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Comparison of devices for measuring soil matric potential and effects on soil hydraulic functions and related parameters

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ABSTRACT

The tensiometer represents an excellent instrument for measuring in situ soil water status. However, measuring soil matric potential requires a tensiometer reading system sensitive enough to accurately record the matric potential. Hence, an instantaneous profile-type experiment was conducted in the field, to measure the soil matric potentials within a moisture range from saturation to field capacity. After that, matric potential, soil moisture, total potential gradient, flow density and hydraulic conductivity were calculated and van Genuchten equation parameters were estimated through inverse modeling. This study aimed to test the Bourdon pressure gauge and digital tensiometer compared with the mercury manometer to measure the soil matric potential and to examine the differences related to the estimations of soil water content and to the associated variables. In addition, the study also aimed to evaluate soil hydraulic parameters by inverse modeling, based on the matric potentials from each reading system. Bourdon pressure gauge replaces the Hg manometer in the measurement of soil water matric potential within the moisture range from saturation to field capacity; The use of digital tensiometer and Bourdon pressure gauge reduced hydraulic conductivity by four and three times and flow density by approximately three and two times, respectively, at 6 kPa tension and, therefore, are not recommended for the estimation of these hydraulic parameters; Regardless of reading system used in the tensiometer, inverse modeling estimates well van Genuchten equation parameters and, consequently, soil water matric potential.

1. Introduction

Accurate evaluations of soil water status at different spatial and temporal scales is still a challenging task, that has stimulated past and present research (Rallo et al., 2018). The range of measurement, accuracy, repeatability, response time and spatial resolution of specific sensors are important considerations for applications and analyses of soil water measurements (Or and Wraith, 2002).

Tensiometry, despite requiring extensive maintenance and being limited to relatively wet conditions, since it only measures until approximately 0.09 MPa, is an accurate technique widely used to determine soil matric potential (Durner and Or, 2005). For that, the tensiometer has presented itself as an excellent instrument, for directly measuring soil water energy and allowing in-situ measurements, with sensitivity and accuracy of the results dependent on the type of manometer used.

Using the tensiometer to measure soil water matric potential is frequently preferred over other types of soil moisture sensors due to its low cost, easy use, high measurement accuracy and possibility of electronic data acquisition through differential pressure transducers, besides being a non-destructive technique (Zazueta and Xin, 1994), with possibility of providing continuous moisture measurements without causing alteration in the soil (Wallhan, 1939).

Since variables such as hydraulic conductivity have the highest values when the soil is saturated and, consequently, the highest flows through internal drainage occur at soil water contents close to saturation, a good tensiometer reading system must be sensitive enough to accurately record soil matric potentials. Obviously, errors associated to

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each reading system are propagated at higher or lower intensity in the estimates of other soil variables depending on soil matric potential.

The simplest tensiometers is represented by a mercury (Hg) manometer. This system is considered the most sensitive and accurate, besides providing direct reading, which causes it to be taken as a standard to assess other models, but there is the disadvantage that Hg is toxic to humans and poses risk of environmental contamination.

Another measuring system, the pressure gauge, although it had been patented in France, in the XIX century, by the engineer Eugene Bourdon (Çengel and Boles, 2006), comparatively to mercury (Hg) manometer has recently been applied in tensiometers for use in agriculture. According to Brito et al. (2009), in the determination of hydraulic conductivity through the instantaneous profile method, experience has shown that the Bourdon pressure gauge, with the same full scale used in the present study, does not allow detailed assessment of matric potential variation over time, especially in the first hours of redistribution, which correspond to the conditions of higher water content in the soil..

Another alternative to the use of mercury was the introduction of digital tensiometers which use a pressure transducer (Marthaler et al., 1983) as sensitive element to transmit a signal corresponding to the tension at the moment of reading, which suggests a previous calibration of the device. This signal is also digitally shown on the instrument's display. Marthaler et al. (1983) point out a delay in the equilibrium between the water tension inside the tensiometer and the water tension in the soil.

Over time other reading systems have been introduced in the market, aimed at measuring matric potential in an easier, faster and more accurate way, and with capacity for measurements in a wide range of soil water potentials. However, each of these alternative systems has disadvantages, which reduce their use, depending on the conditions. The high cost of acquisition and the need for specialized labor are some of the factors which restrict their use in the field, making them limited to research.

In this context, the study assumed that hypothesis that the reading systems Bourdon pressure gauge and tensiometer with pressure transducer, for the measurement of soil water matric potential, due to their respective operating mechanisms, produce errors that propagate to soil hydraulic functions and related parameters in comparison to the traditional mercury manometers.

Therefore, objective of this study was the assessment of two different devices to monitor soil matric potential, alternative to the mercury manometer, and to evaluate the effects of the precision readings on soil hydraulic functions and related parameters.

2. Material and methods

2.1. Experimental layout

The experiment was carried out in an Argissolo Amarelo (Empresa Brasileira de Pesquisa Agropecuária - EMBRAPA, 2013) and tensiometers were installed in a circular experimental plot, with diameter of 3 m and depth of 0.6 m, following the procedures for hydraulic conductivity determination through the instantaneous profile method (Fig. 1). The soil volume was delimited on the sides by a plastic canvas, to avoid lateral subsurface flows. Hence, to meet the method's boundary conditions, water flow in the center of the plot was guaranteed to occur only in the vertical direction (Hillel et al., 1972).

Undisturbed and disturbed soil samples were collected in the experimental plots for soil physical characterization. Disturbed samples were used to determine soil particle density by the volumetric flask method (Blake and Hartge, 1986a), whereas undisturbed samples, collected using an Uhland soil sampler, in 0.05-m-high steel rings with a diameter of 0.05 m, were used to determine soil water retention curve (SWRC)and soil bulk density (Blake and Hartge, 1986b).

In the determination of SWRC, the water content at saturation was considered as equal to total soil porosity (calculated with the values of soil bulk and particle densities). For low-tension points (0.002; 0.004; 0.006; 0.008 and 0.01 MPa), water content was determined by using Haines' funnel (Haines, 1930), whereas the other points (0.033; 0.1; 0.7; and 1.5 MPa) were determined in Richards' porous plate apparatus (Klute, 1986). The curve was fitted according to the statistical model proposed by van Genuchten (1980). The equation parameters for each soil layer were obtained using the software RETC (van Genuchten et al., 1991), by assuming the dependence between m and n ($m = 1 - 1/n$).

2.2. Construction and installation of tensiometers

Tensiometers were made using rigid PVC pipes with external and internal diameters of 0.021 and 0.016 m, respectively, and length corresponding to the installation depth plus 0.55 m above soil surface (0.20 m of PVC and 0.35 m of transparent acrylic tube). The same instrument was equipped with the three reading systems, so that all of them were subjected to the same conditions.

Nylon tubing (0.002-m internal diameter) glued to the PVC pipe (Fig. 2) was used to connect the tensiometer to the Hg container. The Bourdon pressure gauge had 760 mmHg full scale, with divisions of 20 mmHg. For measurements with the digital tensiometer, the acrylic tubes were sealed using a silicon stopper. The acrylic tube was covered by a PVC cap to avoid direct sunlight, which would lead to differential dilation and, consequently, leaks through the stopper-acrylic tube interface. Because of the way the tensiometer was built (containing three reading systems in only one instrument) and the sequence in which the readings were taken, the systems are independent and do not interfere with one another.

After confirming perfect operation in the laboratory, the tensiometers were installed in the field at soil profile depths of 0.20, 0.35 and 0.50 m, with six replicates, totaling 18 devices. After the procedure of wetting until saturation, the plot was covered by a plastic canvas to avoid any water flow through the surface, also to meet the boundary conditions of the instantaneous profile method (Libardi et al., 1980). Readings in the system were taken daily at 07:00 a.m.

To avoid modifications in the equilibrium established between the air chamber, located in the upper portion of the tensiometer, water in the tensiometer and water in the soil, readings were taken first in the Hg manometer and then in the Bourdon pressure gauge and digital tensiometer. At 0.35 m depth, after assuming that drainage was negligible, i.e., when the soil reached field capacity, the experiment ended. Such condition was assumed when soil moisture variation rate over time, $d\theta/dt$, was $\leq$ 0.001 $cm^3\,cm^{-3}\,d^{-1}$, Fig. 3 (Nascimento et al., 2018).

2.3. Processing of readings

Data of tensiometers with Hg manometer were obtained by measuring the Hg column height in the nylon tubing. For the Bourdon pressure gauge, readings were directly taken on the instrument's display and, for the digital tensiometer with pressure transducer, data were obtained by connecting the sensor to the air chamber using a needle to transfer the tension to the measuring device. The errors of the Hg manometer, Bourdon pressure gauge and digital tensiometer were 1, 20 and 0.076 mmHg, respectively. Subsequently, the readings were converted to matric potential (φ_m, m) through the following equations:

$$\phi m_{Hg} = -12.6 \times h_{Hg} + h_c + z \tag{1}$$

$$\phi m_{Bg} = -(L \times 0.0136) - h_v + h_c + z \tag{2}$$

$$\phi m_{Dt} = -(L_d \times 0.0136) + h_e + z \tag{3}$$

where ϕm_{Hg}, ϕm_{Bg} and ϕm_{Dt} are the matric potential for Hg manometer, Bourdon pressure gauge and digital tensiometer, respectively; h_{Hg} is the Hg column height, h_c is the Hg level height in the container in relation to soil surface, z is the distance between the cup's center and soil