COMPARISON OF METHODS FOR SOIL MOISTURE CONTENT MEASUREMENT BASED ON FIELD AND LABORATORY DATA

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ABSTRACT

Application of rainfall simulations is one of the most important experiments for purposes of a detail description of runoff and soil erosion processes. Both mentioned types of processes are highly dependent on initial soil moisture content which affects mainly infiltration rate and stability of aggregates. It is therefore crucial to measure the initial soil moisture content before each simulation in order to evaluate measured data correctly. Additionally, the record of changes in soil moisture content in time can be very helpful for purposes of detail description of mentioned processes or for purposes of calibration of different models.

In this paper, different procedures and types of sensors are discussed from the point of view of its accuracy and applicability. In detail, gravimetric method which is considered as the most accurate is compared to measurements using two different types of sensors and measurement techniques. These are ThetaProbe ML2x and TMS3 sensors. The comparison is based on data measured under different conditions in field and on the calibration of sensors in laboratory. Initial results based on multiple measurements at two different sites in field conditions indicate in general significant differences in averages between gravimetric method and both considered types of sensors. The data were evaluated with respect to their means as well as to their variance.

Two-tailed t-test was performed in order to check whether means can be considered equal when comparing the data obtained by gravimetric method and two different sensors. The results show significant differences between soil moisture measured using gravimetric method and soil moisture measured using both mentioned type so sensors. Better results were provided by Theta Probe ML2x than by TMS3 sensors which underestimate soil moisture significantly when applied with calibration curve derived based on laboratory experiments.

Recent results indicate high variability in soil moisture content which justifies the need for multiple measurements of soil moisture content before and after each simulation. Recent results show that measurement of soil moisture content using gravimetric method cannot be replaced by sensors without lack of accuracy. Thus, the application of sensors for given purpose needs to be a subject of further research.

Keywords: rainfall simulator, soil moisture content, field experiments, sensors, two-tailed t-test

1. Introduction

The soil moisture content is undoubtedly crucial for infiltration process modelling. Infiltration component is in different ways involved in most hydrological models based on physical description of rainfall-runoff process. The application of rainfall simulators is very popular for investigation of infiltration, rainfall-runoff and soil erosion processes for long time (Corona *et al.*, 2013; Grierson and Oades, 1977; Humphry *et al.*, 2002). Experiments performed using rainfall simulators usually aim in a detail description of the process which is researched. This usually means that also all processes and conditions must be described as much in detail as possible.

New portable rainfall simulator was developed at CTU and applied for soil erosion experiments aimed at the description of vegetation protective effect against soil erosion in last three years (Davidová *et al.*, 2014). The initial soil moisture proved to be a factor significantly affecting measured values of runoff and soil loss (Vahabi and Nikkami, 2008). The soil moisture content was measured at several points around experimental plots before each experiment. However, this way is considered to be one of most precise but it is also time consuming and instant data are also not available in this case which can be used to adjust conditions for the experiment. Thus, it was decided to involve the measurement using soil moisture sensors. The advantage of application of soil moisture sensors consist besides others that they can be installed directly in the plot and that they can provide continual record which can help to better understand the infiltration process. Two different types were available for this purpose. The calibration and testing is described in this paper.

2. Material and methods

There are different methods for measurement of soil moisture content including time domain reflectometry, ground-penetrating radar, capacitance and others. Many of them are described by Topp (2003). However, the gravimetric analysis of undisturbed soil samples is still considered as one of the most accurate and it is often used as a reference when doing the calibration of different sensors. For purposes of measurement of soil moisture during experiments performed using rainfall simulator, two types of soil moisture sensors were calibrated in laboratory and then tested in the field. The sensors used for this purpose were ThetaProbe ML2x and TMS3. The values measured in the field were then compared to the values obtained by gravimetric analysis of undisturbed samples taken in the field during testing.
Theta Probe ML2x (Delta-T Devices) is a sensor which is used for measurements of soil moisture content for different purposes for long time (Nemali *et al.*, 2007; Kaleita *et al.*, 2005; Miller and Gaskin, 1999; Weihemüller *et al.*, 2007). This sensor is based on measurement of change in impedance depending on dielectric constant of soil. It measures the soil moisture content in about 75 cm^3 around 6 cm long signal rod. The sensor cannot work independently which means that it needs a datalogger which supplies it with electric power and measures produced analogue signal in a form of voltage.

TMS3 Measuring System (TOMST) is an independent unit which measures soil and air temperature and soil moisture content. It is relatively new device but it was already used in the field for different studies (Jankovec *et al.*, 2013; Hernandez *et al.*, 2014; Chávez, 2011; Šanda *et al.*, 2014). The soil moisture content is measured on the principle of time domain transmission in a cone of about 4 cm diameter around the axis 10 cm long body.

For both types of devices, calibration curves were created using data measured in laboratory. For this purpose, samples were prepared using soil taken at the experimental site in containers with a volume 1.22 l. Sensors were installed in these samples and samples were saturated (see Figure 1 – left). Then, they were let drying at constant temperature and weighted periodically for about two weeks. At the end, the samples were oven dried to get the weight of dry sample which is necessary for the calculation of water content in the sample during drying.

In the field, the measurements were carried out at two sites in the area where rainfall simulations are carried out. The experimental area is located in the catchment of Divišovský stream 40 km south-east of Prague in a rural area with high percentage of agricultural land. Soils in this area are mostly loamy sands and sandy loams as resulted of particle site analysis of disturbed samples.

At each site, the measurements were taken within the square having side 1.5 m (see Figure 1 - right). For each measurement, six TMS3 sensors were installed first as they need some time for stabilisation in the profile disturbed by the installation. Then, the soil moisture content was measured at nine points using Theta Probe ML2x. Finally, nine undisturbed samples were taken for gravimetrical analysis in the laboratory.

Figure 1: Theta Probe ML2x installed in the sample in laboratory (left) and soil moisture sensors installed in the field – six TMS3 sensors and one Theta Probe ML2x (right).

3. Results

Calibration curves transforming output signal from both sensors were calculated first. The curve for TMS3 sensors was derived based on data measured in laboratory having R^2=0.96. For Theta Probe ML2x, the curve was derived with R^2=0.99. These curves were then used for the calculation of soil moisture content from measured signal.

Sets of values measured in the field by all three methods were first evaluated individually for each site (Figure 2). First, the data obtained by gravimetric analysis of undisturbed samples were evaluated as they were considered as a reference. The results show significant difference in both means and variances. The difference in means was expected as Site 1 ($\theta_1^{av,grav}$=36.3 %) was located on the foot of the slope close to the stream and Site 2 ($\theta_2^{av,grav}$=24.2 %) more uphill. However, high difference was also identified in variance of measured values. The variance at Site 1 is very high (Var(θ_1^{grav})=19.8 %) while at Site 2 it is low (Var(θ_2^{grav})=2.0 %). This can be caused by the water content in macropores which cannot be averaged with respect to the volume of soil samples (0.318 l) and their spatial distribution.

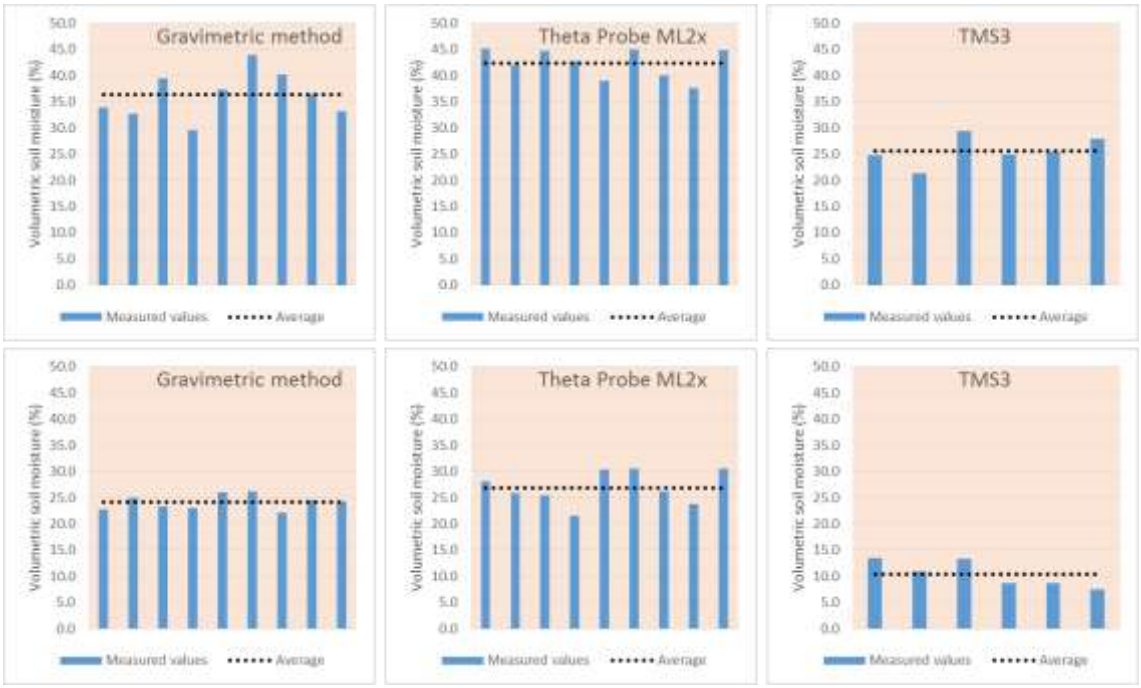

Figure 2: Soil moisture content measured in the field at Site 1 (above) and at Site 2 (below).

The results for Theta Probe show the overestimation of mean soil moisture content in comparison to the results of gravimetric method at both sites. These are $\theta_1^{av,Theta}$=42.3 % and $\theta_2^{av,Theta}$=26.9 % respectively. Variances for both sites are much closer in case of this type of measurement being Var(θ_1^{Theta})=10.2 % and Var(θ_2^{Theta}). In case of TMS3 sensors, measured values of soil moisture content are significantly underestimated. Means are for this sensor $\theta_1^{av,TMS3}$=25.6 % (Var(θ_1^{TMS3})=6.4 %) and $\theta_2^{av,TMS3}$=10.4 % (Var(θ_2^{TMS3})=7.9 %) respectively. Detail overview of means, variances and ranges is provided in Figure 3.

Figure 3. Box plot of statistics for all sets of data obtained at both sites using all considered methods.

Measured values were further analysed from statistical point of view with aim to check whether data are comparable with respect to their mean. Two tailed t-test was performed in order to compare means of each set of measured data. The only case for which the null hypothesis of means equality could not be rejected was the comparison of gravimetric method with Theta Probe at α=0.01 at Site 2. In other cases, means should be considered different from statistical point of view.

4. Conclusions

In this paper, initial analysis is presented which focused on the possibility of different sensors application for purposes of soil moisture content measurement during simulations performed with use of mobile rainfall simulator. The results indicate several recommendations for future simulations with rainfall simulator. First, the variability of soil moisture content is high even within very small area. This implies the need of multiple measurements even for purposes of initial soil moisture identification. Second, the sensors tested within the study do not provide satisfactory results. Thus, undisturbed samples analysis should remain the main source of information about soil moisture content until the more detail analysis on application of sensors is carried out. Third, Theta Probe ML2x appears to be a better option for continuous monitoring of soil moisture content during simulations when it is supported by gravimetric measurement.

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