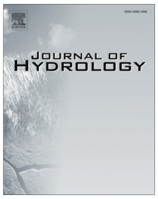
Journal of Hydrology 534 (2016) 251–265

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol



The relevance of in-situ and laboratory characterization of sandy soil hydraulic properties for soil water simulations

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ARTICLE INFO

Article history:
Received 21 October 2015
Received in revised form 23 December 2015
Accepted 31 December 2015
Available online 11 January 2016
This manuscript was handled by Corrado Corradini, Editor-in-Chief, with the assistance of Juan V. Giraldez, Associate Editor

Keywords:
Tension disc infiltrometer
Soil hydraulic properties
Laboratory experiment
Hydrological model
Hydrus 1D/2D/3D
Soil water simulation

SUMMARY

Field water flow processes can be precisely delineated with proper sets of soil hydraulic properties derived from in situ and/or laboratory experiments. In this study we analyzed and compared soil hydraulic properties obtained by traditional laboratory experiments and inverse optimization tension infiltrometer data along the vertical direction within two typical Podzol profiles with sand texture in a potato field. The main goal was to identify proper sets of hydraulic parameters and to evaluate their relevance on hydrological model performance for irrigation management purposes. Tension disc infiltration experiments were carried out at four and five different depths for both profiles at consecutive negative pressure heads of 12, 6, 3 and 0.1 cm. At the same locations and depths undisturbed samples were taken to determine Mualem–van Genuchten (MVG) hydraulic parameters (θ_r, residual water content, θ_s, saturated water content, α and n, shape parameters and K_{ls}, lab saturated hydraulic conductivity) in the laboratory. Results demonstrated horizontal differences and vertical variability of hydraulic properties. The tension disc infiltration data fitted well in inverse modeling using Hydrus 2D/3D in combination with final water content at the end of the experiment, θ_f. Four MVG parameters (θ_s, α, n and field saturated hydraulic conductivity K_{fs}) were estimated (θ_r set to zero), with estimated K_{fs} and α values being relatively similar to values from Wooding's solution which used as initial value and estimated θ_s corresponded to (effective) field saturated water content, θ_f. The laboratory measurement of K_{ls} yielded 2–30 times higher values than the field method K_{fs} from top to subsoil layers, while there was a significant correlation between both K_s values ($r = 0.75$). We found significant differences of MVG parameters θ_s, n and α values between laboratory and field measurements, but again a significant correlation was observed between laboratory and field MVG parameters namely K_s, n, θ_s ($r \geqslant 0.59$). Assessment of the parameter relevance in 1-D model simulations, illustrated that the model over predicted and under predicted top soil-water content using laboratory and field experiments data sets respectively. The field MVG parameter data set resulted in better agreement to observed soil-water content as compared to the laboratory data set at nodes 10 and 20 cm. However, better simulation results were achieved using the laboratory data set at 30–60 cm depths. Results of our study do not confirm whether laboratory or field experiments data sets are most appropriate to predict soil water fluctuations in a complete soil profile, while field experiments are preferred in many studies.

1. Introduction

Field water flow processes can be precisely delineated by using in situ and/or laboratory determined soil hydraulic conductivity functions, $K(h)$ and soil water retention curve, $\theta(h)$. Proper sets of soil hydraulic properties are indispensable as input for crop and hydrological models which especially use a numerical solution of

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http://dx.doi.org/10.1016/j.jhydrol.2015.12.062

the Richards' equation (Gandolfi et al., 2006; Wollschlager et al., 2009; Radcliffe and Šimůnek, 2010) to predict water dynamics in field and laboratory situations. A typical example is Hydrus (Šimůnek et al., 2013). Therefore, comparisons of individual and combined laboratory and in-situ derived hydraulic parameters, and investigations of their spatial variability allow to find appropriate hydraulic parameter sets and enhance our knowledge about the dynamic processes of water flow in the vadose zone. They not only provide information about the uncertainty but also would be helpful in reducing it in simulating the physical processes with various hydrological and crop-based models for precision irrigation management, increasing crop yield and investigating solute and pollutant transport.

Several measurement techniques such as tension disc infiltrometer or constant/falling-head permeameter and sandbox-pressure chambers with soil cores have been developed to determine hydraulic properties in the field and the lab (Dane and Topp, 2002). The most popular methods and benchmarks for evaluating other methods are those that use undisturbed soil cores. The measurements are then carried out under more controlled conditions, and are thus reliable (Fodor et al., 2011) even though they do not necessarily represent field conditions; In that soil core one dimensional flow is imposed and as a result of sampling, preferential flow may be reduced (Jačka et al., 2014) and compaction may have occurred (Reynolds, 2008). The constant/falling head method to determine saturated hydraulic conductivity, K_s, is inexpensive, simple and convenient (Reynolds et al., 2000), whereas sand boxes-pressure plate methods for soil water retention determination are time consuming and labor intensive (Cornelis et al., 2001). The advantages of laboratory methods for K_s is that it is calculated using Darcy's law in which all the flow conditions are defined exactly, i.e., hydraulic head, one dimensional flow and temperature, and the effects of the entrapped air are minimized (Jačka et al., 2014).

On the other hand, the tension disc infiltrometer is a standard method to measure soil hydraulic conductivity for quasi-steady state and transient flow in the field (Reynolds and Elrick, 1991; Logsdon and Jaynes, 1993; Baetens et al., 2009; Verbist et al., 2013; Latorre et al., 2015). It is less time consuming and inexpensive, can be easily operated with minimal disturbance of soil and consistently provides reliable hydraulic properties values (Hu et al., 2009) especially near saturation (Perroux and White, 1988) where soil macrospores are active (Ankeny et al., 1991). Measurements using the tension disc infiltrometer represent the soil matrix (i.e., part of macropores are excluded) and air may be entrapped during the rapid saturation process, thus preventing full saturation of the soil to be obtained. Consequently, hydraulic parameters like water content and hydraulic conductivity at saturation or residual water content, might be underestimated than when using laboratory methods (Fodor et al., 2011). Also under ponding conditions, i.e., at a small positive pressure head and thus including macropores in water transmission, higher K_s values are estimated (Kutílek and Nielsen, 1994), though they are still lower than laboratory values (Reynolds et al., 2000).

Comparison of laboratory and in situ procedures showed different trends for various soil types and field conditions (Ankeny et al., 1991; Warrick, 1992; Hussen and Warrick, 1993; Evett et al., 1999; Reynolds et al., 2000; Ventrella et al., 2005; Ramos et al., 2006; Fodor et al., 2011). Reynolds et al. (2000) encountered very high differences between K_s derived from tension infiltrometer and that from the classical laboratory soil core method, and found very little correlation among the methods used. Overall, the laboratory method mostly provides higher K_s values than field methods (Reynolds et al., 2000; Dušek et al., 2009; Fodor et al., 2011; Jačka et al., 2014), although Ventrella et al. (2005) reported an opposite trend.

Ramos et al. (2006) and Schwartz and Evett (2002) found that the water retention curves obtained by numerical inversion of tension disc experiments closely matched the laboratory measured curves. In contrast, relatively poor agreements were yielded between estimated water retention curves using tension disc numerical inversion and laboratory retention data (Šimůnek et al., 1999; Ventrella et al., 2005). Recently, much research has been dedicated to inversion of tension disc data to soil hydraulic properties, comparing them or not with laboratory derived data (Ventrella et al., 2005; Lazarovitch et al., 2007; Verbist et al., 2013; Latorre et al., 2015; Rashid et al., 2015), but most of them have not assessed the relevance of different approaches for their applications, e.g., evaluation of hydrological model performance and soil-water dynamics as regards to hydraulic parameter sets derived from different measurement methods.

Therefore, the present study focuses on analyzing tension infiltrometer data along the vertical direction within two soil profiles in the field and traditional laboratory-derived data to determine soil hydraulic parameters of a sandy soil. In this study, three calculation procedures were performed to derive hydraulic parameter sets, i.e., (i) a "quasi-steady state" procedure using Wooding's equation, (ii) a "transient" procedure using inverse modeling with Richards' equation, both for tension infiltrometer data and (iii) Darcy's model in combination with curve fitting using the Mualem–van Genuchten equation for the soil core data from the laboratory. The objectives of this study were: (i) to compare the results of in situ and laboratory measurements of soil hydraulic properties; and (ii) to evaluate the relevance and the influence of differently calculated/estimated hydraulic properties on hydrological model performance with the purpose of finding a proper set of hydraulic parameters to describe water movement in typical Podzol profiles with sand texture in a potato field.

2. Material and methods

2.1. Study site and soil profiles description

The study site was located in a sandy agricultural area at the border between Belgium and The Netherlands (with central coordinates 51°18′40″N, 05°10′04″E), characterized by a temperate maritime climate with mild winters and cool summers. The farm is almost flat (less than 3% sloping up from NW to SE) and runoff is not considered to be important. The groundwater table fluctuated between 77 and 130 cm below the soil surface depending on the topography. Reel Sprinkler Gun irrigation (type Bauer rainstar E55, Röhren- und Pumpenwerk BAUER Ges.m.b.H., Austria) was used on a 230 m by 600 m field to improve potato growth in the sandy soil during dry periods in summer. The field was irrigated four times throughout the growing season (96 mm). Two locations were selected based on soil topography and agricultural activities, and soil-water content probes and tensiometers were installed (details in next section) for irrigation management purposes. At each location, a soil profile was excavated, analyzed and sampled to characterize soil hydraulic properties. Fig. 1 shows the elevation map, layout of the field and the location of the soil profiles.

Fig. 2 shows the soil profile, a typical Podzol (Zcg type, moderately drained sandy soils with a clear B horizon, according to the Belgian soil classification) or Hortic-Ortstenic Podzol (Arenic) according to WRB (FAO, 2014) consisting of a uniform dark brown layer of sandy soil (Ap/Ah horizon, 0–47 cm) with elevated organic matter content, followed by a bright brown to yellowish sand including stones and gravels (Bhsm horizon, 52–70 cm). The deeper horizon is light gray sandy soil (C horizon, 70–130 cm), including more stones and gravel (max 20%), but having similar hydraulic