Air entrapment in irrigated paddy fields of northern Senegal: effects on water infiltration and soil solution.

Claude Hammercker[1], Eric Barres[1 2], Jean Luc Maeght[1], Antonio C.D. Antonino [3]

[1] IRD Maison des Sciences de l'Eau, 300 avenue, 34095 Montpellier, France

Abstract

Irrigation has become the only way to perform sustainable agriculture for many arid areas in the world, like northern Senegal. On the other hand, high evaporative demands can jeopardize the benefits of irrigation because of the salinization processes usually associated to irrigation. In the Senegal River valley, irrigated rice cropping has become the major agricultural activity since these last decades, after the construction of two major dams on the river. Nevertheless presence of ancient salt deposits, due to quaternary marine transgression, and irrigation with carbonated water showing positive (Residual Sodium Carbonate) RSC, are potential threats for soil degradation and sustainable cropping. Osmotic stress on plants due to capillary rise of the water table through deep salt affected soil layers, as well as potential alkalinization and sodication processes due to the quality of irrigation water combined with high evaporative conditions are the two main risks for soil and water conservation. In order to evaluate these potential risks in the local conditions and eventually to manage them, a complete monitoring of the water balance and evolution of the soil solution in an irrigated plot, near Podor has been performed. The soil in this area is a vertisol with high clay content (65%) and high CEC values (25 $cmol_c/kg$). As soil sodication is a slow phenomenon, simple field monitoring does not provide the information necessary to quantify this phenomenon and hence numerical modelling is required to evaluate the long-term evolution of soil under these irrigation conditions. The classical numerical models describing solute and water transfer as well as geochemical equilibria, did not agree satisfactorily with experimental results, as they were not able to describe the water flow.

The combination of the presence of a shallow water table in this area (about 2 m deep) and flooded paddy cropping, theoretically favours air entrapment between two water fronts, during the infiltration phase. On the base of water budget in a cropped plot, and common 1D monophasic water flow modelling, it has been pointed out that air entrapment rules water infiltration rate (Hammecker et al, 2003). In order to quantify the incidence of this phenomenon, a specific study on two-phase flow was carried out. Both numerical and experimental methods were used to quantify this mechanism. A 1D two-phase flow model, based on multiphase transport theory described by Touma (1984) in which water and air flows are taken into account, was developed. On the other hand, a simpler model based on Green and Ampt infiltration

model, taking into account air compression and air counter-flow (Grismer et al, 1994; Whang et al., 1998) was used to compare its efficiency. An experimental set-up was designed to determine the relative permeability of air for different water content values.

Infiltration experiments were performed on repacked soil in a closed air-tight, plexiglass container where progression of the wetting front were observed and monitored with tensiometric and TDR water content measurements. Air pressure under the wetting front was monitored during the experiment and air bubbling pressure was determined.

Both models described satisfactorily the infiltration in the experimental device (Figure 1) and were then used for the field conditions. When used for modelling the field conditions (ponding irrigation and shallow water table), these models clearly showed a typical air entrapment phenomenon, where the computed infiltration rate corresponds to the experimental data. Due to its fine texture, air bubbling pressure, i.e. the air pressure required to drain water filled porosity, was not reached easily and air remained entrapped in the soil, blocking normal infiltration of water. The soil profile showed two saturated compartments separated by a partially saturated volume. Soil solution in the upper part of the profile (0-40cm) is consequently not directly related to the water table and is affected by the irrigation water only. Two consequences for soil solution can be pointed out: (i) the water table does not work as natural drain where soluble salts can be leached out of the soil profile (ii) irrigation water concentrates in the upper part of the profile without being affected by the water table composition. These conditions typically increase the risk of alkalisation and sodication, with irrigation water.

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