Spatio-Temporal Variability of the Soil Hydraulic Properties—Effect on Modelling of Water Flow and Solute Transport at Field-Scale

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1 Introduction

In the unsaturated soils, the modeling of water flow and solute transport requires the characterization of hydraulic properties. Several analytical models were developed to describe the characteristic curves of unsaturated soil (Burdine 1953; Brooks and Corcy 1964; Mualem 1976; van Genuchten 1980). The Beerkan test is one of the simplest, the least expensive and the easiest method to set up and carry out in field conditions. In this study, the Beerkan method (Haverkamp et al. 1994) was used to characterize the hydraulic properties of the soil. The BEST (Beerkan Estimation of Soil Transfer Parameters) algorithm, presented by Lassabatère et al. (2006), allows processing the infiltration tests. This algorithm specifically relates van Genuchten's expression for the water retention curve (van Genuchten 1980) with Burdine's condition (Burdine 1953) and use the Brooks and Corey equation for the hydraulic conductivity curve (Brooks and Corey 1964). The main objective of investigation was to study the effect of spatial and temporal variations of the soil hydraulic properties on water flow and solute transport through numerical modeling.

2 Materials and Methods

A square land parcel (10 m × 10 m) was chosen in the city of Ariana ([36°50′40.791″N, 10°11′13.795″E], Tunisia) with a clay loam soil. A mesh size of 5 m^2 (9 points) was chosen to perform Beerkan infiltration tests. The Beerkan infiltration method uses a simple annular ring. The cylinder was positioned at the soil surface and inserted to a depth of about 1 cm to avoid lateral loss of the ponded water at the soil surface. A fixed volume of water is poured into the cylinder at time zero, and the time elapsed during the infiltration of the known volume of water was measured. When the first volume has completely infiltrated, a second known volume of water was added to the cylinder, and the time needed for it to infiltrate was measured (cumulative time). The procedure was repeated for a series of about 8–15 known volumes and cumulative infiltration was recorded. The results were processed according the BEST algorithm (Lassabatère et al. 2006) in an Excel sheet developed by Di Prima (2013). The algorithm requires as input the ring diameter, the initial water content, the soil granulometric composition and the experimental data. After the final processing, the hydraulic properties were estimated as output.

Hydrus-1D (Simunek et al. 2005) model was used to simulate the water flow and solute transport. The simulation period lasted 383 days from 01/08/2015 (initial profiles) to 15/08/2016 (final profiles) with a daily step-time and 80 cm in depth. The measured profiles were located at the coordinate point (5,5) which corresponds to the center of the land parcel. The hydrodynamic parameters were specified from values measured by the Beerkan infiltration tests and the transport parameters of the solutes were introduced from the literature (Kanzari and Bouhlila 2014). For the water

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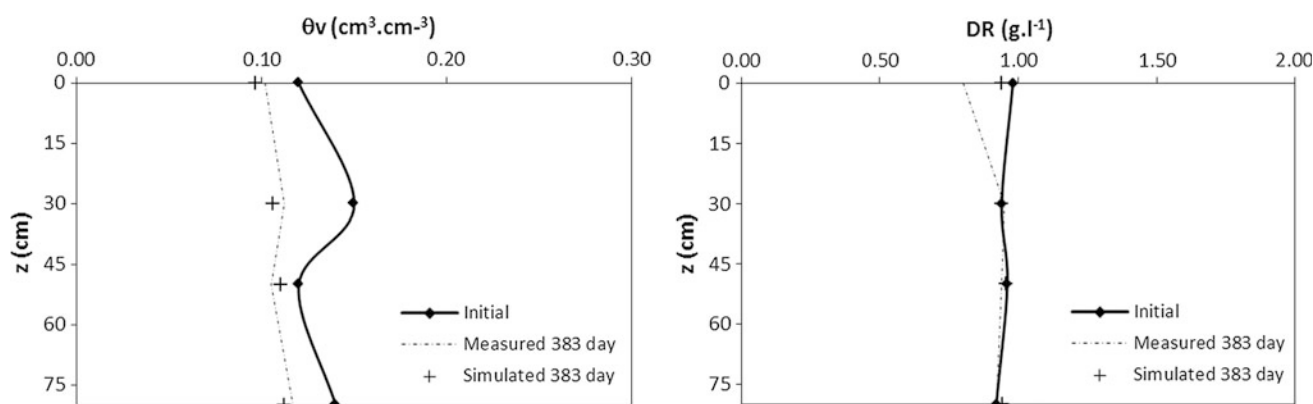Tunisia
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Fig. 1 Measured and simualted profiles at point 5 (5,5)

dynamics, boundary conditions, at the upper limit, "atmospheric BC with surface layer" where rainfall and evapotranspiration were introduced and at the lower limit, were "free drainage" type. For the transport of solutes, the boundary conditions were "Concentration Flux" type. The Root Mean Square Error (RMSE) was calculated to evaluate the simulation results.

3 Results and Discussion

The hydraulic properties were characterized using the BEST algorithm. The form parameters n, m and η are constant for all measurment points (n = 2.111, m = 0.052 and η = 21.07) because they were estimated from the soil particle size composition, whereas the normalization parameters appeared to be related to the structural state of the soil and vary from one point to another except for the water content at saturation which was equal to 0.46 cm^3.cm^{-3}. The values of the saturated hydraulic conductivity and the capillary length are presented in the following table.

The spatial variability of the saturated hydraulic conductivity shows that most permeable zones were located around the boundary points of coordinates (0,0) and (5,10), whereas for the rest of the parcel, Ks is fairly homogeneous. The capillary length varies from 24.5 cm to 38.5 cm. The largest value was around the coordinate point (5.0) and the lowest values were within the boundaries.

The variation of the soil water content and soil salinity showed that the content varied between 0.09 cm^3.cm^{-3} and 0.18 cm^3.cm^{-3}, mainly between 0 cm to 40 cm in depth. While the salt concentration varied between 1 g.l^{-1} and 1.3 g. l^{-1} in the surface layer (0–20 cm) and was stabilized around 1.2 g.l^{-1} in deeper layers.

The simulated profiles using the measured hydraulic properties at the different points were close to the measured profiles at the center of the land parcel. However, the

Table 1 Normalization parameters values

Point	Hg (cm)	Ks (cm.d^{-1})
1 (0,0)	−17.88	1239
2 (5,0)	−23.19	990
3 (10,0)	−20.63	416
4 (0,5)	−20.45	757
5 (5,5)	−31	551
6 (10,5)	−26.7	391
7 (0,10)	−23.62	1775
8 (5,10)	−20.17	425
9 (10,10)	−16.53	599

hydraulic properties measured at point 5 (5,5) gave the best match between measured and simulated values (Fig. 1). This result is confirmed by the values of RMSE at the same point, which are lowest with a value of 0.08 for both the water content and the soil salinity profiles.

To study the effect of temporal variation of hydraulic properties on water flow and solute transport modeling, two sets of parameters were used: the hydraulic properties measured by (Kanzari et al. 2015) in August 2015 and those measured in August 2016 (Table 1) in point 5 in the center of the land parcel. The simulated profiles were very close to those measured. The calculated RMSE values calculated were small and confirmed the graphical results.

4 Conclusion

In the case of a homogeneous soil, the spatial variation of the hydraulic properties does not seem to have a significant effect on the modeling of water and solute dynamics for a distance of 5 m from the measurement point. Indeed, the Hydrus-1D model adequately reproduces the measured profiles. The same result is observed for a

temporal variation of the hydraulic properties during one year.

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