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SALINIZATION AND DESALINIZATION IN A SILTY SOIL INFLUENCED BY GROUNDWATER.

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Abstract.

The process of salinization was investigated in a groundwater influenced silty alluvial soil which was either cropped or kept fallow. The rate of salinization increased with decreasing distance of the groundwater table from the soil surface and with the salt concentration in the groundwater.

Three phases of salinization could be distinguished in the fallow soil: a phase limited by energy, one limited by soil (properties) and a stationary phase. Cropping greatly accelerated salinization. The water requirement of the plants under the existing conditions was the critical factor in determining the rate of salinization,

The principle source of solutes for salinization were the salts in the subsoil which were rapidly transferred by the rising water into the rooting horizon. The import of solutes by the irrigation water was relatively small. The salt injury to plants over extended periods resulted mainly from salts contained in the groundwater.

The magnitude of the capillary rise, which is a principal factor in salinization, was determined for different depths of the groundwater. In order to predict the rate of capillary rise in cultivated soils, a transport model was developed for non-exchangeable solutes. The leaching requirement was also determined.

1. Introduction

Capillary rise from the groundwater is often the main cause of a secondary salinization that threatens irrigated agriculture. This is the case in the area under consideration in this report; it is situated in southwestern Switzerland and is one of the most productive in agriculture in the country. Here the groundwater represents an important source of water for plants. However, the plants are stressed on the fine-textured alluvial soils not only because of solutes in the groundwater but also because of insufficient soil aeration.

The objectives of this research were to investigate the mechanism of secondary salinization in cropped and fallow soils, to find a method for predicting salinization and to develop measures to ameliorate salinized soils.

Material and Methods

Salinization was investigated in soil columns contained in plastic tubes of 25 cm diameter. Three different levels of groundwater were investigated, namely at depths of 60, 90 and 120 cm. The soil columns were buried in the field so that the upper surface was at the same level as the surrounding soil. The columns were kept fallow during the first year and then were planted with carrots.

The experimental design is depicted in figure 1 which also shows the arrangement of tensiometers, salt sensors and suction cups for obtaining soil solution. Water was supplied from calibrated bottles on which the evapotranspirational loss of water could be read. The groundwater was maintained at a constant level by a float regulator. An outlet above the groundwater level permitted the collection of drainage water.

The plastic tubes were filled homogeneously with a silty soil to a density of 1.32 g/ cm^3. The composition of the soil was: clay 6%, silt 75%, sand 19%; CaCO3 8%; organic substance 0.6%. The pH(H_2O) was 8.2, the CEC 6.1 meq/100 g soil, and the ECs 13.68 mS/cm. The ionic composition of the saturation extract in meq/l was: Ca 60, Mg 118, Na 46, K 1.3, Cl 41.4. SO_4 148.9, NO_3 21.3. The saturated hydraulic conductivity was 8 cm/day. The composition of the irrigation water in meq/l was : Ca 4.9, Mg 4.2, Na 1.9, K 0.35 and the EC was 1.03 mS/cm.

Further details about the methods will be given with the descriptions of the individual experiments.

Salinization of an uncropped soil

A complete series of soils including all three groundwater depths was kept under cover. An additional set of soil columns for the 90 cm groundwater level was exposed to the natural precipitation. The dry soil columns were carefully irrigated from the top until water appeared at the drainage pipe. The resulting "initial" salt distribution is shown in figure 3 for day 1.

The process of evaporation and thus also of salinization is controlled by internal and external factors. It can be separated into three phases (Kolasew, 1941; Philip, 1957; Hillel, 1975). These three phases also manifest themselves in the capillary rise of water from the groundwater (Fig.2). In a first phase the evaporation occurs from a moist soil and is limited by atmospheric conditions, i.e. by the influx of

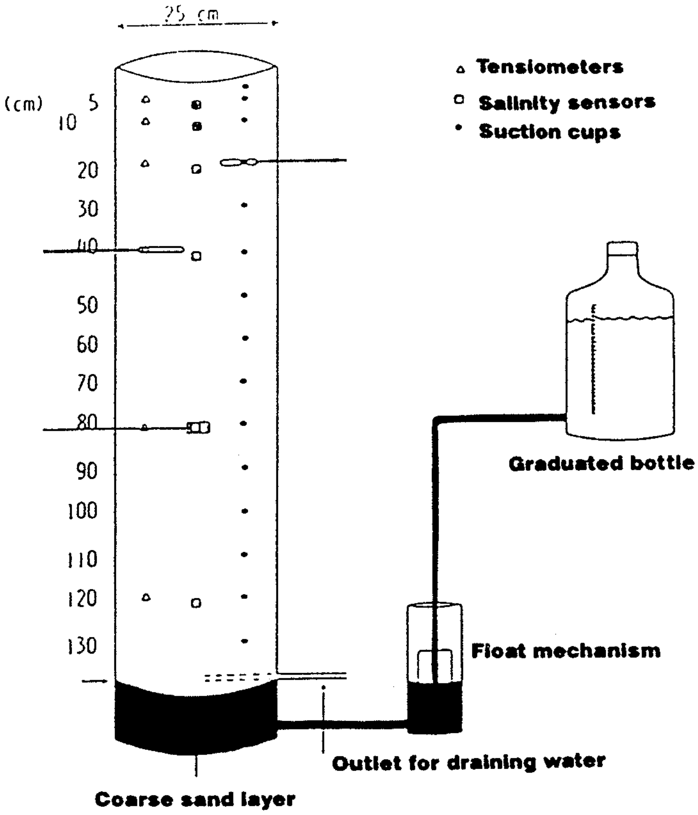


Fig.1. Experimental set-up showing the locations of tensiometers, salt sensors and suction cups

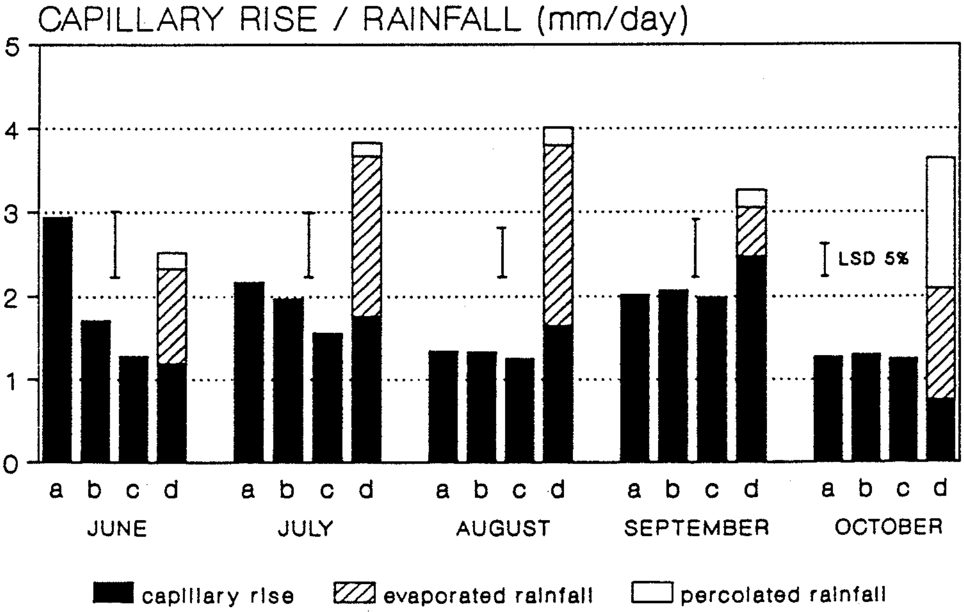


Fig.2. Dependence of the capillary rise in fallow soil columns on the depth of groundwater (a=60 cm, b=90 cm, c=120 cm, d=90 cm) and on precipitation. Treatments a,b, and c were protected from precipitation, d was exposed to natural precipitation.

energy. This was the case for the groundwater at a depth of 60 cm during the month of June (Fig. 2). As the soil dries out the rate of evaporation decreases and the rate of capillary rise is determined by the water conducting properties of the soil. This was the case in July for the groundwater at a depth of 60 cm. The third phase occurs in an even drier soil when the rate of capillary rise dropped to a constant, low level. This occurred for all depths of groundwater during the months of August and October.

The reduction in the capillary rise during the second phase is the result of a "selfmulching" effect caused by a thin suface layer of a dry soil in which the hydraulic conductivity has been much reduced. Moreover solutes that accumulate near the soil suface form a crust and further reduce the hydraulic conductivity and the vapor pressure of water (Qayyum and Kemper, 1962; Letey et al., 1965). The change in albedo after formation of the salt crust will also affect the energy flux and reduce the flow of water.

Destruction of this selfmulching surface layer reconstitutes the soil capillarity and the rate of capillary rise increased (Fig. 2, September, all groundwater depths).

The soil columns exposed to natural precipitation initially showed a slightly lower, thereafter a higher rate of capillary rise than the covered columns. Evaporation from the columns open to rainfall was definitely higher and the greater part of the precipitation was lost through evaporation.

During the approximately 5-month experiment, the total capillary rises for the groundwater depths of 60, 90, and 120 cm amounted to 298, 256, and 224 mm, respectively. The columns exposed to precipitation took 221 mm from the groundwater. Lifting the level of the groundwater from 120 to 60 cm increased the rate of capillary rise by 33%. The influx of salts from the groundwater, however, increased by 166%. The salinization increased by 56% with an increase in the level of the groundwater from 120 to 90 cm. Shallow groundwater thus accelerates salinization considerably. Salinization profiles as they are observed for the different periods and treatments are shown in Fig. 3. Apparently the rate of diffusion of solutes back into the subsoil must be negligible, a result that is confirmed by the findings of Doering et al. (1964); this is to be expected from the properties of diffusion which is ineffective over long distances.

Precipitation had little effect on the salt distribution in soils during the first 4 months. During the fifth month (October), when the evaporative demand was reduced due to climatic reasons the downward percolation of water became more noticeable and caused some leaching of salts (Fig. 3).

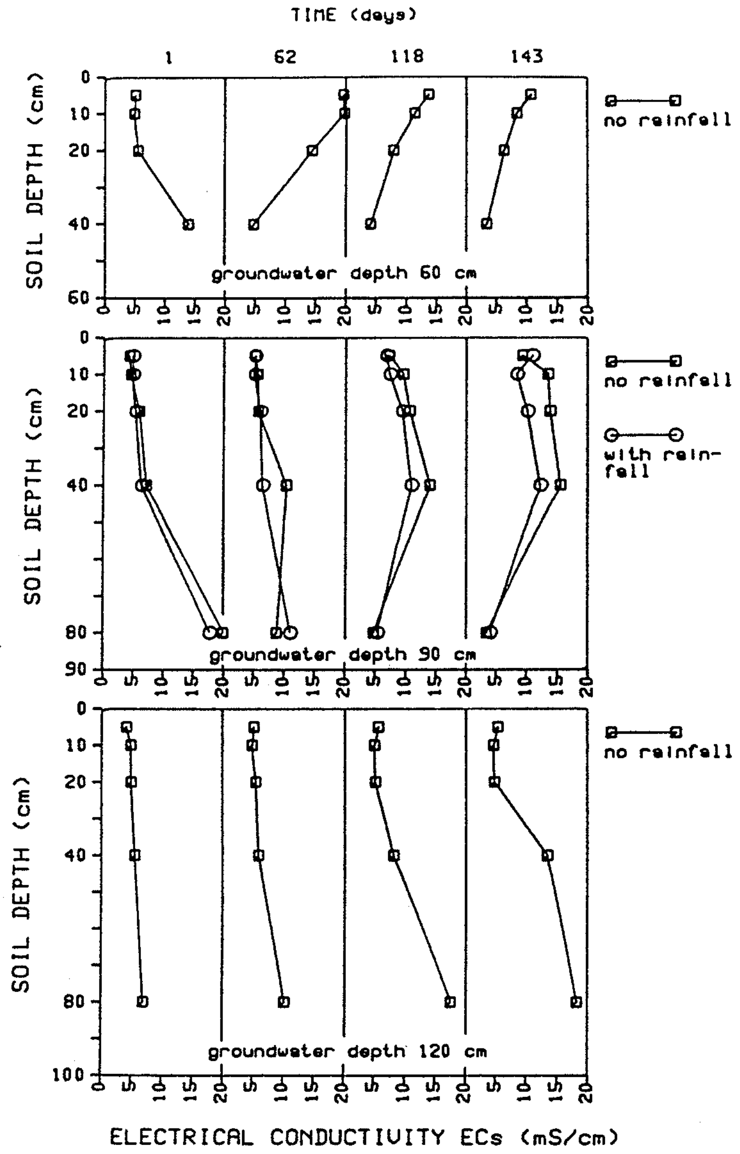
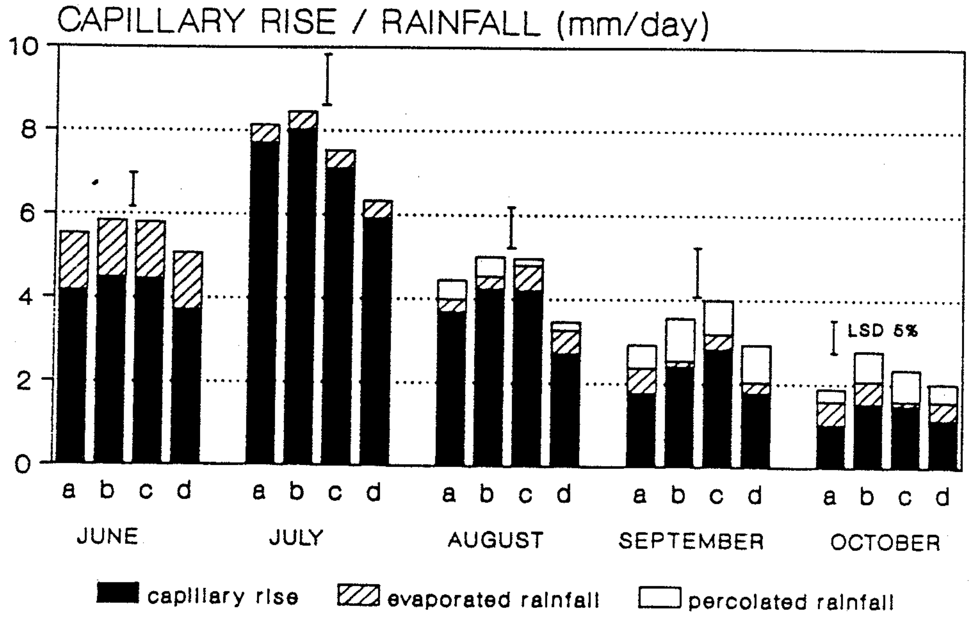


Fig. 3. (left) Electrical conductivity of the soil solution (ECs) of the uncropped soil at intervals from the beginning of the experiment and depending on the depths of groundwater and on precipitation. The electrical conductivity of the groundwater was 2.59 mS/cm.

Fig. 4. (below) Dependence of the capillary rise in soil columns cropped with carrots on the depth of the groundwater (a=60 cm, b=90 cm, c=120 cm, d=90 cm) and on the initial degree of salinity. The treatments a,b, and c were initially mildly saline, the treatment d moderately saline.



Salinization in a cropped soil

Soil columns that had been prepared in exactly the same way as in the previous experiment were sown with carrots (Daucus carota L., var. Nandor). One series containing the usual groundwater depths of 60, 90, and 120 cm had only a mild initial salt content (Fig.5,left). A second series with a moderate initial salt content was restricted to the 90 cm level of groundwater. The salt concentration averaged 4 mS/cm and 6 mS/cm in the layers 0-30cm and 30 to 90 cm, respectively. All soils were fertilized with 35 kg P per ha and with 84 kg K per ha in the form of superphosphate and potassium chloride (60%), respectively. Four days before the initiation of the experiment, 50 carrot seeds were planted in each soil column. The surrounding terrain was also sown with carrots. Germination was complete after 10 days. Thirty days later the number of plants was reduced to 10 per column. During seedling growth, the columns were irrigated twice with a total of 18 mm of water.

Cropping greatly enhanced the capillary rise (Fig. 4) which was 2.5 times greater than in the uncropped soil. The capillary rise was determined by soil evaporation and by transpiration and the formation of a selfmulching surface layer had a much smaller effect since the plant roots reached the lower humid soil horizons. The capillary rise was comparable for the 90 and 120 cm treatments but it was smaller for the 60 cm depth of groundwater. Thus, in the cropped soil the sequence is reversed from the fallow soil. Our explanation for this is, that with the shallow depth of the groundwater most soil pores were filled with water and root development was impeded due to an oxygen deficiency. Soil columns with an initially higher solute content had a lower rate of evapotranspiration and of capillary rise.

Precipitation had only little effect on the soil water potentials which were rapidly readjusted to the initial values after the rainfall had ceased. The development of salinization can be seen in Figure 5 which shows the distribution of salts in the profiles at the beginning and at the end of the experiment. Apparently the higher intial salt concentration near the groundwater level at 120 cm increased the final degree of salinization. The increased salinization in the upper horizons is obviously due to the capillary rise of salts. At the moderate salinity level, a higher secondary surface salinization was reached. Instead of a conductivity of 4 mS/cm with mild salinity, we now observed 14 mS/cm in a layer of 0-30 cm and 4.5 mS/ cm at the depth 30 to 90 cm. Cropping enhanced salinization considerably. The total amount of water lifted through capillary rise amounted to 600 mm in comparison to only 250 mm for the fallow soil.

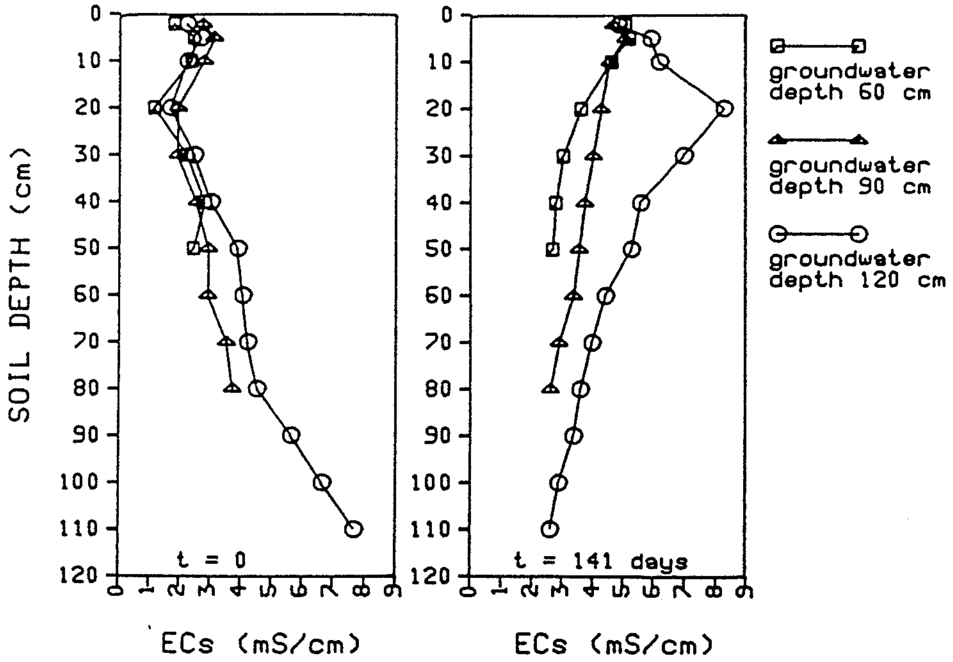


Fig. 5. Electrical conductivity (ECs) of the soil solution in soils cropped with carrots. Dependence on the depths of the groundwater at the beginning and at the end of the experiment. EC of groundwater 2.59 mS/cm.

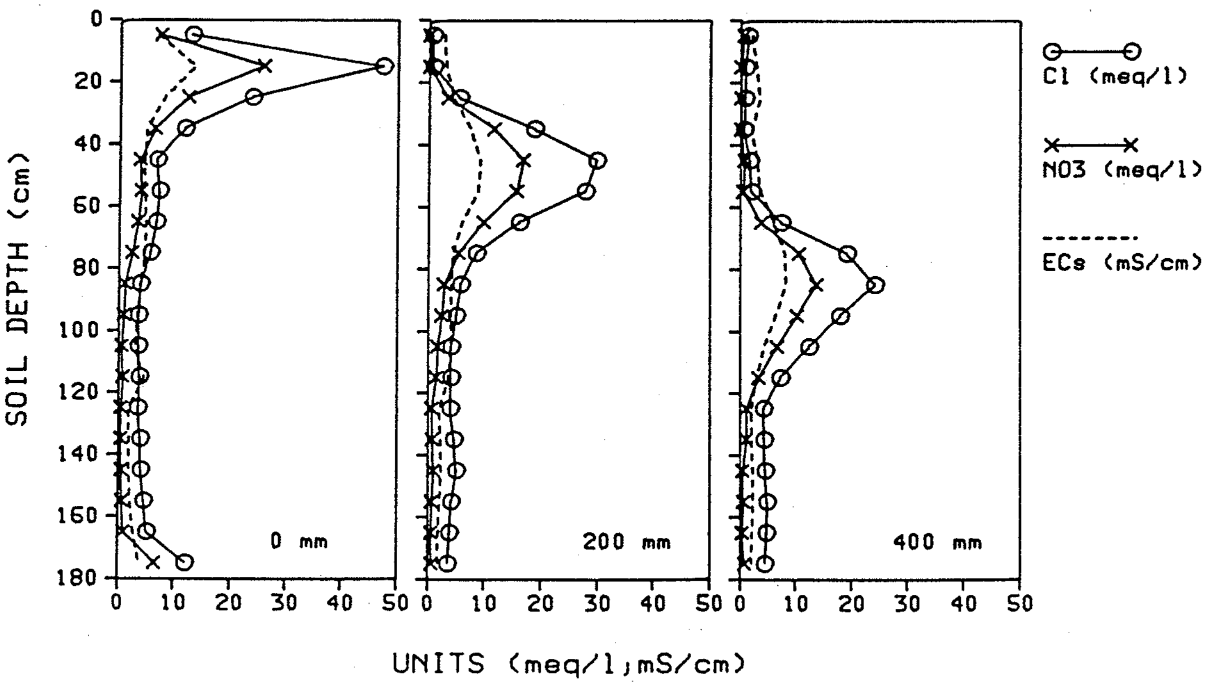


Fig. 6. Effect of the amount of leaching water on the profile distribution of chlorides, nitrates, and total salinity. (Based on 1:1 extracts).

Desalinization

A 12 x 36 m^2 plot was irrigated daily with 20 mm of water for 20 days. Soil samples were collected daily from different depths every 10 cm down to 180 cm. The soil samples were analysed in 1:1 extracts for the composition and concentration of the solutes.

About 600 mm of water are required to move the salts to a depth of 1 meter (Fig. 6). Due to dispersion and some weak interaction between solutes and the soil the solute peaks become wider as the salts are moved downward in the profile. The movement of chloride and nitrate is practically identical and coincides with that of the total salinity. In this soil, the movement of cations was similar to that of the anions, an observation that would have been expected from the low CEC. The mobility of the cations decreased in the following order Na>Mg>K>>Ca.

Salinity originating from salts present in the subsoil above the groundwater table and transferred by capillary rise into the rooting horizon initially poses the greatest risk to cultivated plants. Over longer periods though the contribution of salts stemming directly from the groundwater increases in importance whereas the fraction of salts imported by the sprinkler irrigation remains small at all times. It is especially important that a non-salinized rooting horizon is present during germination. Thanks to their larger root system older plants can tap water of a better quality from a greater depth even when the surface horizon has become salinized. Leaching and drainage of solutes will ameliorate the salt-affected soils as has been known for a long time.

Modelling the salinization process

The capillary rise is the principal mechanism that leads to secondary salinization in our study. Salt and water transport are linked closely. A major factor is the depth and the salt content of the groundwater. Salts contained in the irrigation water are of minor importance.
During summer there is a net movement of water in upward direction, the amount of which is influenced mainly by atmospheric and plant specific factors (energy balance at the leaf surface). Oxygen and nutrient supply in the root horizon are examples of additional factors to be considered.

An improvement of soil salinity and of soil aeration can be achieved through lowering the water table. A thorough knowledge of the dependence of the capillary rise from the depth of the water table would therefore be most helpful for the management of these salt-affected soils. The experimental determination of these interrelations is very time-consuming. Numerical calculations are more simple provided the necessary

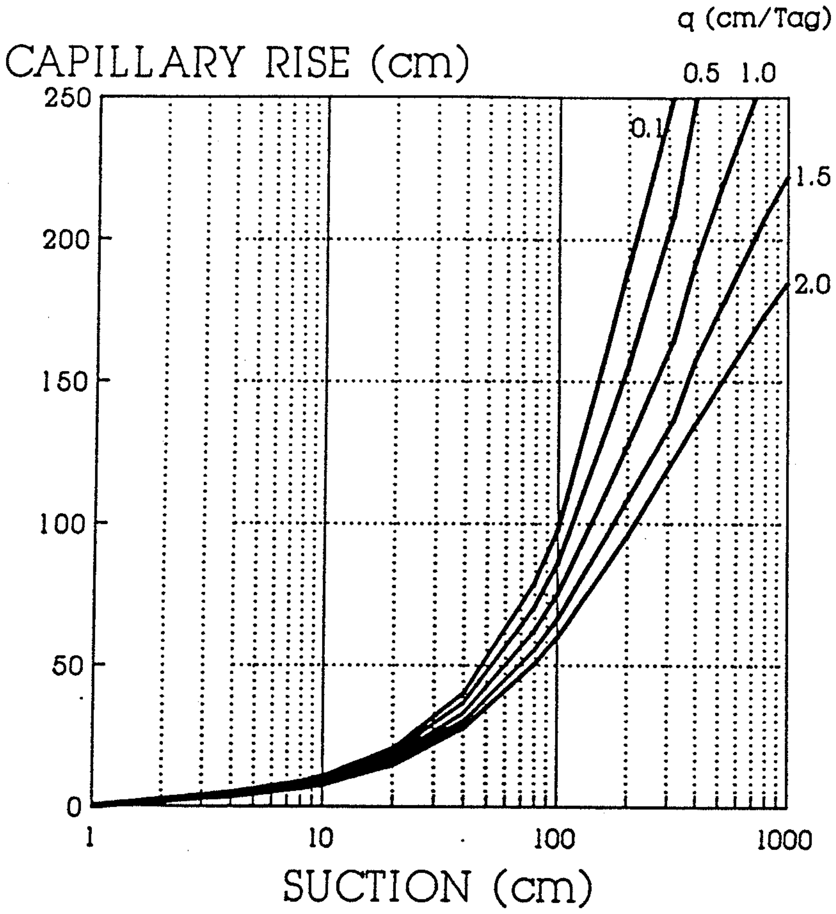


Fig.7. Comparison of measured and calculated chloride distributions at different time intervals in a soil profile with the groundwater table at 50 cm. The silty soil was planted with carrots.

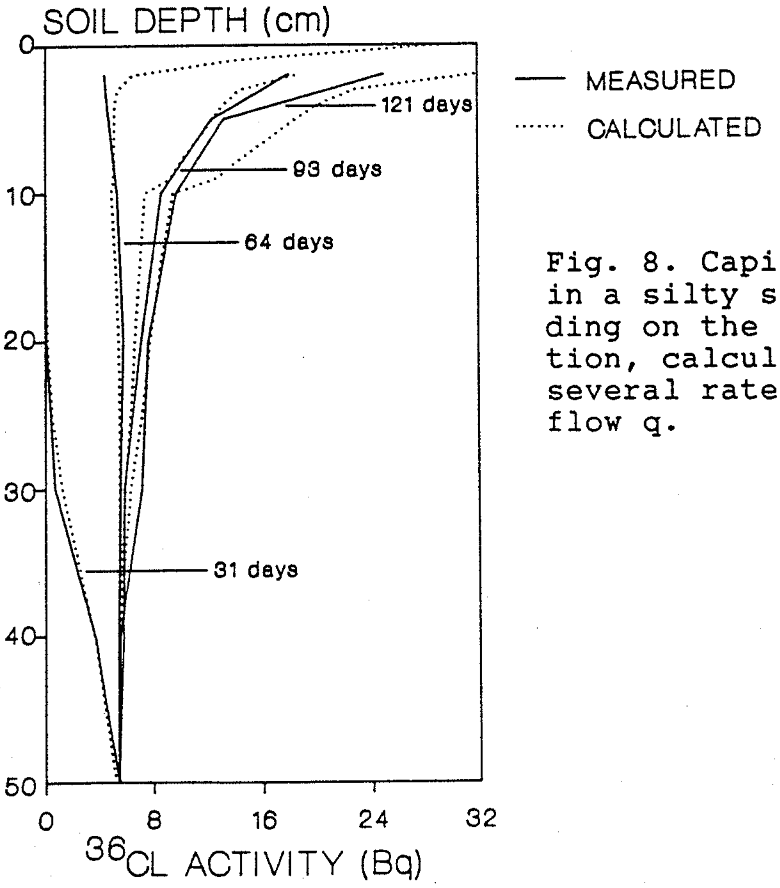


Fig. 8. Capillary rise in a silty soil depending on the soil suction, calculated for several rates of water flow q.

parameters, in this case the unsaturated conductivities, are available. These relations were determined in the field by the instantaneous profile method of Watson (1966). For the dependence of the unsaturated conductivity k(h) on the suction in cm we found

$$(k(h) = 1208/(229+h^{1.355}).$$

We determined the capillary rise under stationary conditions with numerical and analytical-numerical methods . (Schmidhalter, 1986). It was possible to characterize the capillary rise at the specific site as a steady or quasisteady flow which allowed us to predict the effect of the groundwater depth on the supply of water to the plants. Evidently these soils can supply water at high rates from considerable depths (Fig. 7). The height of capillary rise in these cultivated soils is determined by atmospheric and plant-specific conditions and not by soil properties within the range of groundwater levels which were studied here. The calculated values could be confirmed by experiments (Schmidhalter, 1986).

The movement of water is a rough indicator for the salinization potential. This is particularly true for the present soils, in which, because of a low CEC, the transport of the bulk of salts is closely related to the movement of chlorides. Based on such assumptions, the upward movement of salts resulting from capillary rise of groundwater was calculated for conditions that prevailed during the growing period. A sink-term for the water uptake was included in these calculations and a numerical solution was used for a convective-diffusive equation. The results showed good agreement between calculated and measured values and the results agreed with the solute distribution in soils (Fig.8). Thus, the model is able to predict quantitatively the dynamics of secondary salinization.

So far we have discussed the effect the water transport on the solute distribution. However, the solute distribution can furnish information about the water transport: because of the negligible uptake of chloride by plants relative to the large import via capillary rise, the change in chlorides in the rooting horizon can be used as an approximate measure for the water uptake by plants (Schmidhalter, 1986, Schmidhalter et al., 1988).

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