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Comparison of unconfined and confined unsaturated hydraulic conductivity

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Abstract

The field tension infiltrometer (TI) and the laboratory unit hydraulic gradient (UHG) methods are widely applied to determine the near-saturated soil hydraulic conductivity, K. Comparison between the two methods is relevant given that they differ in the explored soil volume (undetached or detached) and in the flow process (unconfined or confined). The objective of this investigation was to compare unconfined and confined measurements of unsaturated hydraulic conductivity. Twenty TI experiments were conducted in a relatively coarse-textured soil having an appreciable hysteretic behavior by using two different dry-to-wet-to-dry (DTWTD) sequences of pressure head, h_0, values that differed by the highest h_0 value imposed within the sequence (i.e. h_0=−150, −75, −30, +5, −30, −75, −150 in site A or h_0=−150, −75, −30, −10, −30, −75, −150 in site B). The same pressure head sequences were applied on twenty undisturbed soil cores, collected at the exact location of the TI measurements, to perform the laboratory UHG measurements. Regardless of the type of experiment (i.e. unconfined or confined) and the applied pressure head sequence (i.e. site A or B), higher K_0 values were obtained with a drying sequence of h_0 values ($K_{0,d}$) than with a wetting one ($K_{0,w}$) and the discrepancies between $K_{0,w}$ and $K_{0,d}$ decreased as the imposed h_0 value increased, as it was expected due to hysteresis. A tendency of the UHG method to overestimate the K_0 values was detected (ratios of mean $K_{0,1D}$ to mean $K_{0,3D}$ values ranging from 0.93 to 4.35), but the statistical significance of the observed differences varied with the considered sequence of pressure head values. It was concluded that both the TI and the UHG methods were effective in detecting hysteresis effects on K_0, but the laboratory method resulted in K_0 values that were higher and more variable probably as a consequence of a more substantial effect of macropore flow on the measured flow rates.

Keywords: Infiltration; Measurement; Soil hydraulic conductivity

1. Introduction

Knowledge of the soil hydraulic conductivity (K) vs. pressure head (h) relationship is important for characterizing many aspects of unsaturated water flow such as rainfall partition between infiltration and runoff, aquifer recharge, migration of nutrients, pesticides and contaminants through the soil profile, design and monitoring of irrigation and drainage systems (Reynolds, 1993; Hillel, 1998). The hydraulic conductivity of near-saturated soil is critically important since the water flux and solute transport are highest in near-saturated soils. Due to hysteresis, higher values of K occur during a drying process than during a wetting one because drying soils are wetter than wetting soils at a given pressure head (Hillel, 1998). Wetter soils have more continuous and thicker water films, resulting in faster infiltration rates. In general, the soil hydraulic conductivity varies appreciably in space and time. Different methods may be used to measure K both in the field and in the laboratory (e.g. Reynolds, 1993), but they often yield dissimilar results due to differences in sample size, flow geometry, sample collection procedures. The comparisons among methods for measuring K provide one of the few sources of information that practitioners can draw upon to select methods that are appropriate for their circumstances (Reynolds et al., 2000).

The tension infiltrometer (TI) method (Perroux and White, 1988) is one of the most widely used field methods whereas the unit hydraulic gradient (UHG) method (Klute and Dirksen, 1986) is one of the most widely used laboratory methods. A three-dimensional (3D) unconfined process is established with the TI method and a one-dimensional (1D) confined process is established with the UHG method. For a given set of ordered pressure heads, a multipotential experiment can be carried out with both methods by first setting either the highest pressure

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head (increasing suctions; wet-to-dry, WTD, sequence) or the lowest one (decreasing suctions; dry-to-wet, DTW, sequence). Few works have been conducted to compare the largely applied TI and UHG methods, and incomplete or contradictory results have been obtained.

Ankeny et al. (1991) compared unconfined and confined K data for a silty clay loam soil. Unconfined steady-state rates were measured in the field at pressure heads of 0, −30, −60 and −150 mm. Confined data were obtained in laboratory on soil cores taken at the exact location of the TI measurements by applying the −30, −60 and −150 mm sequence and then by measuring the saturated hydraulic conductivity. The field estimates of K were usually three times larger than the laboratory ones. Ankeny et al. (1991) attributed the discrepancies to some truncation and destruction of macropores that occurred when the undisturbed soil sample was taken and to a slight compaction of the soil core during sampling.

Logsdon and Jaynes (1993) compared unconfined and confined K data for a clay loam soil. The pressure head sequence imposed with the TI was +10, −30, −60, and −150 mm whereas pressure head values of −30, −60, and −150 mm were used in the laboratory. A unit hydraulic gradient was assumed to analyze the confined laboratory measurements although no constant negative head was applied at the base of the column. The agreement between the unconfined and confined results varied with the method used to analyze the TI data. In particular, a bias for the Ankeny et al. (1991) method to underestimate K was detected (slope of the regression equation forced through the origin between 3D-K and 1D-K equal to 0.59) whereas nonlinear regression (Logsdon and Jaynes, 1993) yielded similar results between the two methods (slope=1.05). The scatter in the data was attributed to different initial conditions.

Furthermore, several investigations have been carried out to establish the influence of the pressure head sequence (DTW, WTD) on the K values determined with the TI method (Logsdon et al., 1993; Mecke et al., 2000; Bagarello et al., 2000, 2005) or the UHG one (McKenzie et al., 2001). Previous studies have not corroborated results of TI and UHG with each other. This topic deserves attention given that hysteresis in soil water characteristics is a key factor to interpret comparisons of laboratory and field measured hydraulic properties (Basile et al., 2003).

The main objective of this investigation was to compare unconfined and confined measurements of unsaturated hydraulic conductivity for a relatively coarse-textured soil having an appreciable hysteretic behavior. The comparison was carried out for different sequences of imposed pressure heads with the aim of also establishing the relative ability of the two methods to detect hysteresis effects on the measured soil hydraulic conductivity.

2. Materials and methods

2.1. Field site

A 150-m^2 flat area was used for this study at the Faculty of Agriculture of the Palermo University. The study was conducted on a soil (Typic Rhodoxeralf) having a relatively high sand and gravel content. According to the USDA classification (Gee and Or, 2002) the soil texture of the upper 300 mm layer was sandy loam (Bagarello and Iovino, 2003).

2.2. Field measurements

Tension infiltrometer experiments were conducted at randomly selected locations by using an instrument manufactured by Soil Measurement System[1] (Tucson, AZ) consisting of separate water supply and base-plate units. At each location, the soil surface was carefully leveled and smoothed before the experiment and attempts were made to prevent infiltration surface smearing. A level was used to assure that the disc and the reservoir base were always at the same height (zero relative distance), so that the head between the bubbling outlet at the bottom of the water supply tube and the disc membrane was constant. A retaining ring with a radius of 120 mm and a nylon guard cloth having an air entry value of −160 mm were placed on the soil surface. To avoid formation of artificial pores due to ineffective contact with the soil surface, the nylon cloth guard was previously wetted and carefully spread on the soil surface. A contact layer having a thickness of 10 mm was prepared by using dry Spheriglass no. 2227 glass spheres (Potter Ballotini GmbH, Kirchheimbolanden, Germany[1]). Pressure heads imposed at the infiltrometer membrane were corrected to account for the thickness of the contact material layer (Reynolds and Zebchuk, 1996).

A total of twenty TI experiments were conducted in the summer months of 2002. Multipotential experiments were conducted by applying an ascending–descending sequence of pressure heads at the soil surface (i.e. a dry-to-wet-to-dry sequence, DTWTD). This experimental strategy was found to be appropriate to evaluate the effects of hysteresis on the soil hydraulic conductivity measured in the field with the TI (Bagarello et al., 2005). Two different DTWTD sequences were applied to also evaluate the effect of the highest pressure head, h_0 (L), value imposed within the descending pressure head sequence on the measured hydraulic conductivity. In particular, the following h_0 values were imposed in sequence without interruption in 10 sites (site A): −150, −75, −30, +5, −30, −75, −150 mm. The positive pressure head at the soil surface resulted from a −5 mm pressure head established on the infiltrometer membrane and the thickness (10 mm) of the contact material layer (Reynolds and Zebchuk, 1996). A small positive pressure head was used instead of $h_0=0$ to be reasonably sure that field-saturated conditions were established with the highest pressure head of the sequence (Logsdon et al., 1993). The following h_0 values were imposed in the other 10 sites (site B): −150, −75, −30, −10, −30, −75, −150 mm. The mean duration of the experiments for a given pressure head varied between a minimum of 22.3 min for $h_0=+5$ mm and a maximum of 59.8 min for $h_0=-150$ mm (wetting sequence). Water level readings were collected visually at 0.25- to 5-min intervals. Apparent steady-state infiltration rates were calculated from the

[1] Mention of a product does not constitute endorsement by the University of Palermo or by the authors.