CALIBRATION OF MOISTURE SENSOR CAPACITIVE TYPE FOR TWO DIFFERENT SUBSTRATES

Adriano Valentim Diotto[1], Mariana Gontigo[2], Rodrigo Rafael Salvador[3]

ABSTRACT: For good irrigation management it is necessary effective scheduling and a good understanding of the soil-water dynamics. Precise knowledge of soil moisture allows water savings and the use of moisture sensors can provide information on a different time scale and subsidies the water application on a sustainable rate. Capacitive sensors are commonly used for moisture estimation and need to be calibrated in the function of the media where the sensor will be installed. Soilless culture systems use growing media (substrate) for plant support and water retention. This technique uses normally a chemically and biologically almost inert media with a great variation of material and a specific calibration for each substrate is recommended even by the 10HS sensor manufacturer. A calibration curve was elaborated for two commercial substrates with distinguish bulk density, 480 kg m-3and 200 kg m-3respective for S1 and S2. Using the manufacturer-supplied calibration to estimate the substrate moisture the Mean Absolute Error was 0.031 cm3 cm-3 to S1 and 0.029 cm3 cm-3 for S1. The Root Mean Square Error values were 0.035 and 0.034 for S1 and S2 respectively. Using a specific calibration for each substrate increase considerable precision in the moisture estimation and the manufacturer calibration curve for potting soil shows a problem, specifically for the stream conditions with high or very low moisture.

KEYWORDS: Irrigation management, soilless systems, soil water balance.

CALIBRAÇÃO DE SENSOR DE UMIDADE DE SOLO DO TIPO CAPACITIVO PARA DOIS DIFERENTES SUBSTRATOS

[1] Prof. Dr., Departamento de Recursos Hídricos e Saneamento, Universidade Federal de Lavras, Caixa Postal 3037, CEP 37200-000, Lavras, MG. Fone (35) 3829 1664. Email: adriano.diotto@ufla.br.
[2] Doutorando, Programa de Pós-Graduação em Recursos Hídricos, Departamento de Recursos Hídricos e Saneamento, Universidade Federal de Lavras, Lavras, MG.
[3] Graduando, Engenharia Agrícola, Universidade Federal de Lavras, Lavras, MG.

RESUMO: Para um bom manejo da irrigação é necessário um bom entendimento da dinâmica da água no solo. O conhecimento preciso da umidade do solo permite economia de água e o uso de sensores de estimativa de umidade pode fornecer informações em escala de tempo diferentes e subsidiar a aplicação da água de maneira mais sustentável. Sensores capacitivos são comumente usados para estimativa de umidade e precisam ser calibrados em na função do meio onde será instalado. Os sistemas de cultivo sem solo usam meios de crescimento (substrato) para suporte de plantas e retenção de água. Essa técnica usa normalmente um meio quimicamente e biologicamente quase inerte com uma grande variação de material, portanto, uma calibração específica para cada substrato é recomendada até mesmo pelo fabricante do sensor 10HS. Uma curva de calibração foi elaborada para dois substratos comerciais com densidade distinta, 480 kg m^{-3} e 200 kg m^{-3}, respectivamente, para S1 e S2. Usando a calibração fornecida pelo fabricante para estimar a umidade do substrato, o MAE foi de 0,031 cm^3 cm^{-3} para S1 e 0,029 cm^3 cm^{-3} para S1. Os valores de RMSE foram 0,035 e 0,034 para S1 e S2, respectivamente. O uso de uma calibração específica para cada substrato aumentou a precisão considerável na estimativa de umidade e a curva de calibração do fabricante resultou em um problema, especificamente para as condições de fluxo com umidade alta ou muito baixa.
PALAVRAS-CHAVE: Manejo de irrigação, produção sem solo, balanço de água no solo.

INTRODUCTION

Good irrigation management requires effective scheduling and a good understand of the soil-water dynamics in the plant root zone. To reach such a goal it is necessary accurate measurement of soil moisture (Zhu et al., 2019). Precise knowledge of soil moisture allows water savings and the use of moisture sensors can provide information on different time scale and subsidies the water application (Spelman et al., 2013). Soilless culture systems, for example, came with the advantage to have better water use efficiency, better product quality and easier control of pests and disease (Putra & Yuliando, 2015).

Different from the hydroponic, some soilless culture systems use a growing media (substrate) for plant support and water retention. This technique uses normally a chemically and biologically almost inert media with a great variation of material, such as the inorganic rockwool and organic such as peat, bark, rice hulls and others (Putra & Yuliando, 2015). As the substrate is not only for the support but also for water retention for plant use, it is necessary substrate moisture monitoring to achieve better water management.

A lot of commercial sensors can be found at the market for moisture monitoring, using different technologies to estimate the soil or substrate moisture. (Zhu et al., 2019) present most of the common methods used for quantifying soil-water: gravimetric method, time domain reflectometry, ground penetrating radar, capacitance, radar scatterometry or active or passive microwaves, electromagnetic induction, neutron thermalization, nuclear magnetic resonance, gamma-ray attenuation, resistive sensors, tensiometry, hygrometric techniques, remote sensing, and optical methods. Besides the methods used to quantify the moisture, the sensors performance can also be affected by other parameters such as soil temperature, clay content, texture, porosity, and bulk density (Irmak & Irmak, 2013; Kargas & Soulis, 2019; Spelman et al., 2013; Zhu et al., 2019). Therefore, site-specific calibration for different use conditions could improve sensor performance.

The sensor 10HS® is one of the sensors at the market, measures volumetric water content by means of capacitance technology (Delta-T Devices, 2019). Some calibration curve is found by the sensor manufacturer, but in the manual, even them presented the possibility to generate a site-specific calibration curve for improving the sensor performance. Therefore, this work aims to develop a calibration curve for the sensor 10HS in two different substrates and compare them with the manufacture calibration for potting soil.

MATERIAL AND METHODS

The calibration curve was developed at the soil physics analysis laboratory, water resources department of the University of Lavras. Correlating different volumetric water content with the 10Hs raw readings for two commercial substrates. For the calibration, a bucket with 7700 cm^3 volume was used in three reps for each substrate. The sensor in each evaluation was installed in the center of the bucket to ensure enough space around the sensor and no interference of the bucket wall at the readings. The procedure was repeated several times starting with the substrate complete dry until the saturation. Once determine the first amount of dry substrate (grams of the substrate) need to fill the 7700 cm^3 bucket, this value was used to calculate the bulk density in kilograms per cubic meter. After the first round of data collection, the content of the bucket was mixed with 500 ml of water and well homogenized. The substrate with the new water content was returned to the bucket and the sensors readings were taken again. A sample of the substrate was taken in each round for substrate water content measurement using a gravimetric method. Two commercials substrate was used, choose especially by their different dry bulk density, one it is the substrate Multiplant® (S1) e the other is the Carolina Soil® (S2).

A water retention curve was done using the standard IN31 (BRASIL, 2008) and adjusted by van Genuchten's model. Three samples each substrate was used and was determine the total porosity (TP), the total solids volume (TS), the water retention at 10hPa (WR10) that represent the available water on the substrate after saturation and free drainage, the real available water (RAW) that is the water removed between the tensions of 10 and 50hPa, and the WR50 that is the water available below the tension of 50 hPa. The water retention curve was done using the same dry bulk density used on the buckets for the sensor calibration.

$$\theta=\theta_R+\frac{\theta_S-\theta_R}{[1+(\alpha|\Psi_m|)^n]^m} \quad (1)$$

Where:

θ – Volumetric water content at a given tension of water in the soil ($cm^3\ cm^{-3}$);

θ_R – Residual volumetric water content ($cm^3\ cm^{-3}$);

θ_S – Volumetric water content at the saturation condition ($cm^3\ cm^{-3}$);

α, m and n – Adjusted parameters of the van Genuchten's model;

Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) was used in conjunction with the coefficient of determination (R2) to evaluate the calibration curves proposed in this study and compare with the manufacturer-supplied curve for pot soils.

$$MAE=\sum_1^n\frac{|\hat{Y}-Y|}{n} \quad (1)$$

$$RMSE=\sqrt{\frac{\sum_1^n(\hat{Y}-Y)^2}{n}} \quad (2)$$

Where:

$\hat{Y}$ – Estimated values;

Y – Estimated values;

n – Number of observations.

RESULTS AND DISCUSSION

The obtained dry bulk density in the buckets was 480 kg m^{-3} for the S1 and 200 kg m^{-3} for the S2. The water retention curve for both substrates is observed in figure 1A, and the coefficients adjusted for the van Genuchten's equation is in table 1. It was possible to observe a great difference between the substrates related to water retention. The commercial substrate S2 had higher water retention in all tension applied. The parameters TP, WR_{10}, RAW, and WR_{50}. The real available water, that is an important parameter for plant production it is just 6% for the S1 and 15% for S2.

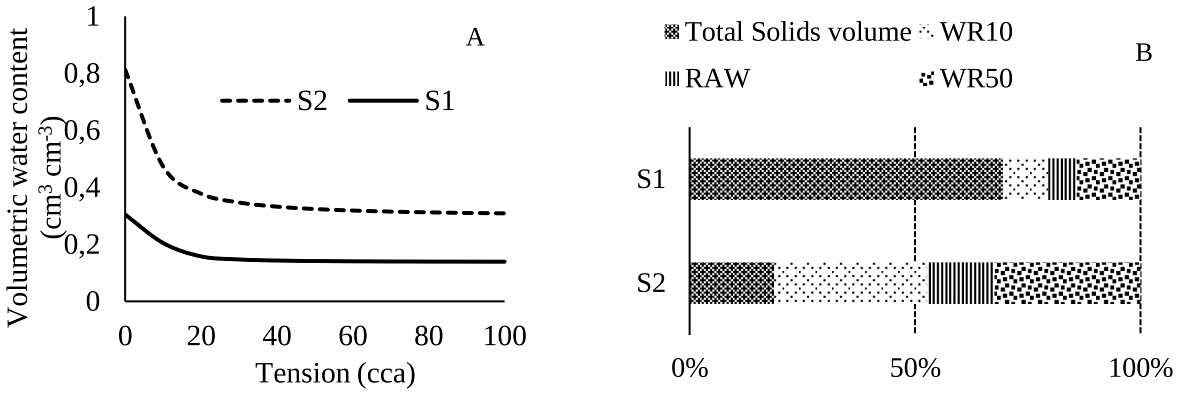

Figure 1. Water retention curve (A) and the other parameters (B), total solids volume (TS), water retention at 10 hPa (WR10), Real Available Water (RAW) and Water Retention below 50 hPa (WR50) for both substrates evaluated.

Table 1. van Genuchten's equation coefficients for the substrates water retention curve

Substrate	θS	θR	a	m	N
S1	0.3046	0.1384	0.1428	0.6697	3.028
S2	0.8125	0.2972	0.2249	0.5500	2.220

In figure 2 it is showing the correlation between the raw readings and the real moisture for both substrates evaluated, and the manufacturer recommended curve for potting soil. It is possible to observe that the manufacturer proposed curve does not fit very well for the measure of the extreme values in both substrates evaluated. Differences between the manufacturer-supplied calibration curve and the real moisture data were also observed by (Spelman et al., 2013) for four different soils, especially for the highest moisture values. The manufacturer, in the sensor operator's manual presents the manufacture calibration curve and emphasize the calibration may not be applicable for all soil types, encourages the customers to do the soil-specific calibration.

Using the manufacturer-supplied calibration to estimate the substrate moisture the MAE was 0.031 cm^3 cm^{-3} to S1 and 0.029 cm^3 cm^{-3} for S1. The RMSE values were 0.035 and 0.034 for S1 and S2 respectively. In table 2 it is possible to observe the adjusted calibration equation founded for each substrate and one for a general substrate using all data from both types of substrate evaluated. The values of MAE and RMSE decrease substantially when using the specific calibration. The MAE and RMSE reduce more than a half and the values of R2 are higher than 0.97 for both substrates evaluated, emphasize the importance of calibration when a precise estimate is necessary.

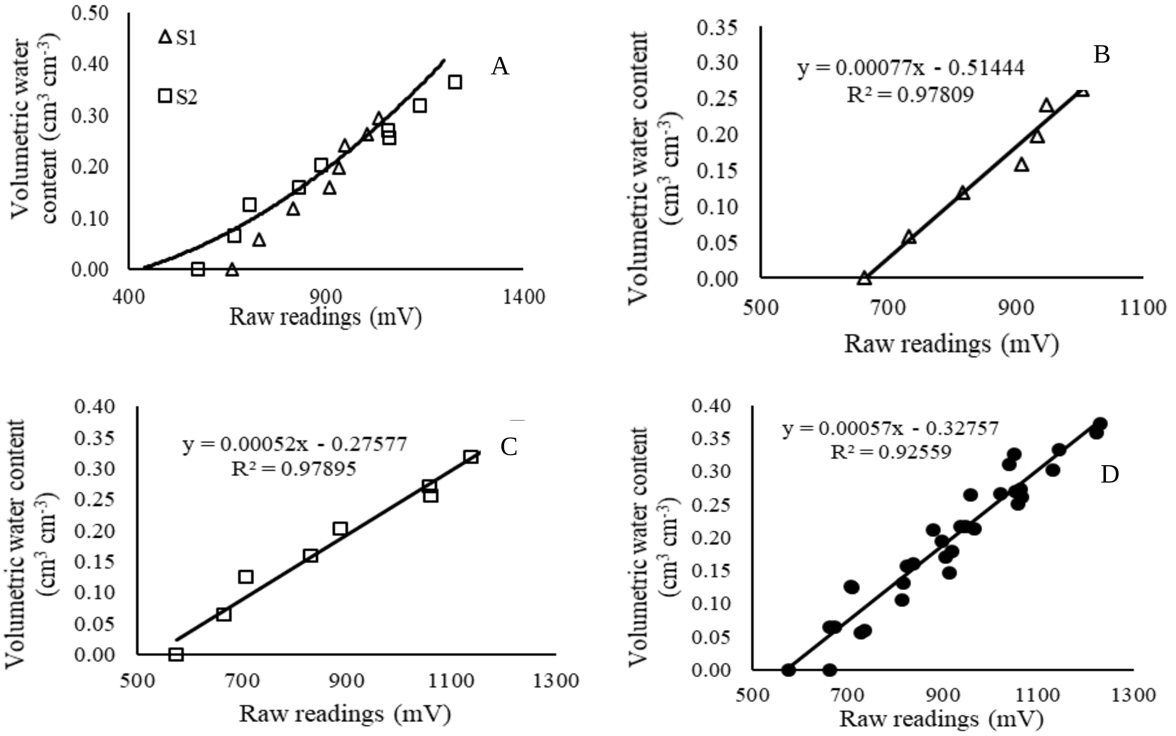

Figure 2. Correlation between raw readings and the volumetric water content for both substrates evaluates, and the manufacture correlation curve proposed for potting soils (A). Correlation between raw readings and the real volumetric water content for S1 (B), S2 (C), and the general correlation using all data set for both substrate (D).

Table 2. Calibration curve for each substrate evaluated and general calibration using all data

Substrate	Adjusted calibration equation	MAE	RMSE	R2
S1	θ = 0.00077 mV - 0.51444	0.015709	0.019489	0.97809
S2	θ = 0.00052 mV- 0.27577	0.012178	0.016529	0.97895
S1+S2*	θ = 0.00057 mV - 0.32757	0.021863	0.027495	0.92559

* using all data set for predicting the substrate moisture.

CONCLUSION

Using a specific calibration for each substrate increased considerable precision in the moisture estimation. The use of the manufacturer calibration curve for potting soil is not recommended, specifically for the stream conditions with high or very low moisture.

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