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Technical note

Effect of Time-Domain Reflectometry probe location on soil moisture measurement during wetting and drying processes

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ABSTRACT

In this paper studies on the impact of the location of Time-Domain Reflectometry probes in soil samples on the moisture measurement are presented. In particular, we were interested if the commonly accepted assumption that moisture measurements performed by TDR probes correctly average the value of the soil water content in a soil sample. Soil samples having different physical properties, both undisturbed and disturbed, were used. Our results show that the soil moisture measurement depends on the placement of the TDR probe in the sample, and a TDR probe placed vertically measures the arithmetic mean of soil moisture for the whole sample, for both the wetting and the drying cycles. This result is general and does not depend on the analyzed sample.

1. Introduction

Soil moisture predominantly affects all processes occurring in the soil. For example, mass and energy exchange processes in the soil–plant-atmosphere system are determined by soil thermal parameters (conductivity and capacity), which mainly depend on soil water content [1,2]. Also, soil water conductivity or soil air conductivity varies depending on the soil moisture. Soil acts not only as a reservoir of available water for plants, but the soil solution carries nutrients to the plant roots themselves, thus soil water content has an impact on plant growth conditions. Therefore, soil water content measurements are one of the most important issues, not just in meteorology, but also in hydrological and agricultural applications. Over the past 70 years many new soil moisture measuring techniques have been developed. The basic method of measuring soil water content is the gravimetric method. While this method is an integral part of soil moisture measurements, it has a serious drawback – it is destructive. However, there are non-destructive ways to measure soil moisture, such as neutron scattering, reflectometric or capacitance methods. The basics of these measurement techniques, as well as comparisons of their advantages and disadvantages, may be found in other articles [3–6].

The reflectometric method is a well-known method used for measuring soil water content and electrical conductivity. It was firstly applied to soil water measurements more than 30 years ago [7,8] and since that time the method has been further developed, both in the time (TDR) and frequency (FDR) domains [9–13]. This is due to the fact that the reflectometric method is non-destructive, fast and easy to apply, all of which are the main advantages of TDR over other soil water content measurement methods [14]. This allows one to measure moisture not only in the laboratory, but also to monitor and collect moisture data under field conditions [15], especially in places where it is important to preserve the soil structure. Certain phenomena measurements, such as hysteresis, require continuous monitoring of soil moisture changes during the dynamic processes of drying and wetting of soil. One of the best ways to capture these changes is using the TDR technique. This method has been also characterized

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by high accuracy (about ±2% of volumetric water content compared to standard gravimetric data when using the manufacturer's calibration relationship [15,14]). Moreover the TDR technique has good spatial and temporal resolution [14].

There has been some research conducted into the accuracy of measurements and also how probe placement affects the results [16–20]. The sensitivity zone of TDR probes has been studied and identified as well [20]. These studies drew our attention to several interesting questions. Given that TDR probe rods have a spatial dimension (length) and that the medium into which these rods are inserted is usually heterogeneous, does the measured soil water content correspond to an arithmetic average of soil water content in the rod area? If so, then there exists a TDR probe placement where the moisture measurement will characterize the entire sample. The above issues appear to be particularly important when the examined sample is sufficiently large that the moisture non-uniformity occurring due to gravitational potential cannot be neglected. It is also interesting to see if the above relationships do not change during rapid processes of wetting and drying in a soil sample. Thus far the above issues were examined only in the case when disturbed soil was gradually wetted to saturation by $CaCl_2$ solutions [21], not by water.

The main objective of this paper is as follows – to compare the results from three TDR probes inserted horizontally at different levels into soil samples to results obtained from a TDR probe inserted from the top during the dynamic processes of wetting and drying. Also, we test the hypothesis that a probe inserted vertically gives a value representative for the whole sample, even during rapid changes in soil moisture.

2. Methods

Soil samples were acquired in the Fall of 2012 from two different sites in the Lublin Province, where an Orthic Luvisol soil developed from loess over limestone. The soils, according to the Polish Society of Soil Science '2008 classification [22], were a loamy silt, hereinafter referred to as Soil A, and a clay silt, from now on referred to as Soil B. The physical properties of the soils are presented in Table 1. Particle size distribution was measured using the laser diffraction method [23–26]. Undisturbed soil samples were collected into the steel cylinders with a volume of 165 cm^3 (base diameter – 55 mm, height – 70 mm). Disturbed soil samples were also collected, air-dried and sieved to ⩽2 mm diameter, then repacked uniformly into cylinders of the same size. The soil height in each column was 61 mm. Soil samples for the experiment were taken from the cultivated topsoil (5–15 cm depth).

The cylinders with the soil samples were placed onto a ceramic plate for about 10 weeks, while being subjected to cycles of wetting at a water potential of 0.0981 kPa (corresponding to 1 cm H_2O, pF 0) and drying at a water potential of −9.81 kPa (corresponding to −100 cm H_2O, pF 2). The experiment was conducted in an air-conditioned room at a constant temperature of 24 °C. TDR measurements were made using LP/ms Laboratory Operated Meter (LOM) probes and TDR/MUX Integrated Measuring Module produced by E-Test company under the license of the Institute of Agrophysics, Polish Academy of Sciences in Lublin. The measuring system was calibrated with water and air as calibration media, according to the manufacturer instructions [27]. Soil moisture measurements were performed once every 5 min. Four TDR probes were inserted into each of the cylinders, three of them horizontally (probes Phb, Phm and Pht) and one from the top (probe Pv) (Fig. 1). Each TDR probe consisted of parallel twin 53 mm long stainless steel rods 0.8 mm in diameter, with a 5 mm separation gap. The above experiment configuration ensured that the end of the Pv probe rods reached below the Phb probe rods. The probes were inserted in such a way that their sensitivity zones did not overlap, which for this type of laboratory probe were: (i) the volume of a cuboid 58 mm high, 6 mm wide and a thickness equal to the diameter of the probe rods, when measurements were carried out in the air dry soil, and (ii) the volume of an elliptical cylinder of height 55 mm and length of the major and minor semi-axes of 8 mm and 5 mm respectively, when the soil was saturated [20].

3. Results and discussion

The moisture measurements for Soil A samples, both undisturbed and disturbed, are presented in Fig. 2, while for Soil B the undisturbed and disturbed samples are presented in Fig. 3. The lack of results for the plots at the end of first week and during the seventh week of measurements was due to the failure of the data collecting computer. For the air dried samples a water potential of 0.0981 kPa was set to initiate the wetting process. Wetting began in the lowest part of the sample (probe Phb), as the source of water was located at the bottom, in the ceramic plate. After the soil samples were wetted and the moisture stabilized, the water potential was changed to −9.81 kPa and the process of drying started for the whole volume of the sample at the same time. The soil water content gradient at depths 42 mm apart (between probes Phb and Pht) was highly noticeable. The differences in soil moisture

Table 1
Physical properties of the soil samples.

	Soil type	Bulk density (Mg m^{-3})	Organic matter (%)	Soil fractions (%)		
				Sand	Silt	Clay
Soil A	Orthic Luvisol	1.62	1.13	35	56	9
Soil B	Orthic Luvisol	1.41	0.92	21	68	11