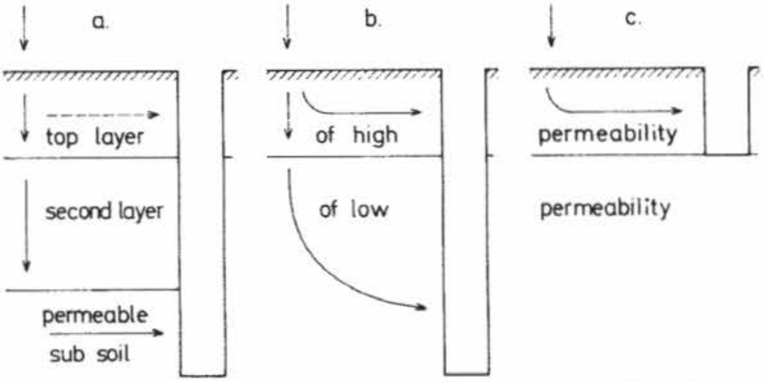

Figure 1. Water movement in heavy clay soil towards subsurface and surface drains

In the absence of a highly permeable subsoil, the water table will rise faster causing a decrease of the infiltration rate. If moreover the rainfall rate is higher than under Dutch conditions, part of the water will move downward through the second layer of low permeability, but an important part of it will flow through the top layer towards the drain trench (Figure 1b).

In the case of a surface drainage system consisting of furrows, water will infiltrate at the start of the rainy season into the layer of low permeability causing a rise of the water table to the top layer; afterwards all rainfall will be discharged by horizontal flow through the top layer (Figure 1c).

The structure of heavy clay soils is characterized by rather big soil aggregates separated by large pores formed as root or worm holes by biological activity or as cracks during dry periods. Owing to the biological activity and the alternation of crack formation and swelling the hydraulic conductivity generally increases in summer and decreases in winter, a reversible process with short and long term trends. Better drainage leads on long term to a clear increase of the hydraulic conductivity, whereas bad drainage and shallow groundwater tables cause a decrease in hydraulic conductivity in soils which originally had a low water table (Van Hoorn, 1981).

The large pores are essential for the removal of surplus water by gravity force and determine the saturated hydraulic conductivity. Inside the soil aggregates pores are too small for water movement by gravity force and water can only be removed by the evapotranspiration process.

2. Natural conditions of the experimental sites

The salt movement in heavy clay soils will be illustrated by examples from two saline areas:

- the Marismas in the Quadalquivir delta in Southern Spain (Van Hoorn et al., 1976),
- the Leziria Grande near Lisbon between the rivers Tague and Soraya (Mann et al., 1982).

The soils in both areas can be classified as silty clay, containing in the Marismas about 20% $CaCO_3$ and $MgCO_3$ and in the Leziria less than 1.5% $CaCO_3$.

Both areas are characterized by rainfall from September through May, the average precipitation being about 550 mm in the Marismas and 650 mm in the Leziria.

Table 1 presents the salinity at the start of reclamation of an experimental station in the Marismas and of three experimental fields in the Leziria. The salinity is expressed as electrical conductivity in mS/cm of an extract of 200 g of water per 100 g of dry soil ($EC_{1:2}$). Since the saturated paste contains about 80 g of water per 100 g of dry soil, $EC_{1:2}$ can be converted into EC_e by multiplication by 2.5.

Table 1. $EC_{1:2}$ in mS/cm at the start of reclamation

Layer in cm	0-25	25-50	50-75	75-100	100-125	125-150	150-200	0-125
Marismas	12.0	20.0	26.0	28.0	30.0	32.0	34.0	23.2
Leziria 1	7.6	9.6	15.6	19.3	25.8	33.0	34.2	15.6
2	6.5	7.7	10.9	14.1	19.7	24.2	28.2	11.8
3	3.3	5.3	7.2	9.7	13.0	18.1	23.6	7.7

Before the installation of the experimental station the soil in the Marismas was inundated every year during autumn and winter and water was removed by natural surface flow to depressions and by evaporation. The Leziria was already protected by dikes and water was drained off by a system of shallow surface drains. This difference in drainage between the two areas is reflected on the one hand in the salinity, as shown in table 1, and on the other hand in the hydraulic conductivity of the upper meter of the soil profile. Whereas the hydraulic conductivity of the Marismas soil to a depth of about 1 m ranged around 0.1 m/day, the Leziria soil showed a value of about 0.3 m/day.

3. Horizontal flow versus vertical flow

Table 2 presents the relation between drain spacing and the average salinity of drain water from the experimental station in the Marismas. A wider spacing leads to a higher water table (Figure 2) and an increase of horizontal flow through the top layer.

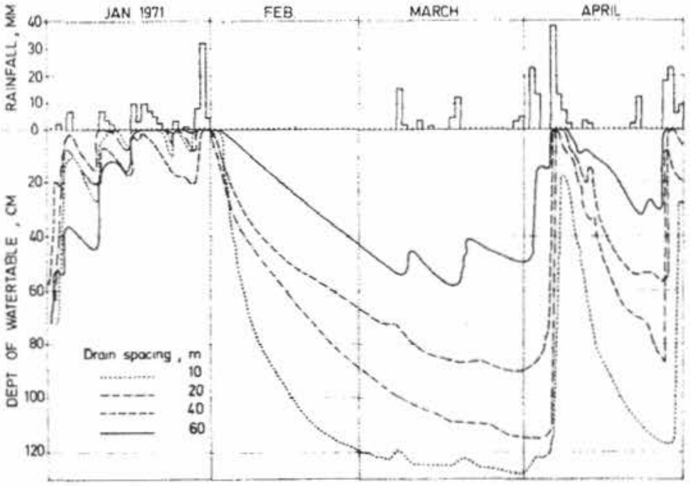

Figure 2. Drainspacing and depth of water table

Table 2. Drain spacing versus average salinity of drain water, winterperiod 1970-74, Marismas

Spacing , m	10	20	40	60
Salinity , g/l	60	55	48	41

Table 3 shows the change in salinity of drain water from surface and subsurface drains during a winter period. It presents a second example of the increase of horizontal flow through the top layer due to a higher water table, in this case as a consequence of more precipitation.

Table 3. Salinity of drain water from surface and subsurface drains, winterperiod 1970-71, Marismas

Month		Nov	Dec	Jan	Feb	M	Apr	May	Aver.	Min.
Rainfall	,mm	53	108	104	2	42	168	62		
Surface	,g/l	58	27	19	9	48	8	27	17	5
Subsurface	,g/l	91	39	31	19	75	29	72	34	18

Table 4 presents the salinity of drain water for three successive winter periods from surface and subsurface drains, the latter one expressed as average for the whole winter period and also at low discharge. The salinity of drain water at low discharge corresponds with that of soil water at a depth of about 1 m.

Table 4. Salinity of drain water from surface and subsurface drains, average of 3 experimental plots, Leziria

Winter period		1976-77	1977-78	1978-79
Surface drain	,g/l	10.5	5.8	4.8
Subsurface drain, average	,g/l	30.8	16.4	10.4
, at low discharge	,g/l	40.3	29.7	23.0

These examples clearly show that part of the water is drained off by vertical flow through the soil profile and part of it as horizontal flow through the top layer. The ratio between vertical and horizontal flow changes with the depth of the water table, the latter one depending on spacing and precipitation.

4. Salt movement from soil aggregates to large pores

Table 5 presents for six succesive years the precipitation, the drain discharge and the average salinity of the subsurface drains of the three experimental fields in the Leziria

Table 5. Salinity of subsurface drains during 6 winter periods,Leziria

		1976-77	1977-78	1978-79	1979-80	1980-81	1981-82
Rainfall	,mm	620	712	748	415	308	554
Discharge	,mm	269	210	230	0	0	113
Salinity,	field 1,g/l	41.3	19.5	12.4	-	-	23.7
	field 2,g/l	23.8	19.3	12.6	-	-	21.9
	field 3,g/l	27.4	10.5	6.3	-	-	17.7

During the first 3 years the salinity of the soil decreased, owing to the leaching by the rainfall. The lower the salinity of the soil, the lower the salinity of the drainage water, which is quite normal.During the first year, however, field 2 showed a lower salinity of the drainage water than field 3 despite a higher soil salinity (Table 1). This points to a lower leaching efficiency coefficient on field 2, that means a larger part of the water is passing through cracks without mixing with soil water. During the third year, fields 1 and 2, which in spring 1978 attained a soil salinity level equal to that of field 3 in 1976, showed a lower drainwater salinity than field 3 during the first year. Such a decrease of the leaching efficiency coefficient with time is often observed. This phenomenon can be ascribed to rapid leaching of easily attainable salts in cracks and large pores, whereas the removal of salt inside the soil aggregates takes much longer.

After two dry years without drain discharge the drain water salinity increased strongly. During the dry period salt moved from the interior of the structural elements towards the large pores and new cracks were probably formed, providing a fresh oppurtunity for leaching by the rain water.

Assuming a yearly precipitation of 650 mm in the period 1979-81, a drain discharge of about 200 mm per winter and a continuing decrease of the drain water salinity, this higher rainfall during two winters would not have leached more salt from the soil than the rainfall in the winter 1981-82, that was even below the average.

5. Leaching by applying irrigation water

Trying to accelarate the leaching process of heavy clay soils by large water applications does not seem an interesting and useful operation. An irrigation test carried out on the experimental farm of the Marismas points in a similar direction (Table 6).

During this test two amounts of irrigation water were compared, spread over three applications during a period of about one month. Part of the water was used for filling up the soil water deficit and for evapotranspiration, so that in the case of the small water application of about 200 mm the amount of drain water remained very low. However, this low amount of drain water was more or less compensated by the high salinity of the water,whereas in the case of the large water application the drain water salinity decreased considerably. This decrease may be ascribed to an increase of horizontal flow through the top layer and to a closing of cracks.

Table 6. Irrigation test for desalinization, Marismas

Irrigation	Drainage	Salinity drain water	Salt removed
197 mm	9.0 mm	82 g/l	7.4 t/ha
462	90.3	19	16.9

In stead of applying large amounts of irrigation water in summer it seems more interesting to apply a modest amount of water in early autumn in order to fill up the soil water deficit and to promote more drainage from winter rainfall.

6. Resalinization of the top layer by capillary rise

During summer the salinity of the top layer increases again by capillary rise of saline water from underlying layers. Figure 3 shows an example of such a redistribution of the salinity, observed in the Marismas. According to calculations based on the amount of salt transported to the top layer capillary rise from the underlying layer (15-75 cm) ranged in the order from 25 to 30 mm. This rather low amount may be ascribed to horizontal cracks that are formed when the soil is drying out and that impede the vertical capillary movement.

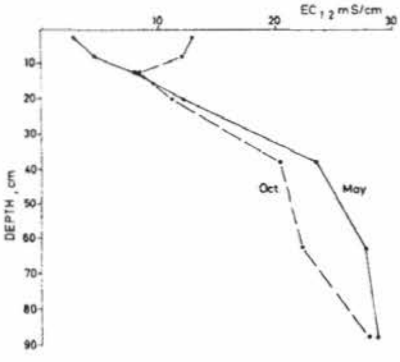

Figure 3. Redistribution of salinity due to capillary movement

Although the amount of water moving upward in summer is rather small, it can bring a considerable amount of salt into the top layer. For example in the case of the Marismas the average value of $EC_{1:2}$ was 20 mS/cm in the layer 25-50 cm (Table 1), corresponding with about 65 g/l for the soil water at field capacity. Capillary rise of 25 mm corresponds then with 16 t of salt per ha.

At the start of the rainy season part of this salt will move downward again and part of it will be removed by horizontal flow through the top layer. Owing to this combination of capillary rise during the dry season and surface flow during the rainy season a surface drainage system can also contribute on long term to the desalinization of heavy clay soils, although the process will take more time than desalinization by subsurface drains and may not attain the same depth.

7. Model for prediction of desalinization

Desalinization of heavy clay soil is characterized by three typical phenomena:

- the combination of horizontal flow through the top layer and vertical water movement through the deeper layers;
- the leaching efficiency coefficient, expressing the percentage of rain or irrigation water mixing with the soil solution, can either

decrease or increase with time, depending on the amount of water applied and the alternation of wet and dry periods;
- the resalinization of the top layer by capillary rise during the dry season.

Owing to these phenomena it is not possible to predict desalinization of heavy clay soil by using leaching formulas that assume the same vertical flow through the entire rootzone, e.g. over a depth of at least 1 m.

For the Marismas the desalinization process by rainfall was calculated by a numerical method, assuming a decrease of the amount of percolation water with depth: 100 % of the water percolates the first layer (0-25cm), 80 % the second layer (25-50cm), 60 % the third layer (50-75cm), 40 % the fourth layer /75-100cm) and 20 % the fifth layer (100-125cm).

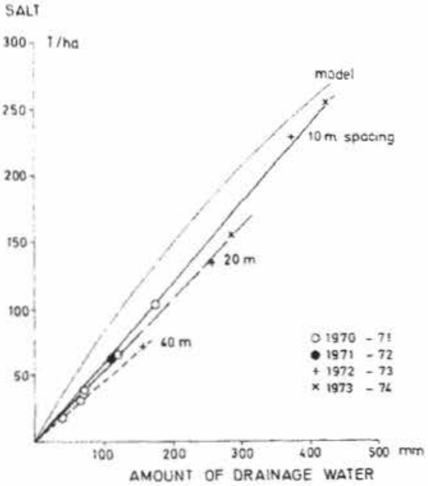

Figure 4. Quantity of salt leached versus amount of drainge water

Figure 4 shows the relation between the amount of drainage water and the amount of salt removed, on the one hand calculated according to the model described above and on the other hand observed for three different drain spacings. The observations for a spacing of 10 m are rather close to the calculated curve; the observations for the wider spacings deviate more and more, probably because more water is drained off by surface flow.

Although Figure 4 indicates a rather good agreement between the model used for the calculation and the observations, the model has a very limited value for the prediction of salinization, since it does not take into account the resalinization of the top layer by capillary rise and the change of the leaching efficiency coefficient with time. In reality a part of the desalinization may have been caused by the combination of capillary rise in summer and surface flow in winter and vertical flow may have been less than assumed in the model, both phenomena compensating each other more or less. The change of the leaching efficiency coefficient owing to the alternation of wet and dry periods is however unpredictable.

8. Desodification

In order to maintain or improve the structure and the infiltration rate of heavy clay soil, gypsum can be applied if the $CaCO_3$ content is low. The soil of the Marismas experimental farm contained about 20 % $CaCO_3$ and $MgCO_3$ and did not show any response to gypsum application. Since the desalinization process is slow, $CaCO_3$ notwithstandig its low solubility provides sufficient calcium for the desodification of the soil.

The soil in the Leziria only contained between 0.2 and 1.5 % $CaCO_3$ in in the upper 50 cm. Gypsum application at a rate of 10 t/ha per year during 4 years lowered the E.S.P., improved the infiltration rate and the amount of drainage water. However, a comparison between the amount of calcium applied as gypsum and the amount exchanged in the soil showed that only part of the calcium applied as gypsum was used in the exchange process. Also the decrease in ESP between 1978 and 1980 was smaller than between 1976 and 1978. This points in the same direction as the decrease of the leaching efficiency coefficient between 1976 and 1979. The exchange of sodium by calcium inside the structural elements of heavy clay soil is a slow process. In order to avoid losses, small amounts of gypsum should be applied with intervals of several years.

References

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Discussion

M.G.M. Bruggenwert:

Can you give some information concerning your statement, 'The Marismas soil did not show any response to gypsum application, and $CaCO_3$ provides sufficient calcium for the desodification'? What were the total salt concentration and composition of the soil solution during the desodification process, in particular the initial and final E.S.P.?

Author:

In contrast to the Leziria soil, the Marismas soil did not show improvement of soil structure and infiltration rate in the case of gypsum application. The water discharged by the tile drains was always clear and free of dispersed soil particles, whereas in the Leziria the water was loaded with fine clay particles, tiles had to be cleaned regularly and, finally, gypsum had to be applied to the drain trench.

The total salt concentration in the top layer of the Marismas was at the start about 300/meq/l in the saturated paste and, in the case of the Leziria, about 150 meq/l, decreasing to 60-70 meq/l within a few years. For these marine clay soils the composition of the soil solution resembles that of seawater, sodium about 80%, calcium plus magnesium about 20%, chloride 85%, and sulphate 10-15%. The initial E.S.P. in both cases ranged between 25% and 30% and decreased to about 15% in 4 years. In a soil containing 20% $CaCO_3$ and $MgCO_3$, sufficient calcium and magnesium are available to replace sodium if $CaCO_3$ and $MgCO_3$ are well distributed and not occurring in concretions, and if the desalinization process is slow.

P.A.C. Raats:

What is the basis for the assumed decrease of the amount of percolation water, with depth in the model, mentioned in paragraph 7 (figure 4)?

Author:

In the case of the Marismas the hydraulic conductivity of the soil profile decreases with depth, and the drains at a depth of 1.25 m are located on a layer that can be considered as impervious. In the top layer we may assume that the soil is unsaturated and the flow is vertical for most of the time; in the underlying, predominantly saturated layers the flow decreases with depth owing to the decreasing hydraulic conductivity. The data assumed for the successive layers (100%, 80%, etc.) are a guess.