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Automated single ring infiltrometer with a low-cost microcontroller circuit

S. Di Prima *

Dipartimento di Scienze Agrarie e Forestali, Università degli Studi di Palermo, Viale delle Scienze 90128, Palermo, Italy

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ABSTRACT

A method to automate data collection with a compact infiltrometer under constant head conditions was developed. The infiltrometer consists of a containment ring with a small quasi-constant head of water (i.e., 2–3 mm) that is controlled by a Mariotte reservoir and a data acquisition system based on the open source microcontroller platform Arduino and a differential pressure transducer. The presented design can be easily reproduced and operated.

The infiltrometer was tested in a citrus orchard on a sandy loam soil. A simple methodology was applied for accurate data acquisition from the initial stage of the process and to minimize the disturbance of the soil surface. A new approach to process the data was proposed for determining an accurate cumulative infiltration curve from transducer output. The BEST algorithm by Lassabatère et al. (2006) was applied to determine the hydraulic properties of the soil. A comparison between the automated procedure and the original BEST procedure was made.

Automatic data collection increases measurement speed, permits measurement at shorter time intervals, improves measurement precision, and allows for more efficient data handling and analysis. The proposed electronic data acquisition system based on the open source Arduino board has proved to be accurate and reliable, constituting a very cost effective alternative to previous proposed equipment. The very limited cost could represent a step toward a cheaper and widespread application of accurate and automated infiltration rate measurement. This infiltrometer could be used for situations where a large number of readings need to be collected.

1. Introduction

The hydraulic conductivity of saturated soil is one of the most important soil properties controlling water infiltration and surface runoff, leaching of pesticides from agricultural lands, and migration of pollutants from contaminated sites to the ground water (Reynolds et al., 2000). Saturated hydraulic conductivity depends strongly on soil texture and structure, and therefore can vary widely in space. Since hydraulic conductivity is determined essentially at points on a field scale, a large number of determinations is required to assess the magnitude and structure of the variation within the selected area (Logsdon and Jaynes, 1996). Spatially distributed determinations of hydraulic conductivity have to be repeated at different times, particularly in soils where structure varies over time because of natural or anthropogenic factors (Prieksat et al., 1994). For structured soils in particular, saturated hydraulic conductivity has to be measured directly in the field to minimize disturbance of the sampled soil volume and to maintain its functional connection with the surrounding soil (Bouma, 1982). Reliable field data should be collected with a reasonably simple and rapid experiment.

Haverkamp et al. (1996) pioneered a method, termed as the "Beerkan method", that allows for simultaneous characterization of both the soil water retention curve and the hydraulic conductivity function. An improved version of this methodology, called the Beerkan Estimation of Soil Transfer parameters (BEST) procedure, was developed by Lassabatère et al. (2006) to simplify soil hydraulic characterization. With BEST procedure, cumulative infiltration data have to be collected. Lassabatère 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 considered a zero ponded infiltration model which was assumed respected under infiltration run performed with small, but positive, pressure head. This assumption was supported by numerical tests carried out by Touma et al. (2007). According to Alagna et al. (2015) and Bagarello et al. (2014a,b), the infiltration experiment prescribed by Lassabatère

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* Tel.: +39 091 23897065.
E-mail address: simone.diprima@unipa.it

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et al. (2006) can be sensitive to soil disturbance and air entrapment during repeated water application. These alterations were expected to have a more appreciable impact on the measured conductivity with the BEST technique than a ponding infiltration experiment since a constant ponded depth of water was maintained during the run with the latter technique whereas the water is repeatedly poured with the former one. Moreover, several problems yet arise with BEST method, including (1) the need for an operator over the whole duration of the experiment; (2) the need to reach steady state infiltration, which can be extremely long in certain cases; and (3) the experimental error and the variable skillness among operators. Therefore, since reliable field data should be collected with a reasonably simple and rapid experiment, and a ponding infiltration test is expected to minimize soil disturbance, the use of a single-ring infiltrometer along with BEST algorithm could be advisable. Different single-ring infiltrometers were developed (e.g., Prieksat et al., 1992; Matula and Kozáková, 1997). These infiltrometers maintain a quasi-constant head in a containment ring, allowing to calculate flow rates from changes in water height in a Mariotte reservoir with time. Automated measurements of reservoir water levels using a differential transducer were first tested by Casey and Derby (2002). 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). Nevertheless, the advantages of simplified methodologies, such as BEST, are their simplicity and cheapness (Madsen and Chandler, 2007; Dohnal et al., 2010). The use of expensive devices or time consuming procedures could contradict their original purpose. In fact, automatic data collection increases measurement speed and improves measurement precision but monitoring equipment often contains proprietary technology with prohibitive cost for this purpose. Recently, advances in electronic technologies have provided researchers to access to low-cost, solid-state sensors and programmable microcontroller-based circuits (Fisher and Gould, 2012). In this work, it is presented a compact automated infiltrometer (Fig. 1) which consists of a containment ring with a small quasi-constant head of water (i.e., 2–3 mm) that is controlled by a Mariotte reservoir and a data acquisition system based on the open source microcontroller platform Arduino (protected trademark of Arduino LLC).

Fig. 1. Single ring infiltrometer and data acquisition system.

The infiltrometer was tested in a citrus orchard on a sandy loam soil. The BEST algorithm by Lassabatère et al. (2006) was applied to determine the hydraulic properties of the soil using a total of ten infiltration experiments performed using both the proposed infiltrometer and the BEST procedure. A comparison between the automated procedure and the original BEST procedure was made.

2. Materials and methods

2.1. The Mariotte reservoir

The automatic infiltrometer 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. A schematic diagram of the infiltrometer is reported in Fig. 2. The bottle consists of a transparent cylinder with an inner diameter of 94 mm, a height of 520 mm and a base outlet of 26 mm. Allowing to store a maximum volume of water corresponding to a total cumulative infiltration of 130 mm (i.e., 2.3 L). An air entry tube (6.5 mm inner diameter) controls the level inside the ring by allowing air entry at very close distance from the reservoir base. Detailed scheme of all components can be consulted in Appendix A.

A standard practice to minimize the impact of the water application procedure on the saturated soil hydraulic conductivity values measured by a ponding infiltration experiment has not been established, although several suggestions have been formulated to minimize this impact, including slowly raising the piston of

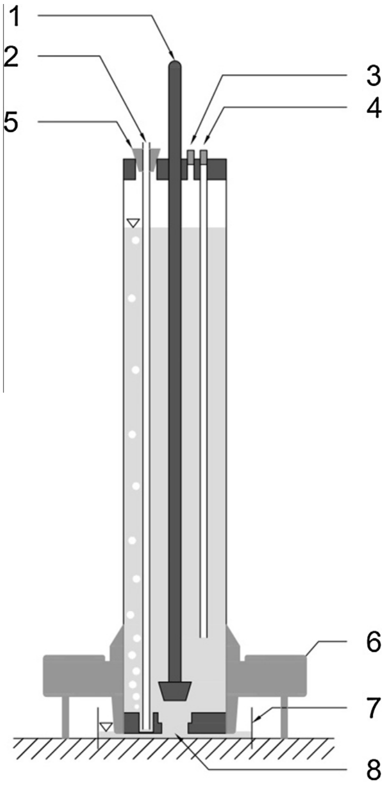

Fig. 2. Schematic diagram of the single-ring infiltrometer. (1) Piston; (2) air entry tube; (3) connector for vacuum side of the pressure sensor; (4) connector for pressure side of the pressure sensor; (5) rubber; (6) tripod; (7) water containment ring and (8) outlet.