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New method for monitoring soil water infiltration rates applied to a disc infiltrometer

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SUMMARY

Disc infiltrometers commonly use low-capacity water-supply reservoirs made of small diameter tubes. This reservoir geometry allows accurate measurements of water levels, but makes it necessary to stop the infiltration measurements to refill the water-supply reservoir when long-term infiltration experiments are conducted. The purpose of this study is to determine if a double Mariotte system provides accurate infiltration rate data from disc infiltrometer. To this end, infiltration rates (Q) is calculated from the head losses (ΔH_T) produced by the water flowing along a flexible silicone pipe that connects a high-capacity water-supply reservoir and the disc of the infiltrometer. The method was calibrated in the laboratory using 2- and 3-mm internal diameter (i.d.) and 50- and 100-cm-long silicone pipes by comparing the measured ΔH_T with the corresponding theoretical values, for different Q measured from the drop in water level in the water-supply reservoir. This method was next applied to field conditions, where the infiltration rates (at four supply pressure heads in five different soils) measured from the water-level drop in the water-supply reservoir of a double Mariotte disc infiltrometer (using 2- and 3-mm-i.d. and 100-cm-long silicone pipes) were compared with the corresponding values calculated from ΔH_T measured in the Mariotte tube. An excellent correlation was found in the laboratory experiment between the calculated and the measured ΔH_T ($r^2 = 0.99$), and between Q measured from the water-supply reservoir and that calculated from the measured ΔH_T ($r^2 = 0.99$). In the field experiments, excellent correlation was shown between the infiltration rates measured from the water-level drop in the water-supply reservoir and the corresponding values calculated from the ΔH_T measured in the Mariotte tube. This correspondence indicated that this method would be a consistent alternative to the standard procedure used in the disc infiltrometry technique.

Introduction

The disc infiltrometer (Perroux and White, 1988) has become a very popular instrument for estimations of soil hydraulic properties at the near-zero soil water pressure head. The relatively rapid and portable nature of this technique and its easy applicability in situ makes the disc infiltrometer a very valuable tool in many hydrological and soil science studies. Soil hydraulic properties such as hydraulic conductivity (K), sorptivity (S) (White et al., 1992), and the size and number of the soil's macro- and meso-water-conductive pores (Moret and Arrúe, 2007) are commonly calculated from the cumulative water-infiltration curves measured with the disc infiltrometer.

Typically, this instrument consists of three parts made of Plexiglass: a base disc covered by a nylon cloth, a graduated reservoir that provides the water-supply, and a bubble tower with a moveable air-entry tube that imposes the pressure head of the water at the cloth base (Angulo-Jaramillo et al., 2000). Commonly, the water-supply reservoir consists of a low-water-capacity clear plastic tube of small diameter, which makes it possible to reduce the infiltrometer weight on the soil surface, and allows for more accurate measurements of water-level changes in the tube. However, this reservoir geometry has the limitation that it results in interruptions of the infiltration measurements to refill the water-supply reservoir when long-term infiltration experiments (i.e. infiltration at successive supply pressure heads at the same sampling point) are performed.

Cumulative soil water-infiltration curves obtained with disc infiltrometers are commonly measured by visually noting, at constant intervals of time, the drop in water level in the water-supply reservoir. This method, however, is time-consuming and can lead to errors in water-level measurements due to reader distractions when long-time infiltration samplings are performed. This limitation was satisfactorily solved by Ankeny et al. (1988) and Casey and Derby (2002), who monitored drops in the water level by

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incorporating two gage transducers or a single differential transducer in the water-supply reservoir, respectively. Similarly, Moret et al. (2004) developed an automated method to measure the changes in water level in the water-supply reservoir by means of a long three-rod coated Time Domain Reflectometry (TDR) probe vertically inserted in the water-supply reservoir.

Other advances in disc infiltrometry technique have addressed new designs in which the disc has been separated from the water-supply reservoir and the bubble tower (Casey and Derby, 2002; Moret and Arrúe, 2005). This reduces the weight of the infiltrometer on the soil surface, reduces the risk of macrostructure collapse when applied on unstructured or freshly tilled soils (Moret and Arrúe, 2005) and consequently results in more accurate estimations of the actual soil hydraulic properties.

The objective of this study is to present an alternative procedure and experimental set-up for disc infiltrometry: a double Mariotte system method which makes it possible to calculate infiltration rates from the head losses produced by the water flowing along a flexible silicone pipe that connects a high-capacity water-supply reservoir and the disc of the infiltrometer. The method was calibrated in the laboratory using 2- and 3-mm internal diameter (i.d.) and 50- and 100-cm-long silicone pipes, and subsequently tested in five field experiments for measuring infiltration rates at different supply water pressure heads.

Theory

An incompressible fluid moving along a circular pipe can be described by the Bernoulli equation (Giles et al., 1994). When there is no energy input, this equation is

$$\frac{V_1^2}{2g}+\frac{P_1}{\gamma}+Z_1=\frac{V_2^2}{2g}+\frac{P_2}{\gamma}+Z_2+\Delta H_T \tag{1}$$

where V_i (m s^{-1}), Z_i (m) and P_i (kg m^{-1} s^{-2}) are the average flow velocity, the elevation in the direction of gravity from a reference level, and the pressure at point i, respectively. The g (m s^{-2}) parameter is the acceleration due to gravity; γ (kg m^{-2} s^{-2}) is the specific weight of the fluid, defined as density (kg m^{-3}) multiplied by g; and ΔH_T (m) is the total head losses produced by the friction of the fluid moving through the pipe. Considering two reservoirs connected with a pipe of length L and diameter D (Fig. 1), the head losses produced between points one and two, when the fluid flows from the right to the left reservoir, can be approached from Eq. (1) according to

$$\Delta H_T = h_B - h_{B'} \tag{2}$$

where h_i is the difference in height between the B and the B' points shown in Fig. 1.

The total head losses, ΔH_T, in the system can be calculated according to

$$\Delta H_T = \Delta H_C + \sum_{1}^{n} \Delta H_{s\_i} \tag{3}$$

where ΔH_C is the continuous head loss produced by the water flowing along the tube and ΔH_{s_i} is the singular head loss which corresponds to the head losses produced by necks or constrictions in the pipes, or by other singularities.

The ΔH_C is described by the Darcy–Weisbach (Giles et al., 1994) equation according to

$$\Delta H_C = f\left(\mathrm{Re},\frac{\varepsilon}{D}\right)\cdot\frac{L}{D}\cdot\frac{V^2}{2g} \tag{4}$$

where f is the friction coefficient, ε is the pipe roughness (m), D is the pipe diameter (m), L is the pipe length (m) and Re is the Reynolds number defined as

$$\mathrm{Re} = \frac{VD}{\nu} \tag{5}$$

where ν is the kinematic viscosity (m^2 s^{-1}) of the fluid. The relationship between the water temperature, t (°C), and the kinematic viscosity of water can be described according to the empirical equation (r^2 = 0.99) obtained from the table in Giles et al. (1994) for the usual values of t,

$$\nu = 6.95\times10^{-10}t^2 - 5.31\times10^{-8}t + 1.78\cdot10^{-6} \tag{6}$$

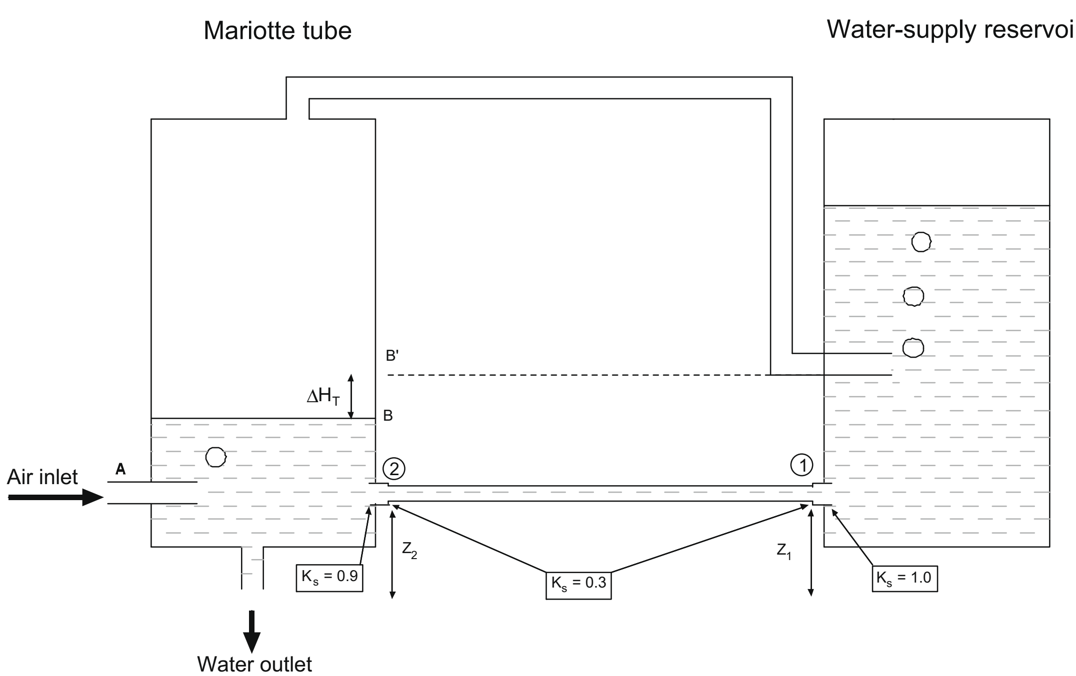

Fig. 1. Schematic diagram of the double Mariotte system used in the laboratory experiment to calibrate the water head losses produced by the different silicone pipes shown in Table 1.