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Performance Evaluation of TDR Soil Moisture Sensor

H. Kirnak* and Y. Akpinar

University of Erciyes, Faculty of Agriculture, Department of Biosystem Engineering, TR 38039 Talas, Turkey
*Correspondence: hkirnak@yahoo.com

Abstract. Optimization of irrigation scheduling and water management greatly benefit from soil moisture sensors that accurately measure soil water content since accuracy of soil moisture sensor directly affects the irrigation efficiency. In this study, a performance evaluation of TDR-Slammer with a 40 cm waveguide was done under field conditions. Experimental data were collected in a drip irrigated pumpkin (Cucurbita pepo L.) field, Kayseri, Turkey during the 2015 growing season. Measured soil water content values on a loamy soil were compared with corresponding values derived from gravimetric samples. Results showed that TDR-Slammer could be safely used as an acceptable, reliable and accurate method for measuring soil water content on loamy soils.

Key words: Time domain reflectometry, soil water content, calibration, dielectric constant.

INTRODUCTION

A reliable determination of soil water content is important since it directly affects plant growth. Soil moisture measurements are also necessary for assessing the effect of irrigation management on agricultural crops. There are several different methods to measure or to estimate soil moisture contents using either destructive (gravimetric) or non-destructive methods (neutron probe, TDR, porous blocks, tensiometer, etc.). In irrigation scheduling studies, use of gravimetric methods are mostly defined as time consuming and labour intensive.

During the last 30 years, Time Domain Reflectometry (TDR) has become quite common and popular for measuring volumetric soil moisture content. The use of TDR is quite easy and gives reliable and accurate results without disturbing the soil. Since the TDR is not a direct method of measuring soil water content (Θ), a calibration is required for different soil types. The TDR determines relative dielectric constant (K) of soil by measuring the propagation velocity of an electronic wave guide along electrodes. Topp et al. (1980) developed an empirical relationship (Equation 1) between the dielectric constant and volumetric moisture content of soil as independently of some soil parameters such as bulk density, temperature and salinity.

$$\theta = 4.3 \times 10^{-6}K^3 - 5.5 \times 10^{-4}K^2 + 2.92 \times 10^{-2}K - 5.3 \times 10^{-2} \quad (1)$$

TDR measurements commonly depend on apparent dielectric constant of soil which changes with moisture content. The advantages of TDR system over other methods are (1) calibration requirements are minimal, (2) effects of temperature and hysteresis (the relationship between matric potential and soil water content for a given soil is not unique and varies depending on whether the soil is drying or wetting) on TDR measurement are small, (3) simultaneous measurements are possible (Quinones et al., 2003; Miyamoto & Chikushi, 2006). A third-order polynomial equation proposed for mineral soils by Topp et al. (1980) is adequate for many soils except for organic and clayey soils. However, many researchers (Take et al., 2007; Ju et al., 2010) indicated that TDR measurements most probably could be influenced by soil bulk density, soil temperature, soil texture, soil structure, organic matter content and salinity. Therefore, a site specific calibration is required to obtain a higher accuracy instead of using universal Topp equation. Ju et al. (2010) showed that Topp equation could work well with coarse-textured soils with bulk densities between 1.0–1.78 g cm^{-3}.

The overall objective of this study was to determine accuracy of TDR-slammer for measuring soil water content under drip irrigated pumpkin field and also to investigate the need for a site-specific calibration for TDR-slammer in loamy soil.

MATERIALS AND METHODS

Experiments were conducted in 2015 over the experimental fields of Agriculture Research Station of Erciyes University, Kayseri, Turkey (1,094 m altitude, 38° 18′ N and 34° 56′ E coordinates) under drip irrigated pumpkin field. Irrigation water was supplied from a deep well with a quality class of C_2S_1 and pH and EC (electrical conductivity) values of irrigation water were 7.60 and 0.242 dS m^{-1}, respectively. The study site had 6 differt irrigation treatments starting from dry to full irrigation. Amount of water applied to treatments were increased from treatment 1 to treatment 5. The treatment 1 had the least irrigation water application while the treatment 5 had full irrigation. Irrigations were initiated on 19th of June in 2015 and stopped on 6th of August. The tests were repeated in different dates under different soil moisture levels of drip irrigated pumpkin. A total of twenty five data points (n = 25) were used in the analysis of volumetric soil moisture content. The soil properties of the site (FC_w – Field Capacity in weigth and PWP_w – Permenant Wilting Point in weigth) are provided in Table 1. There are several different types of available commercial TDR sensors to determine soil moisture content. The TDR-slammer is designed for inserting waveguides into hard, dry and compacted soils (Fig. 1).

Table 1. Soil properties of the study site

Depth (cm)	Texture	pH	EC (mmhos cm^{-1})	FC_w (%)	PWP_w (%)	Organic matter (%)	Bulk density (g cm^{-3})
0–20	Loam	8.00	0.226	21.2	9.7	0.98	1.30
20–40	Loam	8.25	0.214	25.7	11.8	1.51	1.28

In each irrigation treatment, the sensor was installed roughly 0.10 m apart from the dripper of the lateral. Data collection began in the late June and continued till the begining of August. The gravimetric samples were taken using a soil auger approximately 0.20 m away from each sensor location. The sensor was inserted vertically into soil and several soil water content readings were taken and then averaged. After each sensor reading, soil gravimetric samples were taken from the both sides of the TDR probe. The standard procedures was applied over the gravimetric samples to determine the gravimetric soil moisture content. Soil samples were always taken at different locations. In order to convert the gravimetric soil moisture into volumetric soil moisture content (VWC), the soil bulk density was considered. During the gravimetric samplings, soil tempeartures ranged between 22–35 °C in dry treatment, 23–28 °C in treatment 1, 22–30 °C in treatment 2, 22–28 °C in treatment 3, 21–28 °C in treatment 4 and 22–25 °C in treatment 5.

Figure 1. TDR–slammer with a 40 cm waveguide.

Three statistical parameters were used to compare predicted (Pi) data from TDR measurements with the observed (Oi) gravimetric samples (*n*). The statistical measures were (a) the cofficient of determination (R^2), (b) mean bias error (MBE) and (c) root mean square error (RMSE) as defined by Chavez et al. (2011). Paired-sample *t test* was also applied to present statistical significance of differences between TDR measured VWC and actual VWC determined by gravimetric process.

$$MBE = n^{-1} \sum_{i=1}^{n} (Pi - Oi) \tag{2}$$

$$RSME = \left[n^{-1} \sum_{i=1}^{n} (Pi - Oi)^2 \right]^{0.5} \tag{3}$$

RESULTS AND DISCUSSION

During the field calibration process, the volumetric soil moisture content was within the PWP to FC range of water contents. Fig. 2 shows the data of gravimetrically measured VWC versus TDR measured K values. The calculated RMSE and MBE values were 1.9 and -0.16, respectively. Chaves et al. (2011) found the MBE and RMSE values as 0.05 and 0.025, respectively for forest soil. Ju et al. (2010) obtained the RMSE as

0.06 for clay loam soil. These differences could be due to different soil texture and management conditions. Fig. 3 presents the comparison of VWC from TDR versus gravimetric method. The significant differences between water contents measured with TDR-slammer and gravimetric method are listed in Table 2. The paired-sample *t test* indicated that the difference between TDR-slammer and gravimetric method was insignificant at $p < 0.05$ level. The standard error of mean (SEM) was 0.90 and 0.78 for TDR and gravimetric method, respectively, while the standard deviation (SD) was 4.54 and 3.90, respectively. The changes of VWC obtained from gravimetric method and TDR Slammer are presented in Fig. 4.

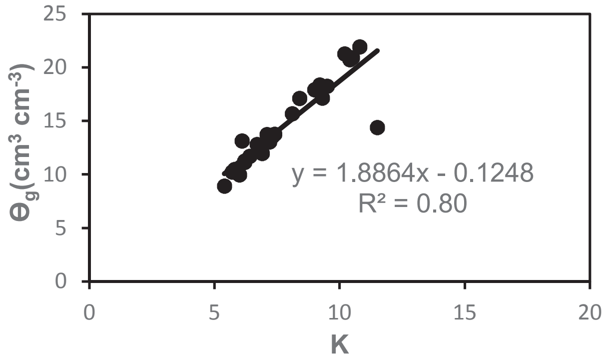

Figure 2. Comparison of measured VWC from the gravimetric procedure (Θ_g) versus measured dielectric constant (K).

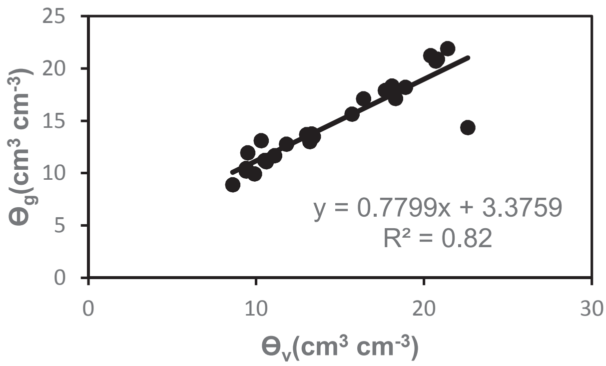

Figure 3. Comparison of measured VWC from the gravimetric procedure (Θ_g) versus TDR-Slammer (Θ_v).

Table 2. The significant differences between VWC measured with TDR-slammer and gravimetric method

	Mean	SD	SEM	*t-stat*	*p*
TDR-Slammer	14.60	4.54	0.90	0.13	0.89
Gravimetric method	14.80	3.90	0.78		

The Fig. 4 shows a very close relationship in VWC of TDR-slammer technique and gravimetric method. Fig. 2 presents that a simple linear model could be used to measure VWC in loamy soils ($\Theta_g = 1.8864 \times K - 0.1248$ with an R^2 of 0.80) instead of using polynomial Topp equation. The Fig. 3 showed that there was a very close relationship in measured VWC of TDR-slammer and gravimetric method. The test results showed that the TDR-slammer with the manufacturer's Topp equation could safely be used to measure VWC in loamy soils (Figs 3–4). Current study also confirmed that the Topp equation could be confidently used to estimate VWC accurately from dielectric data (K) in the loamy soils. The Topp equation known as universal was adequate for the studied soil type.

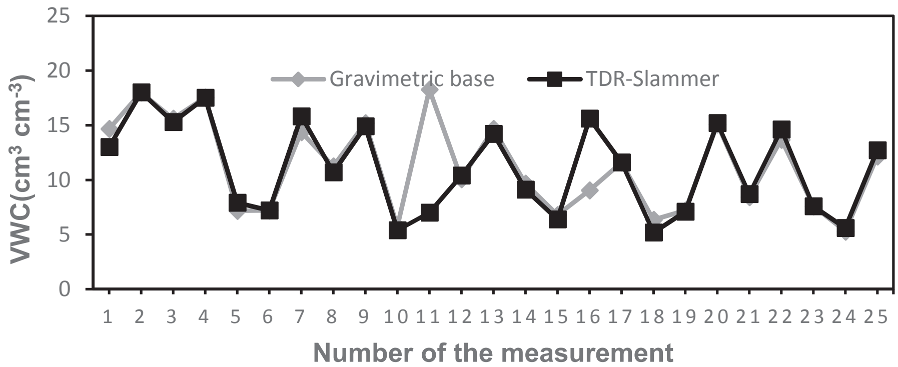

Figure 4. Changes of VWC obtained from gravimetric method and TDR Slammer.

The *t*-test between TDR technique and gravimetric method showed that there was no significant difference at $p > 0.05$ level. However, more studies including soil parameters should be done for the calibration of different types of TDR under different soil type and management conditions.

CONCLUSIONS

Major conclusions of this investigation are (1) The TDR-slammer could securely be used as an accurate soil moisture device for measuring soil water content in compacted loamy soils. (2) The TDR-slammer with manufacturer's Topp equation could safely be used without a site-specific calibration if necessary. (3) There was a clear relationship between the K and Θ_g and this relationship was best described ($R^2 = 0.80$) with a simple linear equation of the form $\Theta_g = 1.8864 \times K - 0.1248$. This simple linear model, instead of using polynomial Topp's equation, could be used for compacted loamy soils.

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