Geoderma 262 (2016) 20–34

Contents lists available at ScienceDirect

Geoderma

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

Testing a new automated single ring infiltrometer for Beerkan infiltration experiments

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ARTICLE INFO

Article history:
Received 23 January 2015
Received in revised form 4 August 2015
Accepted 5 August 2015
Available online 15 August 2015

Keywords:
Automated single-ring infiltrometer
BEST (Beerkan Estimation of Soil Transfer parameters) procedure
Soil hydraulic properties

ABSTRACT

The Beerkan method along with BEST algorithms is an alternative technique to conventional laboratory or field measurements for rapid and low-cost estimation of soil hydraulic properties. The Beerkan method is simple to conduct but requires an operator to repeatedly pour known volumes of water through a ring positioned at the soil surface. A cheap infiltrometer equipped with a data acquisition system was recently designed to automate Beerkan infiltration experiments. In this paper, the current prototype of the automated infiltrometer was tested to validate its applicability to the Beerkan infiltration experiment under several experimental circumstances. In addition, the accuracy of the estimated saturated soil hydraulic conductivity, K_s, and sorptivity, S, was assessed by applying different BEST algorithms to the data obtained with the infiltrometer. At this purpose, both analytically generated and real experimental data were used. The analytical assessment showed that the use of the infiltrometer along with BEST methods could lead to accurate estimates of the considered soil properties in most cases, which validated the design of the infiltrometer and its combination with BEST algorithms. Loamy soils and high initial water contents led to misestimating K_s and S or to failure of BEST algorithms, but advices about the infiltrometer design were developed to alleviate such problems. A comparison between the automated procedure and the original BEST procedure was made at three field sites in Sicily (Italy). Other experiments were carried out in an infiltration basin located in the pumping well field of Crépieux-Charmy (Lyon, France), in order to assess the ability of the automated infiltrometer to check clogging effects on K_s. The experiments showed that the automatic data collection increased measurement speed, allowed a more efficient data handling and analysis, and reduced sensitivity of the calculated hydraulic parameters on the applied BEST algorithm.

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1. Introduction

The saturated soil hydraulic conductivity, K_s, and the soil sorptivity, S, are important soil properties controlling water infiltration and movement into the unsaturated soil profile. Saturated hydraulic conductivity depends strongly on soil texture and structure whereas sorptivity also depends on the initial and final soil water contents and, when present, the water depth at soil surface (Touma et al., 2007). Both soil hydraulic properties thus exhibit strong spatial and temporal variations and a large number of determinations are required to assess the magnitude of the variation within the selected area (Logsdon and Jaynes, 1996). Assessment of simple and rapid field techniques is therefore important to obtain reliable data with a sustainable effort.

The Beerkan Estimation of Soil Transfer (BEST) parameters procedure by Lassabatere et al. (2006) is very attractive for practical use since it allows an estimation of both the soil water retention and the hydraulic conductivity functions from cumulative infiltration collected during a ponded field experiment and a few routinely laboratory determinations. Lassabatere et al. (2006) suggested to measure the infiltration time of small volumes of water repeatedly poured on the soil surface confined by a ring inserted to a depth of about 1 cm into the soil. BEST considers a zero ponded infiltration model which was assumed to be appropriate for an infiltration run performed with small, but positive, pressure heads. This assumption was supported by numerical tests carried out by Touma et al. (2007). Yet, several problems arise with this method, including (i) the need for an operator over the whole duration of the experiment; (ii) the need to reach steady state infiltration, which can be extremely long in certain cases; and (iii) the experimental error in the measured infiltration times and the variable skillness among operators. Moreover several algorithms were developed to analyze the infiltration data, i.e., BEST-slope (Lassabatere et al., 2006), BEST-intercept (Yilmaz et al., 2010) and BEST-steady (Bagarello et al., 2014b), but the relative performance of the alternative algorithms has not yet been tested.

Automatic data collection increases measurement speed, permits measurement at short time intervals, improves measurement precision, allows for more efficient data handling and analysis, and reduces the amount of effort involved and the potential for errors that may occur when manual procedures are applied (Madsen and Chandler, 2007; Dohnal et al., 2010). Nevertheless, the advantages

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http://dx.doi.org/10.1016/j.geoderma.2015.08.006
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of simplified methodologies, such as BEST, are their simplicity and cheapness. The use of expensive devices or time consuming procedures contradicts the original purpose of these simplified methodologies and monitoring equipment often contains proprietary technology with prohibitive cost. Yet, rapid advances in electronic technologies have allowed researchers and practitioners access to low-cost, solid-state sensors and programmable microcontroller-based circuits (Fisher and Gould, 2012).

Recently, Di Prima (submitted for publication) developed a method to automate data collection with a compact infiltrometer under constant head conditions. The device, maintaining a small quasi-constant head of water (i.e., 2–3 mm) on the infiltration surface, is equipped with a differential pressure transducer to measure the stepwise drop of water level in the reservoir, and, in turn, to quantify cumulative infiltration into the soil. The data acquisition system has been designed with low cost components and it is based on the open source microcontroller platform, Arduino. Total measurable cumulative infiltration and the increment between two successive experimental points are fixed, since they depend on the capacity of the Mariotte reservoir and the radius of air entry tube, respectively. The very limited cost of the system could represent a step towards a cheaper and more widespread application of accurate and automated infiltration rate measurement. However, the current version of the infiltrometer has not been tested yet against a wide range of experimental conditions in terms of soils and initial water contents.

The main objective of this paper was to check the usability of the device to automatize the Beerkan infiltration experiment and to analyze the infiltration data to characterize soil hydraulic properties. The focus is put on the derivation of saturated soil hydraulic conductivity and soil sorptivity by using the combination of the automated infiltrometer and the three BEST algorithms. The proposed combination is assessed by using both analytically generated and field data and with regard to reliable predictions of the saturated soil hydraulic conductivity and soil sorptivity.

2. Automated infiltrometer along with BEST method for estimating hydraulic parameters

2.1. Automated infiltrometer

The automatic infiltrometer by Di Prima (submitted for publication) (Fig. 1) allows to maintain a small constant water head on a soil surface confined by a 150 mm inner diameter ring using a Mariotte bottle for water supply. Depending on the surface roughness, the Mariotte bottle can be regulated in height so that the surface confined by the ring is entirely submerged under a practically negligible water depth, i.e., 2–3 mm. The bottle has an inner diameter of 94 mm and a height of 520 mm, allowing to store a maximum volume of water corresponding to a total cumulative infiltration of 130 mm. An air entry tube with a 6.5 mm inner diameter controls the level inside the ring by allowing air entry at very close distance from the reservoir base. To minimize disturbance on the soil surface and to have an accurate data acquisition from the beginning of the run, the water head is initially applied to a fine plastic film positioned on the surface inside the ring. Then, after that water is discharged from a base outlet of 26 mm in diameter, through lifting a piston, the data acquisition can be started. The infiltration starts when the plastic film is removed. When the water level in the ring goes down, the Mariotte bottle provides a certain amount of water to the ring. At this moment, some bubbles can be seen through the bottle from the air entry tube. Avoiding the direct detachment of the bubbles from the bottom outlet allows to minimize turbulence which could affect the soil surface. A specific tripod designed for the reservoir allows to pose the infiltrometer very close to the surface and hence to maintain a small water during the infiltration process.

The core of the data acquisition system consists of a microcontroller board, a shield with an onboard micro-SD card slot, a LCD display and a differential pressure transducer. The voltage output from the transducer is linearly related to the difference between head-space tension and the height of water in the Mariotte reservoir (Constantz and Murphy, 1987). Automated measurements of reservoir water levels using a differential transducer were first tested by Casey and Derby (2002). This improvement makes it easy to obtain early infiltration rate measurements and increases the accuracy of the measured steady flow rate. The differential pressure transducer is connected by small tubes to head-space of the reservoir and to a tube (inside diam. = 6.5 mm, length = 400 mm) descending inside the reservoir so that the pressure difference between the head-space and the bottom of the column of water can be measured. The sensor used for this application is the piezoresistive differential pressure transducer MPXV5004DP from Freescale Semiconductor requiring a power supply of 5 V and with integrated temperature compensation and signal amplification circuit. The transducer provides a linear voltage output for a differential pressure range from 0 to 400 mm H_2O. The data are collected at a rate of 5 s^{-1} and stored on a SD card for later retrieval and simultaneously displayed on a LCD display. The software generates a new comma-separated values (CSV) file every time that the microcontroller is alimented. The name of the generated file can be displayed on the LCD for the first few seconds.

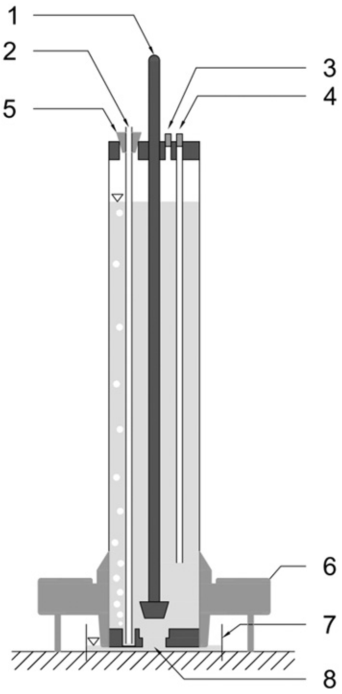

Fig. 1. Schematic diagram of the automated single-ring infiltrometer: 1) piston; 2) air entry tube; 3) connector for vacuum side of the pressure sensor; 4) connector for pressure side of the pressure sensor; 5) rubber; 6) tripod; 7) water containment ring and 8) outlet.

According to the procedure described by Di Prima (submitted for publication), when the water level in the cylinder goes down, the Mariotte bottle provides a certain amount of water into the ring corresponding to 5 mm increments ($\Delta I \approx 5$ mm). Water supply is signaled by a sudden rise of air bubbles from the air entry tube that causes a disturbance in pressure transducer measurement, leading to outliers which can easily be identified and eliminated (Ankeny et al., 1988). Between two consecutive water supplies, the height of water in the reservoir remains constant which results in a step-shaped water level vs. time relationship. The cumulative infiltration curve is deduced by sampling the water levels at time immediately preceding each bubble detachment. At this time, the previous volume poured inside the ring has completely infiltrated but the subsequent volume is not still supplied, thus automatically mimicking the procedure that is followed when executing manually a Beerkan experiment. This procedure cannot

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