Water infiltration in saline sandy soils

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Abstract

In Northeast Thailand 80% of the population is dependent on agriculture, growing mainly rainfed rice in the lowlands, predominantly for household consumption. This region faces water scarcity, inherently low fertility soils, soil compaction and more recently, soil salinity. Over the last decade salinisation problems have increased severely, leading to important yield losses and land abandonment. Despite water resources being limited, their management is one of the most important tools for the farmers to combat salinity, as water flow governs the salt transfer from the saline water table towards the surface. In order to quantify and to model the possibilities offered by water management as precisely as possible, it is necessary to determine flow characteristics of soil within the profile.

Water flow in soil is chiefly governed by hydraulic conductivity which is usually considered as an intrinsic soil property. However in saline soils, the clay fraction can either become dispersed or flocculated depending on the solution composition. Consequently the quality of the solution (Electrical Conductivity and Sodium Adsorption Ratio) affects soil structure, hence hydraulic conductivity of soil and general water flow through a soil profile. In order to quantify this phenomenon in situ hydraulic conductivity measurements have been performed using a disk infiltrometer. Considering field conditions, infiltration measurements have been performed with both, distilled and saline water in order to simulate the behaviour of rain water and groundwater. The results showed clearly that the hydraulic conductivity was significantly lower with distilled water when compared with saline water. Despite having low clay content (approximately 4%) these sandy soils were very responsive to sodicity. Basing on these soil properties, a model of the water flow and saline patches development is proposed.

Introduction

In the Northeast of Thailand, the lowlands are mainly dedicated to sticky (glutinous) rice production for home consumption. However these paddy soils are seriously affected by salinisation and during the last few decades the phenomenon has increased with the rise in saline water tables. After deforestation in the recharge area, groundwater rise effectively mobilizes halite deposits of the Mahasarakham formation, which eventual reach the soil surface. However salinity does not affect soils uniformly, as it appears in discrete patches of 5 to 10 m of diameter. Water flow in soils chiefly controls the salinisation process and it is therefore crucial to understand the water dynamics in these soils, if rehabilitation or management is to be achieved.

In addition to the osmotic stress that salinisation imposes on the crop, sodicity may also modify soil structure. As soil structure chiefly governs the water flow, hydraulic conductivity is consequently affected. The influence of mixed salt solutions percolation on the soil hydraulic conductivity has been studied previously by several authors (Abu-Sharar et al., 1987; Curtin et al., 1994; Amézketa and Aragües, 1995; Abu-Sharar and Salameh, 1995) and empirical models have been established (Mc Neal, 1968; Suarez et al., 1984). These studies assert that elevated exchangeable sodium levels at low concentrations cause dispersion and swelling of the clay minerals and consequently a reduction in hydraulic conductivity of the soil. The development of this phenomenon in the presence of sodium invariably indicates that there is a threshold level for these changes to occur, especially for high Sodium Adsorption Ratio levels. However, most studies have in general been conducted in the laboratory on repacked disturbed soil columns. The results obtained with these experiments are representative of the behaviour of the clay and cannot

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be assumed to be indicative of the behaviour of transport properties under field conditions.

The objective of this study was to measure hydraulic conductivity of soils with different salt solution concentrations in order to evaluate water flow; whether it is natural rain water or saline water originating from the water table, and to asses the influence of organic matter management on soil hydrodynamic properties.

Material and methods

Experimental design

Infiltration properties were measured *in situ* with a disk infiltrometer (Figure 1) in order to evaluate the saturated hydraulic conductivity of the soil under undisturbed conditions and with solutions being representative of field conditions. These properties were measured with both deionized water, and a NaCl brine at the same concentration as the groundwater (250 meq/l) in two contiguous plots, inside and outside saline patches. The two plots have different managements: in the first one L25 the farmer follows carefully the water level during the cropping season

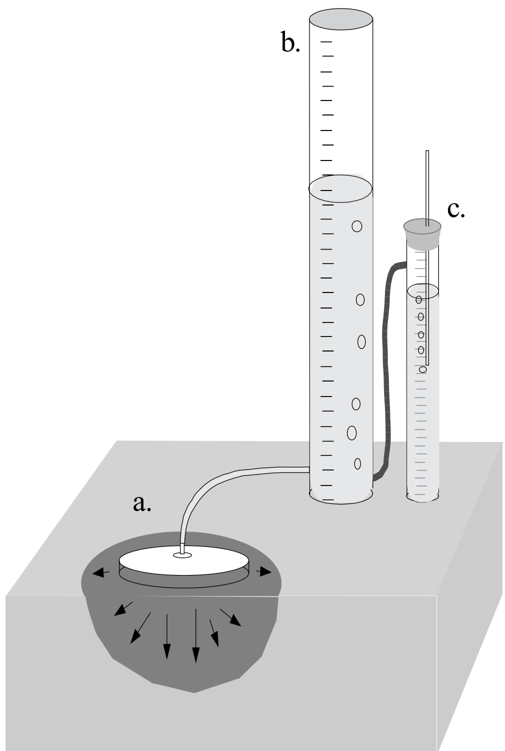

Figure 1. Schematic of a disk infiltrometer showing a. the actual disk on the soil surface allowing for 3D water flow, b. the water (or brine) reservoir and, c. the Mariotte device controlling the suction imposed at the soil surface

and introduces organic matter amendments, especially on the saline patches, whereas in the second one L14, the farmer only puts very little effort in the management of the field. This is a commonly observed where yields of rice have declined significantly and farmers are not willing to invest the effort to try to remediate their fields.

Saturated hydraulic conductivity was calculated with the multipotential method (Perroux and White, 1988; Smettem and Clothier, 1989). Three infiltration measurements were undertaken in each situation at two suction values and for each type of solution. These measurements were undertaken at different depths down the soil profile.

Model

Water Infiltration into soil is usually well described by the Philip equation (1957):

$$I = S\sqrt{t} + A\,t \qquad (1)$$

where S is the sorptivity, resulting from the flow due to capillary pressure head in dry soil, and *A* the constant infiltration rate parameter, depending on the gravity flow. As infiltration from a disc is unconfined and water flow is 3-dimensional, the hydraulic conductivity is calculated with the constant infiltration rate *A* according to Woodings’ equation (1968):

$$A_0 = K_0 + \frac{4 \cdot \phi_0}{\pi \cdot r} \qquad (2)$$

$$\phi_0 = \int_{hi}^{h0} K(h) \cdot dh \qquad (3)$$

where r is the disc radius, A_0 is the constant infiltration rate, K_0 the hydraulic conductivity, and ϕ_0, the matrix flux potential for applied infiltration suction h_0, h_i is the initial pressure head of the soil. Assuming an exponential relation for conductivity with pressure head (Gardner, 1958): $K(h) = K_s \cdot \exp(\alpha \cdot h)$, the matrix flux potential derives into a simple relation, $\phi_0 = K_s \cdot \exp(\alpha \cdot h_0)/\alpha$ where Ks is the saturated hydraulic conductivity and α the exponential slope. Equation (1) becomes:

$$A_0 = K_s \cdot \exp(\alpha \cdot h_0) \cdot \left(1 + \frac{4}{\alpha \cdot \pi \cdot r}\right) \qquad (4)$$

When performed for two pressure heads (h_0 and h_1), the exponential slope is calculated: $\alpha = \mathrm{In}(A_1/A_0)/(h_1 - h_0)$ and introduced into equation (4) to calculate the saturated hydraulic conductivity Ks.

In order to determine easily and graphically, the infiltration parameters *S* and *A* from the infiltration data, Philip’s equation can be rewritten as follows:

$$I/\sqrt{t} = S + A\sqrt{t} \quad (5)$$

When representing these results graphically as I/√t versus √t diagram, the infiltration appears as a straight line defined by a slope *A* and an ordinate to origin *S*.

Location and soils

The study was established in Northeast Thailand, near Pra Yuhn, Khon Kaen region (16º27.8′N, 102º6.9′E). Saline patches in the rice fields were identified and delimited by EM38 measurements. The infiltration experiment was performed during the dry season in March 2005. The soil represents a quaternary aeolian deposits (Lesturgez, 2005), with a fine sandy loam texture, but with a low clay content. However, within the profile the clay content increases from 3% near the surface to 10% at 50-60 cm. Similarly the bulk soil density varied from 1.46 10^3 kg m^{-3} in the most surface layers to 1.92 10^3 kg m^{-3} at 50 cm. This dense layer seems to be continuous except in discrete points under the saline patches where it has not been found. Wider exploration in the area with penetrometer, confirmed this observation.

Results and interpretation

The infiltration measurements were performed during the dry season (March 2005) at different depths. A typical set of infiltration curves is presented in Figure 2, where distilled and saline water have been used to generate the data. It demonstrates clearly that in saline patches, infiltration with a saline solution is in accordance with Philip’s equation and is represented by a straight line according to equation (5). Contrasting this, for distilled water the Philip’s model does not entirely describe the infiltration kinetics, as curvilinear relation was observed (Figure 2). Based on the fact that as the distilled water enters the soil, a dilute salt solution is progressively formed that induces clay dispersion. The consequence is a reduction of hydraulic conductivity depending on the concentration of the infiltrating solution. Previous laboratory experiments on undisturbed soil monoliths (Rivallan, 2004) showed a linear positive relationship between solution concentration and saturated hydraulic conductivity, indicating that infiltration rate decreases with time when distilled water or rain water enters the soil. However, in order to calculate a saturated hydraulic conductivity, we used the tangent to the infiltration curve for an arbitrarily chosen amount of infiltrated water, equivalent for each experiment, as depicted in Figure 2.

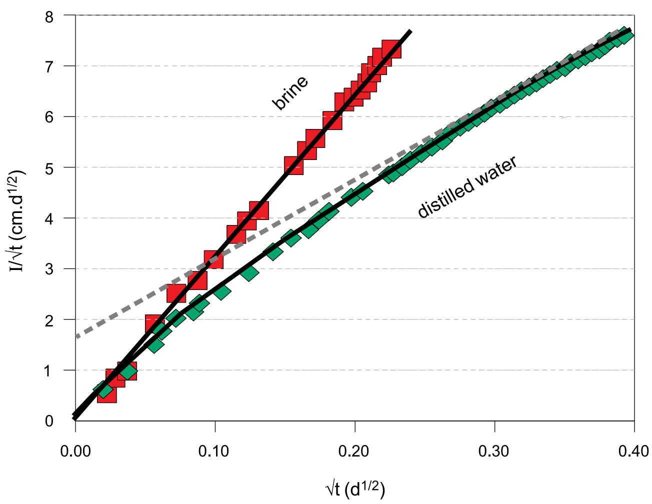

Figure 2. Example of infiltration curves in a I/√t vs √t diagram in a saline patch. Squares infiltration with brine; diamonds infiltration with distilled water. Dotted grey line: tangent for calculating parameter *S* and *A*

As expected, when brine was used for infiltration measurement, the saturated hydraulic conductivity was systematically higher than distilled water (Figure 3). This clearly illustrates the clay dispersion phenomenon under saline soil conditions when diluted with fresh water is applied that leads to the partial blockage of the pores. The measurements performed with brine can be considered as representing the intrinsic Ks values for this soil, as the conditions are fulfilled for clays to be flocculated, and hence optimal for water flow. However, these saturated hydraulic conductivity values are very low for sandy soils as the maximum values are less than 5 cm d^{-1} whereas for sandy soils Ks is usually found 500 to 700 cm d^{-1} (Carsel and Parrish, 1988).

In each of the assessments irrespective of management and within or outside a saline patch, hydraulic conductivity varies with depth in the soil profile. Inside the saline patches, in both plots, the maximum saturated hydraulic conductivity was observed in the surface layers (6 cm), where the salt concentration is highest. This probably illustrates changes in soil structure when salt crystallizes in the pores. Outside saline patches, Ks in the topsoil is 3 times higher in L25 (4.2 cm d^{-1}) than in L14 (1.4 cm d^{-1}). This difference is most probably due to the soil management, as L14 does not receive routine applications of organic matter unlike L25. On the other hand, an important decrease of Ks at a depth of 17 cm represents typically the plough layer. Hydraulic conductivity of the deepest soil layer (56 cm) is not influenced in the case of plot L14 whether measurements are taken inside or outside the saline

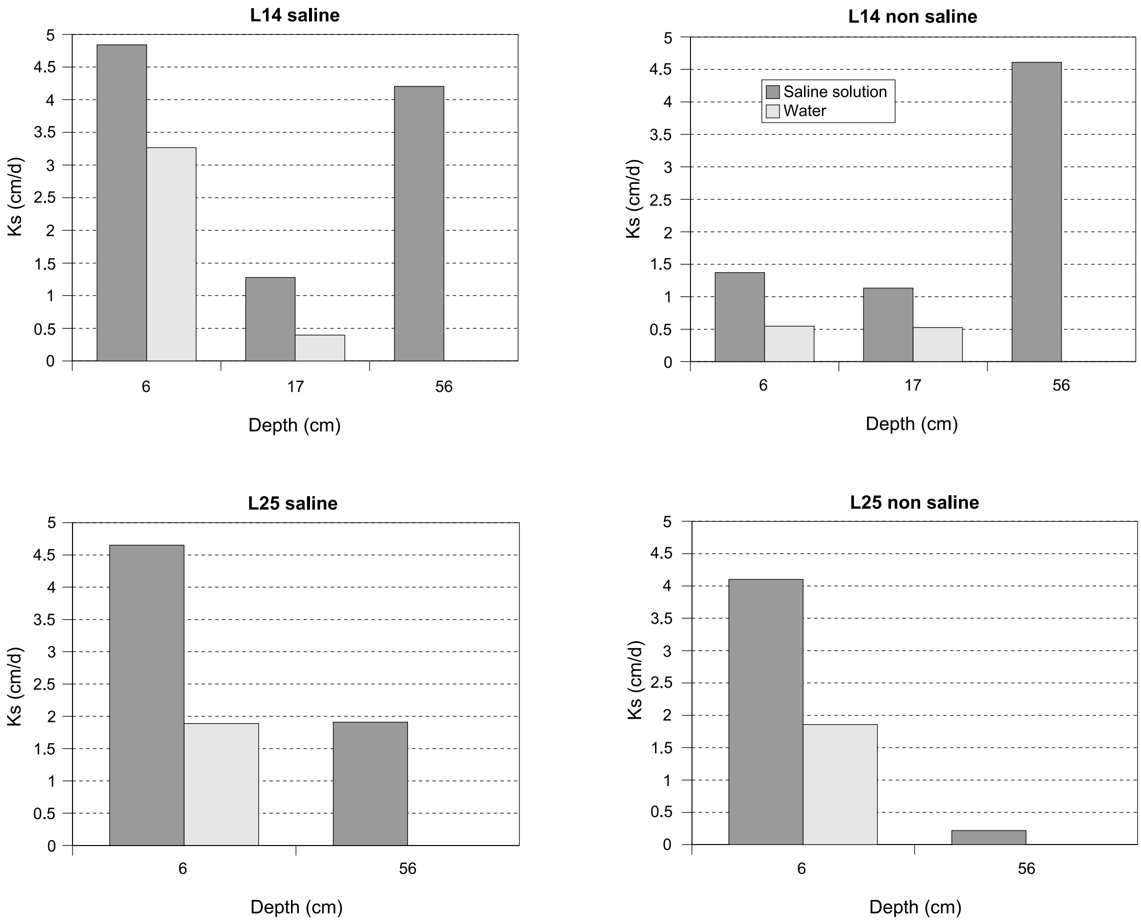

Figure 3. Saturated hydraulic conductivity inside (saline) and outside (non saline) the saline patches in both plots L14 and L25, measured with saline solution (dark grey) and distilled water (light grey)

patch (Figure 3). In contrast, in the case of L25 there is a drastic decrease in Ks between inside and outside the patch at 56 cm depth. The presence of the dense layer described previously is clearly illustrated here in L25, where it fades inside the saline plot. However this difference is not marked as distinctly in L14.

In both plots L14 and L25, the saturated hydraulic conductivity is higher inside the saline patch than outside, whether distilled water or brine is used for infiltration (Figure 3). As infiltration occurs with a limited amount of water (approximately 2 liters), the soils solution in the upper part of the profile does not get diluted sufficiently to reach the optimal dispersion concentration. However one can expect that during the cropping season the dispersion concentration is reached and that Ks declines significantly.

Basing on these first results, one can propose a functional model of water flow and solute transport in these sandy saline soils. As infiltration of fresh water tends to be limited in the saline patches, possibilities of leaching the salts downwards during the cropping season are therefore limited. On the other hand, capillary rise of saline water from the water table towards the soil surface is favoured at the end of the cropping season as Ks increases due to the presence of highly concentrated saline solutions. Consequently, if the plots are not flushed regularly during the cropping season, superficial salinity levels will increase and widespread naturally.

Conclusion

Saturated hydraulic conductivity was measured *in situ* with a disk infiltrometer inside and outside saline patches in two contiguous plots with different management. From this simple experiment several conclusions can be drawn about the i) intrinsic parameters of soils, ii) the techniques used to measure them and iii) the dynamics of water and salt in these soils. The intrinsic saturated hydraulic conductivity measured was very low compared to the values usually observed for sandy soils. The presence of silt is presumably contributing to these observed responses. However this feature ensures the possibility of ponding and consequently favours rice cropping. It has been shown that saturated hydraulic conductivity is dependant on the quality of the infiltrating solution, because distilled water tends to disperse the clays and block infiltration pathways. Hence under saline conditions it is important to measure hydraulic conductivity with solutions that have similar solute compositions to those found naturally. Moreover these results demonstrate that in highly managed plots the infiltration properties are higher than in the low management plot, highlighting the importance of organic amendments. Despite no actual numerical modelling being performed, it can be assumed that if no surface flushing of salts is undertaken during the cropping season, the degree and extent of salinity will increase. Nevertheless the complete water flow and salt transport has to be simulated numerically with a model, taking into account the development of saturated hydraulic conductivity with solution composition and concentration, which still has to be designed.

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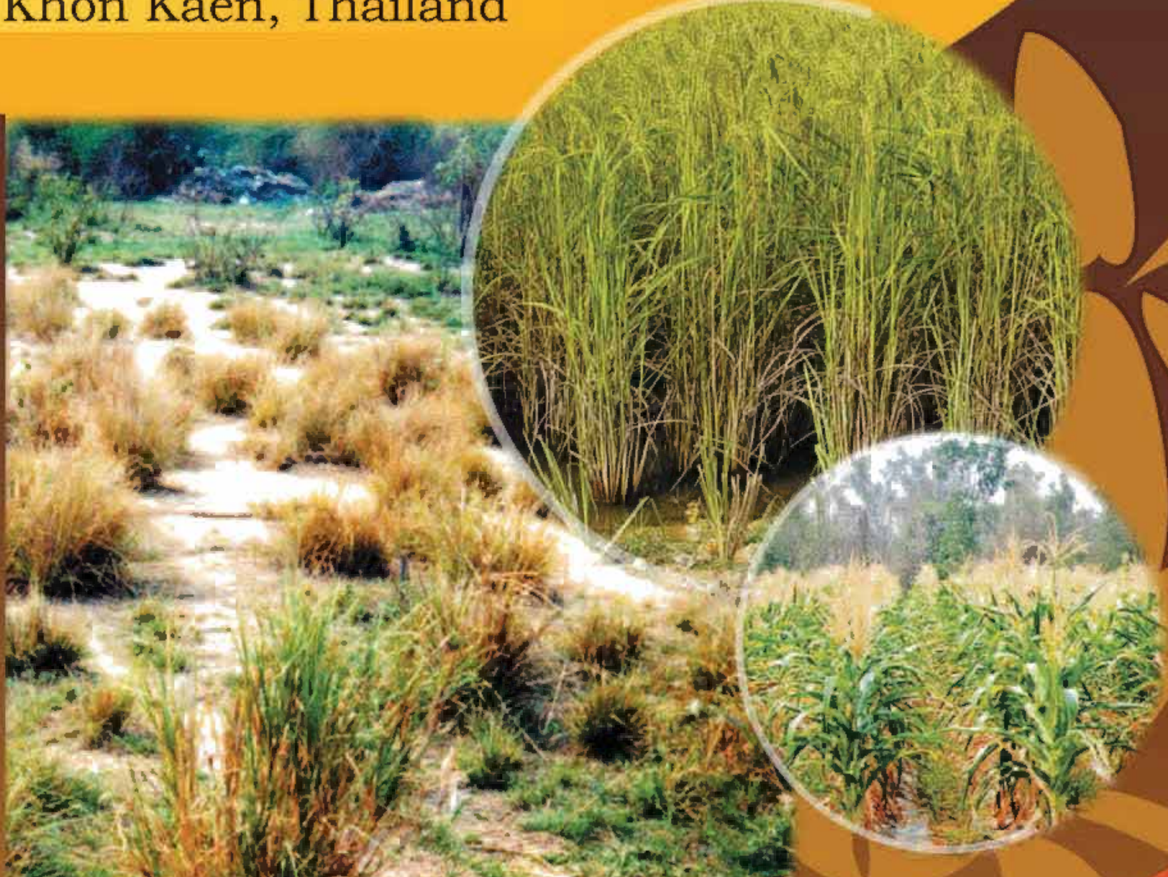

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