CALIBRATION OF FDR PROBE IN EUTROFERRIC RED NITISOL

Prudente Junior, A. C[1]; Mendonça, F. C[2]; Pantojo, D. P[3]; Bretas, L. M[4]; Amorim, D. M[5]

ABSTRACT: Sensors have been frequently utilized in irrigated agriculture to estimate the water consumption of different crops. Among them, capacitance sensors stand out due the possibility to give readings at depth quickly and practically when compared to other methods. To be accurate in the measurements, avoiding bias arising from the heterogeneity of texture and soil density in the soil profile, it is necessary to calibrate the capacitive probe. The objective of this study was to calibrate a Diviner 2000® capacitive probe in an Eutroferric Red nitisol in the city of Piracicaba - SP. Measurements were made with the equipment for every 0.1 m of soil up to a depth of 0.9 m; soil sampling was also used to determine the soil water content in the standard method. Six tubes were arranged and each pair was divided into three different soil moisture conditions – dry, field capacity and saturated. Potential equations were determined at each depth and for all soil profiles, verifying both higher and lower determination coefficients (R^2) and root mean square error.

KEYWORDS: Sensors; capacitance technique; soil moisture

CALIBRAÇÃO DE SONDA FDR EM NITOSSOL VERMELHO LATOSSÓLICO EUTROFÉRRICO

RESUMO: A utilização de sensores vem sendo frequentemente utilizada na agricultura irrigada na estimativa do consumo hídrico de diferentes culturas. Dentre os sensores, os da técnica de capacitância se destacam pois são capazes de conferir leituras em profundidade de forma rápida e prática quando comparado a demais métodos. Para se ter acurácia nas medidas, evitando-se viés advindo da heterogeneidade de textura e densidade do solo no perfil do solo, se faz necessário a calibração da sonda capacitiva. O objetivo deste trabalho foi de calibrar uma sonda capacitiva Diviner 2000 ® em um Nitossolo Vermelho latossólico eutroférrico no

[1]Engenheiro Agrônomo, doutorando em engenharia de sistemas agrícolas, Escola Superior de Agricultura- Universidade de São Paulo, Avenida Pádua Dias - 11, Caixa Postal 9, CEP 13418-900, Piracicaba, SP. Fone (14) 981713800. E-mail:amauri.cassio@usp.br
[2] Prof. Doutor, Depto de Engenharia de Biossistemas, ESALQ-USP, Piracicaba-SP
[3] Doutoranda em engenharia de sistemas agrícolas, ESALQ-USP, Piracicaba-SP
[4] Mestranda em engenharia de sistemas agrícolas, ESALQ-USP, Piracicaba-SP
[5] Doutoranda em engenharia de sistemas agrícolas, ESALQ-USP, Piracicaba-SP.

município de Piracicaba-SP. Foram efetuadas leituras com o equipamento para cada 0,1 m de solo até 0,9 m de profundidade, bem como a coleta de solo para a determinação do teor de água do solo por meio do método direto. Foram dispostos seis tubos onde a cada dois, foram divididos em três diferentes umidades, seco, capacidade de campo e saturado. Equações potenciais foram determinadas em cada profundidade e em todo perfil do solo, verificando maiores coeficientes de determinação (R^2) e menores erros de estimativa na calibração local, sendo a forma mais indicada de operar este instrumento para monitorar a umidade do solo.

PALAVRAS-CHAVE: Sensores; Técnica de capacitância; Umidade do solo.

INTRODUCTION

Agriculture is responsible for the use of 69% of fresh water that is captured in the word (FAO, 2016). Being a fundamental component of various sectors (urban, industrial, agricultural, pleasure, etc.), conservative management of fresh water use is critical. In the agricultural context, water management can be accomplished by monitoring soil water content, thus obtaining the hydric information necessary for a cultivation. (CREMON *et al*., 2014).

There are direct and indirect methods for determining groundwater content (ARAUJO PRIMO, 2013). Gravimetry is considered the standard direct method, with which the humidity present in the soil is obtained by taking the difference in a sample's weight before and after being dried in an oven. However, this method does not allow for obtaining instantaneous results (SILVA, 2013).

On the other hand, indirect methods involve measuring a physical-chemical property of the soil that is correlated to the water content at a specific point in time (LIMA; SILVA, 2012). The advantages of these methods are: they do not require frequent soil sample collection to determine humidity; they are less destructive than direct methods; less time and work is required to obtain measurements (VIONE, 2007).

Some techniques have distinguished themselves for estimating soil water content with precision and safe operation, such as the use of capacitive sensors, among which two methods can be singled out: Time Domain Reflectometry (TDR) and Frequency Domain Reflectometry (FRD) (KHANNA *et al*., 2014; SOUZA *et al*., 2016). Frequency domain reflectometry is a technology that provides quick measurements with precision at different depths and presents the advantages of more easily acquiring data when compared to TDR (precursor to the capacitive technique) and being easier to install (AL-GHOBARI *et al.*, 2016).

One of the limitations of the use of the capacitive methodology is the need for on-site calibration. This practice ensures precise soil moisture readings, avoiding bias originating from factors that can influence soil moisture retention such as alterations in soil density, structure and organic matter (PROVENZANO *et al.*, 2016).

Given this context, the objective of this study was to calibrate and prepare an FDR capacitive probe in a Eutroferric Red nitisol in the municipal of Piracicaba-SP, with the goal of having an efficient instrument for monitoring soil moisture.

MATERIALS AND METHODS

The experiment was conducted between September 2017 and April 2018 in an experimental area of the Escola Superior de Agricultura “Luiz de Queiroz” (ESALQ/USP), in the city of Piracicaba, located at 22º14’02” S e 47º37’23” W and in the Soil and Water Quality Lab of the Biosystems Engineering Department of ESALQ/ESP. The classification of the soil where the experiment was performed is a eutroferric red nitisol (SANTOS *et al*, 2012).

The capacitive probe used was a Diviner® FDR model (Sentek). The probe access tubes were made of PVC, with a diameter of 50 mm and length of 1.4 m. The probe’s sensor collects the relative frequency (RF) with single measurements at each 10 cm of depth.

The capacitive probe calibration was based on the manufacturer’s recommendation, proposed by Sentek (2011), with 3 levels of moisture being used (Figure 1).

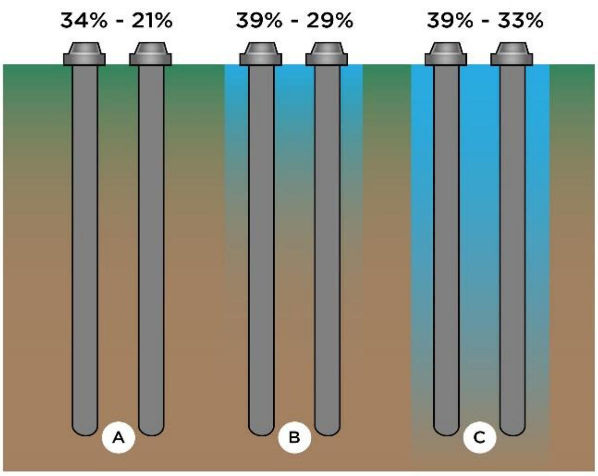

Figure 1. Schematic representation of the moisture levels used to retrieve the undeformed samples used to calibrate the FDR probe. A – dry soil. B – soil moisture close to field capacity. C – soil moisture at field capacity.

To achieve a level of moisture close to saturation, the day before collection, around 250 mm of water were applied in an infiltrometer ring that encompassed each calibration tube. To measure the dry soil humidity, it was left until the soil humidity reached a level close to the permanent wilting point, obtained through the characteristic soil moisture retention curve. Measurement for moisture close to field capacity level was done 2 days after a sequence of 5 days of rain, totaling 51.3 mm.

Firstly, it was necessary to manually install six tubes, in sets of two, representing saturated, field capacity and dry soil. Then, three two-meter trenches were opened with the use of a backhoe, in which it was possible to manually collect undeformed soil samples every 0.1 m to a depth of 0.9 m. Sampling was done by means of metal volumetric rings, with three repetitions per layer.

During the soil collection, a data collection sweep was done with the FDR sensor at all depths, to compare the relative frequency (RF) data with soil moisture (θ). After collecting the soil samples, the wet weight of each one was obtained and, after, they were placed in an electric oven at a temperature of 105 °C until they achieved a constant weight, to obtain their dry weight.

The volumetric moisture (θ, cm^3 cm^{-3}) was determined through the difference of the wet weight and the dry weight of the soil, subtracting the weight of each ring. In calculating the total density of the soil (Ds), the weight of the ring was subtracted from the dry weight of the undeformed soil sample, dividing the resulting value by the volume of the ring.

The actual volumetric moisture calibration equations (θ_a, cm^3 cm^{-3}) in relation to the relative frequency (FR) specific to each layer of soil were obtained through potential regression and follow the model presented in Equation 1:

$$\theta = a \ FR^b \qquad (1)$$

In which:

a e *b* – strength regression parameters

The data estimated with the equations were compared to the observed moisture data, utilizing the determination coefficient (R^2) and the root mean square error (RMSE).

RESULTS AND DISCUSSION

The volumetric moisture profiles (θ) for each depth in the three proposed moisture conditions (saturated, wet, and dry) are presented in Figure 2. The moisture varied from 0.21 $cm^3 cm^{-3}$ for the dry soil condition at a depth of 0.10 m, to 0.39 $cm^3 cm^{-3}$ for the saturated soil condition at a depth of 0.40 m.

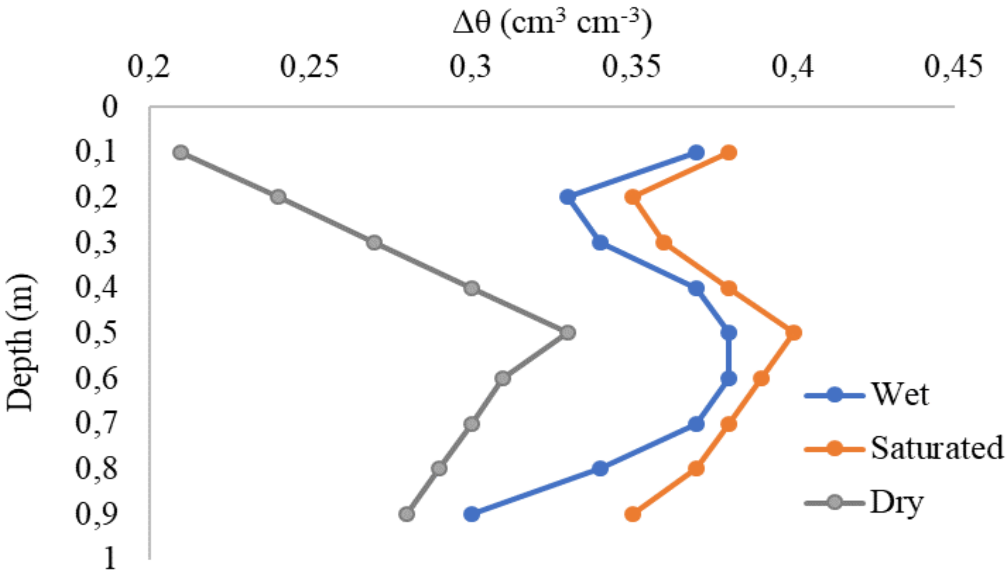

Figure 2. Volumetric moisture for three moisture conditions (saturated, wet and dry) in an Eutroferric Red nitisol, in Piracicaba-SP, 2018.

The large variation in moisture for the dry soil should be highlighted (0.21 to 0.33 $cm^3 cm^{-3}$), due to the physical characteristics of each layer. The largest volumetric moisture values were observed at the depth between 0.40 m and 0.60 m, being explained by the elevated clay content (60.88 and 60.42 %), high microporosity value, and low saturated hydraulic conductivity values of the soil (1.04 and 0.93 cm h^{-1}). These factors result in higher water retention in these layers, since the clay content and percentage of micropores are related to higher specific surface values for the soil particles. The higher the surface area of the particles, the higher the tendency for them to be joined and consequently, the higher the water retention capacity (SAFADOUSTA *et al.*, 2014).

The frequency scale readings at each depth for the three moisture conditions proposed (saturated, wet and dry) are demonstrated in Figure 3. The variation in the relative frequency was from 0.62 at a depth of 0.6 m, for the dry soil condition, to 0.92 at a depth of 0.20 m, for the saturated soil condition.

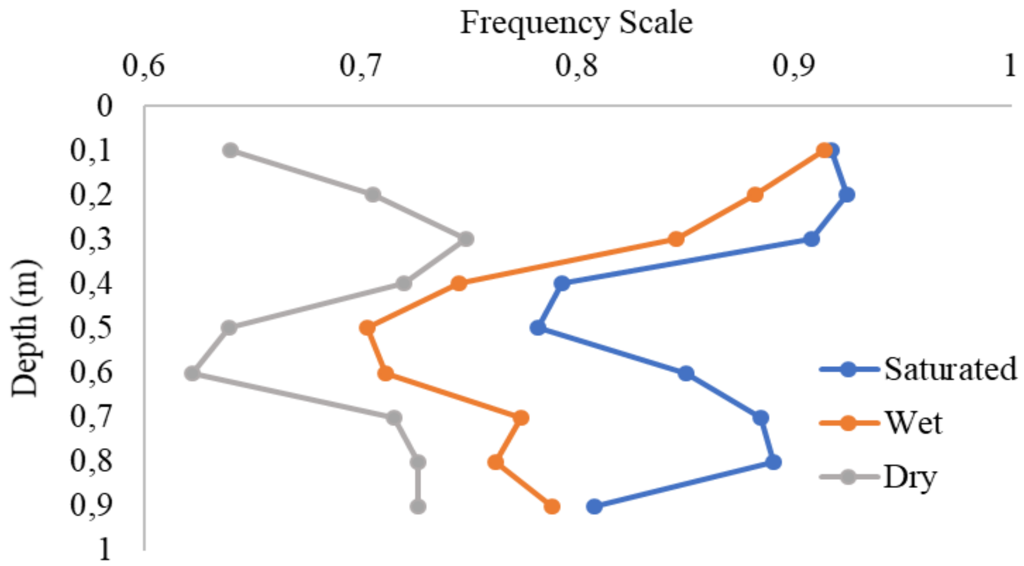

Figure 3. Frequency scale for three moisture conditions (saturated, wet and dry) in a Eutroferric Red nitisol, in Piracicaba-SP, 2018.

There were differences in regards to the FR values, especially in the layers below 0.40 m. The reasons for this variation can also be tied to the soil's physics, being that, beginning at this depth, there is a percentage of clay between 58% and 61%. Bohme *et al.* (2013) performed FDR probe calibration in Kenya, in soils with high concentrations of clay (54% to 79%), and noted that there is a negative correlation between the total volume of pores and the moisture content of the soil.

Table 1 contains the calibration equations, the determination coefficient, the root mean square error (RMSE), and the maximum and minimum moisture values obtained for each depth for each soil profile evaluated. High R^2 values were noticed in the first layers, varying from 0.98 to 0.82, and RMSE from 0.009 and 0.019, in the layers from 0-10 m and 0.2-0.3 m, respectively. In the layers starting at 0.5 m, it was possible to verify lower determination coefficients and higher error values, with R^2 varying from 0.90 to 0.70, and RMSE from 0.011 to 0.025 cm3 cm^{-3} in the layers from 0.4-0.5 m and 0.7-0.8 m, respectively.

Table 1. Calibration equations and minimum and maximum moisture values per layer and for the whole soil profile (0-0.9 m).

Layers (m)	Calibration Equation	R^2	RMSE (cm^3 cm^{-3})	θ_{min} (cm^3cm^{-3})	θ_{max} (cm^3cm^{-3})
0-0,1	θv= 0,4207 *FR^{1,4377}	0,98	0,009	0,21	0,37
0,1-0,2	θv= 0,4025 *FR^{1,4975}	0,87	0,017	0,23	0,35
0,2-0,3	θv= 0,4034* FR^{0,9132}	0,82	0,019	0,26	0,38
0,3-0,4	θv= 0,4402*FR^{1,0335}	0,88	0,012	0,30	0,39
0,4-0,5	θv=0,4014*FR^{0,536}	0,80	0,011	0,32	0,38
0,5-0,6	θv=0,475*FR^{1,04}	0,78	0,018	0,30	0,38
0,6-0,7	θv=0,4239*FR^{0,8381}	0,73	0,016	0,31	0,37
0,7-0,8	θv=0,445*FR^{1,3891}	0,70	0,025	0,26	0,37
0,8-0,9	θv=0,5004*FR^{1,3137}	0,79	0,019	0,27	0,37
0-0,9	θv =0,4067*FR^{0,9287}	0,64	0,025	0,21	0,39

θv = volumetric moisture or water content in the soil, FR = relative frequency.

The increase in error and the decrease in the R^2 values also were found by Haberland *et al*. (2015), who performed specific calibration for each depth to 0.6 m, in order to estimate water content in the soil by use of an FDR Diniver 2000 probe in a vineyard in the O'Higgins region, in Chile. The R^2 values and RMSE decreased at greater depths, showing a R^2 variation from 0.93 to 0.59 and RMSE from 0.017 to 0.078 cm^3 cm^{-3}, for the layers from 0-0.1 m and 0.5-0.6 m, respectively.

Oliveira (2016) performed an FDR *EnviroSCAN* probe calibration in a dystrophic red latosol (oxisol) in the Campinas-SP region, also observing lower R^2 values in deeper layers, from R^2 = 0.91 to 0.67 at depths from 0.4 m and 0.8 m, respectively. Furthermore, higher R^2 values were verified for the calibration per soil layer compared to the single calibration for the whole soil profile, which had a determination coefficient of only 0.60, close to the value determined in this experiment (R^2 = 0.64).

The heterogeneity of the soil density at deeper layers can be a source of error in the frequency scale of the capacitive probes, due to the due to the difference in the quantity of solid material, which can interfere in the frequency captured by the sensor, due to the alteration in the dielectric constant of the soil. Schwartz *et al.* (2014) worked with an automated TDR probe and found variation in the physical characteristics of the soil, which exerts influence on the indirect measuring of the probe. The authors recommended obtaining specific calibration equations for each depth by heterogeneity of the soil profile.

Another possible source of bias is the high iron content present in weathered soils such as nitisols, which influences the electrochemical attributes of the soil. Kaiser *et al.* (2010) performed a study aimed at establishing mathematical correlation models between humidity and dielectric constants in an argosol, two latosols, and one nitisol, based on humidity estimations obtained with a TDR probe. The authors verified the need for specific calibrations for each of these weathered soil types, due to the higher iron content in their compositions.

In light of this, it is fundamental to perform an equation calibration per soil layer, in order to minimize errors in the soil moisture readings and, consequently, in the interpretation of the water consumption of the cultivations.

CONCLUSIONS

The FDR probe was found adequate for measuring soil moisture in Eutroferric Red nitisols. The calibration by depth allowed for higher accuracy when compared to the average of the profiles. It is recommended for studies estimating water consumption and cultivation coefficients.

REFERENCES

AL-GHOBARI, H. M.; EL MARAZKY, M. S.; ABOUKARIMA, A. M.; MINYAWI, M. Calibration of Soil Water Content Data from EnviroSCAN System Using Artificial Neural Network. **American Journal of Experimental Agriculture**, v. 12, n. 5, 2016.

ARAÚJO PRIMO, J. T. **Dinâmica de água no solo e eficiência do uso de água em clones de palma forrageira no semiárido pernambucano**. Dissertação (Mestrado em Produção Vegetal)-Universidade Federal Rural de Pernambuco, Unidade Acadêmica de Serra Talhada, Serra Talhada, 108 f, 2013.

BÖHME, B.; BECKER, M.; DIEKKRÜGER, B. Calibrating a FDR sensor for soil moisture monitoring in a wetland in Central Kenya. Physics and Chemistry of the Earth, Parts A/B/C, v. 66, p. 101-111, 2013.

CREMON, C.; LONGO, L.; MAPELI, N. C.; MENDES, L. A.; DA SILVA, W. M. Determinação da umidade de diferentes solos do Pantanal Matogrossense via micro-ondas e método padrão. **Agrarian**, v. 7, n. 24, p. 280-288, 2014.

FAOAQASTAT. Area equipped for full control irrigation. Disponível em:http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en.Acesso em 10 dez 2016.

HABERLAND, J.; GÁLVEZ, R.; KREMER, C.; ZUÑIGA, C.; RUDOLFFI, Y. Accurate soil water content monitoring in real time with appropriate field calibration of the fdr device "diviner 2000" in a commercial table grape vineyard. **International Journal of Science Environment and Technology**, v. 4, n. 2, p. 273-284, 2015.

KAISER, D.R.; REINERT, D.J.; REICHERT, J.M.; MINELLA, J.P.G. Dielectric constant obtained from TDR and volumetric moisture of soils in southern Brazil. **Revista Brasileira de Ciência do Solo**, v.34, p.649 658, 2010.

KHANNA, N.; SINGH, G.; JAIN, D.K.; KAUR, M. Design and Development of soil moisture sensor and response monitoring system**. International Journal of Latest Research in Science and Technology**, v.3, n.6, p.142-145, 2014.

LIMA, J. E. F. W.; SILVA, E. M. Avaliação do desempenho de sonda de capacitância no monitoramento da umidade de latossolo do cerrado em condições de campo. **Revista Brasileira de Recursos Hídricos**, v. 17, n.1, p.23-32, 2012.

NASCIMENTO, R.; CUNHA, L.; RAMOS, D. Comparações entre o ponto de carga zero (titulação potenciométrica), mineralogia e diversos outros parâmetros para quatorze perfis de Latossolos. Reunião de classificação, correlação de solos e interpretação de aptidão agrícola, Rio de Janeiro, p. 365-390, 1984.

OLIVEIRA, L. A. A. **Uso da técnica de reflectometria no domínio da frequência para estimativa de umidade em Latossolo Vermelho distroférrico**. Dissertação (Mestrado em Engenharia Agrícola), Faculdade de Engenharia Agrícola, Universidade Estadual de Campinas, Campinas, 114p, 2016.

PROVENZANO, G.; RALLO, G.; GHAZOUANI, H. Assessing field and laboratory calibration protocols for the diviner 2000 probe in a range of soils with different textures. **Journal of Irrigation and Drainage Engineering**, v. 142, n. 2, 2015.

SAFADOUSTA, A.; FEIZEEA, P.; MAHBOUBIB, A. A.; GHARABAGHIB, B.; MOSADDEGHIC, M. R.; AHRENSD, B. Least limiting water range as affected by soil texture and cropping system. **Agricultural Water Management**, v. 136, n. 1, p. 34-41, 2014.

SANCHES, C.A. **Coeficiente de cultura (Kc) e correlações de consumo de água, fatores produtivos e biométricos de gramíneas tropicais em cultivo exclusivo e em sobressemeadura com forrageiras de inverno**. Tese de Doutorado. USP/Escola Superior de Agricultura "Luiz de Queiroz". 165 p. Piracicaba. 2017.

SANTOS, K. S; MONTENEGRO, A. A. A.; ALMEIDA, B. G.; MONTENEGRO, S. M. G. L.; ANDRADE, T. S.; FONTES JUNIOR, R.P.V . Variabilidade espacial de atributos físicos em solos de vale aluvial no semiárido de Pernambuco. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v. 16, n. 8, p. 828–835, 2012.

SCHWARTZ, R. C.; CASANOVA, J. J.; BELL, J. M.; EVETT, S. R. A reevaluation of time domain reflectometry propagation time determination in soils. **Vadose Zone Journal**, v. 13, n. 1, 2014.

SENTEK. Calibration Manual: For Sentek Soil Moisture Probes. Stepney: Sentek Pty Ltd, 2011.

SILVA, D. O. M. da. **Validação de um sensor de determinação da umidade do solo para o manejo da irrigação**. Dissertação (Mestrado em Engenharia Agrícola). 2013. 63 f. Universidade Federal do Vale do São Francisco.

SOUZA, C. F.; da SILVA, R.C.; ANDRADE JUNIOR, S.A.; COELHO, E.F. Monitoramento do teor de água no solo em tempo real com as técnicas de TDR e FDR. **Irriga**, v. 1, n. 1, p. 26-42, 2016.

VIONE, M. T. **Modelagem matemática da evaporação da água do solo**. Dissertação (Mestrado em Modelagem Matemática), Departamento de Física, Estatística e Matemática da Universidade Regional do Noroeste do Estado do Rio Grande do Sul, Unijuí, 76 p. 2007.