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A modified hood infiltrometer to estimate the soil hydraulic properties from the transient water flow measurements

D. Moret-Fernández [a,*], C. González-Cebollada [b], B. Latorre [a], V. Pérez [a]

[a] Departamento de Suelo y Agua, Estación Experimental de Aula Dei, Consejo Superior de Investigaciones Científicas (CSIC), PO Box 13034, 50080 Zaragoza, Spain
[b] Área de Mecánica de Fluidos, Escuela Politécnica Superior de Huesca, Universidad de Zaragoza, Carretera de Cuarte s/n, 22071 Huesca, Spain

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SUMMARY

In-situ measurements of soil hydraulic properties on covered soil surfaces (i.e. vegetated or residue covered surfaces) are of paramount importance in many agronomic or hydrological researches. These soil parameters are commonly estimated with the tension infiltrometry technique. This paper presents a portable and modified design of the hood infiltrometer (MHI) that, unlike to the original hood infiltrometer, allows estimating the soil hydraulic properties from the transient cumulative infiltration curve. The MHI consists of a water-supply reservoir attaches to a hat-shaped base placed on the soil surface. The base of the hat is closed by a system of sticks and a malleable material ring. To test the viability of this new design, the hydraulic conductivity (K_s) estimated with MHI in a loam soil using the multiple head approach was compared to the corresponding values calculated from the transient infiltration curve analysis. Next, the MHI was tested on three different soils at saturated conditions, and the sorptivity (S) and K_s estimated by the transient infiltration curve analysis were compared to the corresponding values obtained with a disc infiltrometer (DI). An additional field experiment was performed to compare the hydraulic properties measured with MHI on a bare soil and a soil covered with plants. Results demonstrated that this design allows hermetically closing the base of the hat without disturbing the soil surface. The K_s estimated with the multiple head approach was not statistically different ($p = 0.61$) to that obtained with the transient infiltration curve analysis. No significant differences between the K_s ($p = 0.66$) and S ($p = 0.50$) values estimated with DI and MHI were observed. The S values measured with MHI on the covered soil surface were significantly higher than that measured on the adjacent bare soil. These results indicate that MHI can be a viable alternative to estimate the hydraulic properties of covered soils from the measured transient infiltration curve.

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1. Introduction

Measurements of the sorptivity (S) and hydraulic conductivity (K) on undisturbed soil surface is crucial to solve many hydrological engineering and environmental issues linked to soil water storage and transport in the vadose zone. The tension disc infiltrometer (Perroux and White, 1988) and later the hood infiltrometer (Schwärzel and Punzel, 2007) have become popular infiltration methods because of the relatively rapid and portable nature of this technique, its easy in-situ applicability, and its ability to measure at unsaturated soil conditions (Angulo-Jaramillo et al., 2000). The disc infiltrometer consists of a disc base attached to a graduated water-supply reservoir and a bubbling tower to impose a negative pressure head (h) at the disc base (Perroux and White, 1988). The hood infiltrometer, which can measure on covered soil surface, is a similar instrument where the disc base has been replace the by a side down hood.

The soil hydraulic properties are commonly calculated from the cumulative water-infiltration curves, which are measured from the drop in the water level of the reservoir tower. So far, several methods to estimate the soil hydraulic properties have been proposed: (i) methods based on the Wooding (1968) equation, which uses steady-state data (Ankeny et al., 1991; Reynolds and Elrick, 1991), (ii) methods based on the transient state data (Latorre et al., 2015) and (iii) methods which combine both transient and steady states, like BEST methods (Lassabatere et al., 2006; Yilmaz et al., 2010) The main advantages of the transient water flow procedure is that it requires shorter experiments, which involves smaller sampled soil volumes and more homogeneous initial water distribution (Angulo-Jaramillo et al., 2000).

* Corresponding author. Tel.: +34 976 716140; fax: +34 976 716145.
E-mail address: david@eead.csic.es (D. Moret-Fernández).

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The disc base of the infiltrometer, whose diameter ranges from 25 cm (Perroux and White, 1988) to 3.2 cm (Madsen and Chandler, 2007), is usually covered with a tightened nylon cloth of very small mesh. The base should be completely in contact with the soil surface to accomplish correct infiltration measurements. To achieve this contact, Perroux and White (1988) recommended trimming any vegetation within the sample to ground level and cover the soil with a material (i.e. sand layer) of high hydraulic conductivity. However, according to Reynolds (2006), the contact sand layer introduces an offset between the pressure head set on the bubbling tower and the pressure head applied to the soil surface. This offset should be corrected to prevent the introduction of systematic biases in infiltration results (Reynolds, 2006). These limitations were partially solved by Moret-Fernández et al. (2013), who developed an alternative disc base with a malleable membrane (MDB) that allowed excellent soil surface contact without using a contact sand layer. However, this membrane base prevents infiltration measurements on abrupt surfaces or soils covered with plants or crop residues. This problem was solved by UGT (Müncheberg, Germany), who developed a tension infiltrometer where the disc base was replaced by an acrylic (12.4 cm in diameter) hood. The hood is placed open side down onto the soil, within a retaining ring inserted into the soil, and the water-filled hood is directly in contact to the soil surface. Schwärzel and Punzel (2007) compared this new design with the conventional disc infiltrometer that uses a contact sand layer and observed that the hydraulic conductivities measured with this alternative design were 10 times higher than that measured with the disc infiltrometer. Although this system allows infiltration measurements on covered soils, the slow filling of the hood during the first infiltration times prevents estimating the soil hydraulic properties by using the transient water flow method. In this case, the multiple head approach, which is more time consuming, should be used. On the other hand, the retaining ring used to close the hood, which is slightly inserted into the soil, may create preferential infiltration channels that distort the infiltration measurements.

The objective of this paper is to present a modified hood infiltrometer, MHI, to estimate the soil sorptivity and hydraulic conductivity on covered soil surfaces. Unlike to the original hood infiltrometer, which employs the multiple head approach, this new prototype allows recording and using the transient infiltration curve to estimate the soil hydraulic properties. Because of the multiple head approach has been satisfactorily applied on the hood infiltrometer, this work will be mainly focused on the transient infiltration flow method. To validate this new prototype, the soil hydraulic properties estimated with the MHI in three different uncovered soil surfaces were compared with those estimated with a conventional disc infiltrometer, which, similarly to MHI, also allows estimating the soil hydraulic properties from transient water flow measurements. In a second step, the MHI was tested on a covered soil. To this end, the soil hydraulic properties measured on covered surfaces were compared with those obtained in the adjacent uncovered soil.

2. Material and methods

2.1. Infiltrometer design

Similar to the disc infiltrometer (DI), the modified hood infiltrometer (MHI) consists of a hat-shaped base attached at the top to a water-supply reservoir and a bubbling tower that imposes a negative pressure head (h) at the hat base (Fig. 1a and b). The hat base is a cylindrical acrylic tube (10 cm internal diameter – i.d.; 10 cm height) attached at the base to a metallic flat ring (3 mm thickness and 10 and 15 cm internal and external diameter, respectively), and closed at top by an acrylic lid. Three 1.5-mm deep holes are equidistantly made on the metallic ring, at 2.5 cm from the external diameter. The water reservoir consists of a 5 cm i.d. and 55 cm long acrylic tube. A vertical acrylic tube, that vertically traverses the hat, is connected to the water reservoir through a ball valve (Fig. 1). This vertical tube, which is placed at 1.5 cm from the soil surface, contents a 3 mm i.d. plastic pipe (*air inlet tube*) that is connected to a bubbling tower. A 8 mm i.d. silicone tube (*air flow tube*) connects the top of the water reservoir tube to the top of the hat (Fig. 1). This tube is closed by an air flow plastic stopcock. To check the pressure head on the soil surface a water manometer is inserted at the top of the hat. Finally, a ±0.5 psi differential pressure transducer (PT) (Microswitch, Honeywell), connected to a datalogger (CR1000, Campbell Scientist Inc.), is installed at the bottom of the water-supply reservoir (Casey and Derby, 2002). Previous laboratory experiments demonstrated the accuracy of PT for water level measurements was ±0.27 mm. The base of the hat is closed by compressing the MHI base against the soil surface. To this end, a three detachable sticks system is used (Fig. 1b).

2.2. Infiltrometer setup

Installation of modified hood infiltrometer needed the following steps. Firstly, a 10 cm diameter piece of cloth is placed on the soil surface to be measured. This prevents the soil surface disturbance during the hat water-filling. A malleable material (Plasticine®) ring (11-cm i.d. and 1.5 cm thickness) is pasted under the hat, and the hat plus the malleable material ring are placed on the soil surface, making sure the 10-cm diameter cloth rested within the hat. Three arm-sticks (30-cm length and 2-cm thickness) (Fig. 1b), which are welded to a perforated iron metallic head, are equidistantly and perpendicularly placed against the metallic ring perimeter. A 25 cm long screw is screwed at the end of the arm, resting the ends of the screws on the corresponding metallic ring holes. Three sticks (40-cm length and 2-cm thick) are introduced in the corresponding perforated iron heads (Fig. 1) and subsequently are driven into the soil down to 30-cm depth. The iron heads are blocked and the hat base plus the malleable material is compressed against the soil surface by screwing the arm-stick screws against the hat base (Fig. 1). The strong pressure on the metallic ring, which squashes the malleable material against the soil surface, hermetically closes the base of the hat. In order to obtain sealing of the hat, the screws of the arm-sticks should be progressively and alternatively screwed.

Once the MHI base is installed, the bubbling tower is connected to the MHI *air inlet tube* (Fig. 1) and the water-supply reservoir is assembled on the hat. Next, the *air flow tube* is connected and the corresponding stopcock opened. The ball valve for water flow is turned off and the water reservoir is filled with water. Finally, the pressure transducer is connected to the data logger. Saturated infiltration measurements require that the pressure head inside the bubbling tower is equal to the distance between the soil surface and the end of the *air outlet tube* (Fig. 1). Thus, the pressure head measured with the water manometer (h_M) is

$$h_M = h_{BT} + h_{WL} \tag{1}$$

where h_{BT} is the pressure head supplied by bubble tower and h_{WL} the water level inside the hat (Fig. 1). To start the infiltration measurements, the ball valve for water flow is turned on and the plastic stopcock for air flow is kept opened until the water level inside the hat reaches 2–4 cm height. This mechanism allows the air flows from the hat to the water reservoir, as the hat is filled with water. Once the plastic stopcock is closed, the air for water infiltration is immediately supplied from the bubble tower.

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