Experimental study and numerical modelling of the water transfers in an irrigated plot in Northern Senegal : evidences of air entrapment.

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In arid sahelian areas of West Africa, irrigation has become the only answer to drought and increasing population, for performing sustainable agriculture. On the other hand, under high evaporative demands, irrigation can also result as being a serious hazard for soil conservation, and cropping, as it leads to accumulation of soluble salt in the root area. Salinisation process, responsible for osmotic stress on crops, is usually the major threat in arid areas. Moreover, in the valley of river Senegal, where this study takes place, the quality of the irrigation water shows alkaline composition with a positive sodium carbonate ratio. Although no real evidence of sodic soils has yet been observed, after two decades of irrigation, the intrinsic water quality represents a serious potential threat for soil sodication.

A shallow water table (2m depth), related to the river level, with a neutral saline composition, is present under the irrigation scheme of the studied area. During irrigation periods the water table rises and contributes to salt transfer, but can also be seen as natural drain for water and solutes towards the river.

As soil recuperation or amendment application is economically not possible for the local farmers, adequate water management is the only way to prevent or reduce the potential soil degradation process. Water transfer will play an essential role in the evolution the physico-chemical characteristics of the soil.

To evaluate the risks of salinisation and alkalisation in irrigated paddy fields, apart from a geochemical study it is important to the dynamics of the water and solute transfer.

Therefore a precise monitoring of water budget in an irrigated plot near Podor (N16°40'; W15°) has been performed during a paddy cropping season (100 days). Water inputs have been quantified with the monitoring of the number of calibrated siphons used during each irrigation. Evapotranspiration has been evaluated with lysimeters and the cumulative response of evapotranspiration and vertical infiltration has been quantified by monitoring the daily evolution of the water level in Muntz infiltration rings. At the same time, piezometric level and tensiometric data have been measured in 2 stations in the plot at 5 depths (10, 20, 40, 60 and 80cm).

Global water balances results show that net vertical infiltration of 1.1 mm/d in station 2 and about 0.2mm/d in station 3. In station 2 located in the middle of the plot , evolution of the tensiometric profile follows a typical dynamics with sharp pressure head decrease as infiltration front progresses. In station 3 near the external border, the upper layers (10 an d20cm) follow the same evolution. However at 40 cm the pressure head decreases extremely slowly and progressively during a period of 40 days without reaching complete saturation after the whole period. Underneath the pressure head remains unchanged and unsaturated during the whole cropping period.

Unsaturated hydraulic parameters of van Genuchten (_r, _s, _, n, Ks) have been determined along the profile independently. Consequently, with the tensiometric data, both water contents and water fluxes could be evaluated. Water fluxes calculated with Darcy equation thoroughly

overestimated the values measured with the global water balance method, due to high hydraulic gradients, whereas fluxes estimated from the water stock variation are in agreement.
Water transfer has been modelled with Hydrus-1D and previously determined unsaturated hydraulic parameters. As excepted, the numerical results are in complete disagreement with the experimental data. When used inversely to evaluate the parameters, the best fit of the model gives a saturated conductivity of 0.25mm/d, which does not have a real physical significance as it is 2 orders of magnitude lower than the the saturated hydraulic conductivity determined otherwise. These different results tend to show that infiltration in this area seems to be controlled by a mechanism of air entrapment between the downward wetting front and the shallow water table.
Most of the models simulating transfer in soil consider monophasic flow where air freely escapes, and does not impede water infiltration. However in this case this approximation seems not to be valid.
Basic infiltration models based on Green Ampt concept developed by several authors (Grismer et al 1994, Morel-Seytoux et al 1996, Wang et al. 1997) have been tested to evaluate the hypothesis of air entrapment phenomenon. They have been used with different external conditions : (i) no air escape, (ii) with air counterflow considering that air escapes vertically for a fixed bubbling pressure, (iii) with a maximal air pressure which is the case often observed in experiments (Grismer et al. 1994) and (iv) with a lateral air escape, considering air can escape beyond the irrigated plot. The models have been applied with unsaturated soil hydraulic parameters determined previously, and with the actual water table level evolution.
When no air escape is allowed and the infiltration of water is completely stopped at a depth of around 50 cm and the underneath soil profile remains at its original water saturation. The global solution for infiltration with vertical air counterflow is independent of the water table level,and shows a continuous imbibition dynamics proportional to the square root to time. For both of two other tested cases, infiltration drastically drops at the same depth (around 50-60 cm depth) and where the flux reaches a minimum value around 0.1mm/d, during a period of 100 days, and then accelerate again.
We showed that the dynamics of infiltration measured in field conditions, corresponds to cases where air compression takes place. However the condition with vertical air counterflow does not correspond to the dynamics observed in the field. Moreover no evidence of air bubbles has been observed in the plot during the hole experiment. On the other hand, considering the depth of maximal infiltration reduction and the following water fluxes derived from the models, it seems very likely that air compression occurs in this plot. The particular position of the studied plot, on the border of the irrigation scheme, allows air to escape laterally but due to an important impedance, air pressure builds up and drastically reduces the infiltration rate.
This study showed that in irrigated plots in the area of Podor in the valley of river Senegal, water transfer and consequently solutes, does not follow the classical infiltration models. It has been demonstrated that the presence of a shallow water table and irrigation by immersion for paddy cropping, generates a phenomenon of air entrapment blocking the infiltration of water. The consequence of this mechanisms is that water introduced in the field for irrigation does not leach to the water table and consequently concentrates in the upper part of the soil profile. This unexpected phenomenon, and generally not considered in coupled water and solute transfer models, can chiefly affect the evolution of the soil solution and increase the risk of alkalisation.