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CALIBRATION OF THE CAPACITANCE PROBE FOR SOIL MOISTURE MONITORING

CALIBRAÇÃO DA SONDA DE CAPACITÂNCIA PARA MONITORAMENTO DA UMIDADE DO SOLO

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ABSTRACT: To obtain efficient use of water applied in irrigation, it is necessary to understand the dynamics of water in the soil, which is an important factor in agriculture. The aim of this study was to determine models for calibration and to evaluate thelysimetry methodwith undisturbed samples,using a capacitance probe for monitoring the moisture content of a TypicHapluderts soil under laboratory conditions. The predominant soil in the study area is from the TypicHapluderts soil unit. The soil samples were collected with undisturbed samples, in layers of 0 - 10 cm and 10 - 20 cm depth from the surface, using PVC pipes with a diameter of 315 mm and 600 mm height. The determination of the variation in soil moisture was carried out by weight difference (weighing lysimetry method). The measurements with a Frequency Domain Reflectometry (FDR) were made on a daily frequency and 6 repetitions per measurement. Analyzed calibration models (linear, potential and quadratic), was performed the Shapiro-Wilk normality test. The methodology used provided satisfactory results, with multiple repetitions being performed on the same sample. The model that showed greater precision and better fit for the two profiles under study was the quadratic model.

Keywords: *Soil water content, Capacitance probe, Efficient use of water, TypicHapluderts, Irrigation.*

RESUMO: Para obter um uso eficiente da água aplicada em irrigação, é necessário entender a dinâmica da água no solo, que é fator importante na agricultura. O objetivo deste estudo foi determinar modelos de calibração e avaliar o método da lisimetria com amostras não perturbadas de solo, usando uma sonda de capacitância para monitorar o teor de umidade de um solo TypicHapluderts em condições de laboratório. O solo que predomina na área de estudo é do tipo TypicHapluderts. Foram coletadas amostras indeformadas de solo, em camadas de 0 - 10 e 10 - 20 cm, utilizando tubos de PVC com diâmetro de 315 mm e altura de 600 mm. A determinação da variação de umidade do solo foi realizada pela diferença de peso (método lisimetria de pesagem). As medições com a Reflectometria no Domínio da Freqüência (FDR) foram feitas com frequência diária e 6 repetições por medição. Foram realizados modelos de calibração lineares, potencial e quadrática, também foi realizada teste de normalidade de Shapiro-Wilk. A metodologia empregada apresentou resultados satisfatórios, sendo realizadasmúltiplas repetições na mesma amostra. O modelo que apresentou maior precisão e melhor ajuste para os dois perfis em estudo, foi o modelo quadrático.

Palavras-chave: *Conteúdo de água no solo, Sonda de capacitância, Uso eficiente da água TypicHapluderts, Irrigação.*

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INTRODUCTION

To obtain an efficient use of water applied in irrigation (relationship between water consumption/yield), it is necessary to understand the dynamics of water in the soil, which is an important factor in agriculture. Oliveira et al. (2020) highlight the irrigation management based on monitoring the water content in the soil as a technique that helps the irrigator in making a decision on when and how much water to apply, thus providing the attainment of high yields. With efficient monitoring of soil moisture, irrigation management can be carried out properly, with savings of up to 20% of water and 30% of energy (LIMA et al., 1999).

Another important factor to be considered, for the proper irrigation management is the reduction of the plants' predisposition to diseases resulting from the excess of water applied, in addition to the reduction of fertilizer losses due to leaching, which consequently reflect on the costs of inputs and agricultural pesticides (MAROUELLI et al., 2008; MENDES et al., 2016).

Klein (2008), there are several methods and techniques for determining soil water content, each with its own particularities, in some cases complicated and quite imprecise depending on the soil condition. The main differences between one method and another are costs, measurement method, response time and field operability. As an example of this, direct methods stand out, such as the gravimetric method, considered standard and used for calibration of other methods, but for practical application of management, it is considered a laborious method and requires a response time of at least 24 hours to obtain the result, not allowing repeatability (SOUZA et al., 2013). The use of existing indirect methods to determine the volumetric content of water in the soil has been increasing, as it has the advantage of being a non-destructive method (ABREU et al., 2018); additionally, it is noteworthy that the use of sensors is one of the most accurate means to monitor the water content in the soil, whose technology and application has brought several contributions to the agricultural environment (ABREU et al., 2018). Capacitive-type sensors have an operating principle based on electrical capacitance. Murillo (2001), its application has been widespread in research related to irrigation, as it is a non-invasive method.

Sensors based on Frequency Domain Reflectometry (FDR) are alternatives for quantifying the soil water content, providing accurate and fast readings at different depths (ZHU et al., 2019).

The FDR probe, also known as capacitance probe, is based on a pair of electrodes arranged in parallel and separated by insulating material, constituting a capacitor that when inserted into the ground and activated the water-air matrix forms the dielectric medium of this capacitor. Where capacitance increases with increasing number of free water molecules (BARBOSA et al., 2012; SOUZA et al., 2013).

As main advantages of using FDR sensors, operator safety can be highlighted since there is no radioactive source, ease of operation, provision of fast and accurate readings in depth, possibility of taking indirect moisture readings in several places with just one probe. In addition to being easily adaptable to automatic data collection systems (ANDRADE et al., 2007; GIRALDI; IANNELI, 2009).

These sensors are based on reading the dielectric constant of the soil and present a calibration equation provided by the manufacturer that converts the obtained value to the soil moisture content. However, the dielectric constant of the soil presents variability in terms of salinity, texture, density, soil class and moisture content, therefore, it is necessary to carry out specific calibrations of the sensors for each soil condition, for its correct use (CRUZ, 2018).

The calibration of these sensors takes time, due to the high number of repetitions that are necessary to obtain measurements for a wide range of moisture, these calibrations are necessary mainly in clayey soils and/or with a high content of organic matter (CAICEDO et al, 2021). Thus, considering that different soil properties influence the accuracy of the reading of capacitive probes, calibration as a function of specific conditions for each situation is necessary.

The aim of this study was to determine models for calibration and to evaluate thelysimetry methodwith undisturbed samples,using a capacitance probe for monitoring the moisture content of a TypicHapluderts soil under laboratory conditions.

MATERIAL AND METHODS

The study, was carried out in the laboratory of the Water Department of the Republic University (Uruguay), CENUR-Litoral Norte.

Soil samples were collected in the area of the San Antonio experimental station of the Agronomy Faculty (FAGRO-UdelaR), located on National Route 31, km 21, next to San Antonio´s town, Department of Salto in Uruguay, in the coordinate’s geographical latitude 31º22'31.5"S, longitude 57º43'3.6"W, altitude 82 m.s.n.m.

The climate in the region is classified as humid subtropical, denominated (Cfa), according to the system of classification of Köppen-Geiger (1928). The average annual values of the parameters: precipitation, average temperature and relative humidity are 1322 mm, 18.1°C and 72%, respectively.

Table 1. Granulometric composition and soil water parameters.

Depth (cm)	Texture (%)			Water parameters of the soil				Horizon
	Sand	Silt	Clay	OM (%)	FC (Hv)	PWP (Hv)	BD (gcm^{-3})	
0-20	27	25	48	5.2	37.1	22.4	1.2	Au1
20-40	5	36	59	1.6	32.7	19.2	1.4	Au2
40-60	7	31	62	1.3	32.0	18.7	1.4	Au3
60-80	7	30	63	0.4	33.9	20.1	1.4	Ck

OM: Organic Matter, FC: Field Capacity, PWP: Permanent Wilting Ponit,BD: Bulk Density

Soil classification according to the Soil and Fertilizer Directorate of the Ministry of Livestock, Agriculture and Fiseries in 1976. Uruguay. The predominant soil in the area is typical Brunosoleutrico of the soil unit Itapebí –Three Trees. According to the classification proposed by the Soils and Fertilizers Direction of the MGAP (1976) for the soils in Uruguay and according to the taxonomy of solo (USDA, 1999) gives the unit of solo TypicHapluderts.

The physical and hydric parameters of the soil are shown in (Table 1). Soil samples were collected with undisturbed sampling in layers of 0-10 cm from the surface to 10-20 cm deep (2 samples), using PVC pipes with a diameter of 315 mm and height of 600 mm. The pipes were driven into the ground with hydraulic pressure. Before introducing the pipes, the soil was moistened to field capacity to facilitate penetration of the pipes. Later, a trench was made to remove the pipes and take them to the laboratory. In the laboratory the pipes were submerged in water tofield capacity. Access tubes for the FDR with a diameter of 52 mm and a length of 500 mm was installed in the center of each PVC pipe. A mesh was placed at the bottom of each PVC pipe to facilitate water drainage and prevent soil leakage.

The determination of soil moisture variation was performed by the difference in weight (weighing lysimetry method). Each PVC pipe was placed on an electronic scale with a maximum capacity of 60 kg, minimum 250 g and an accuracy of 10 g. Before and after each FDR measurement each PCV pipe was weighed to calculate the water loss in each sample. Measurements were made with daily frequency and with 6 repetitions per measurement, the entire procedure being repeated 6 times to obtain greater accuracy in the FDR calibration. Regression analyzes was made for the 6 repetitions, were performed to determine the relationship between soil moisture and moisture estimated by the capacitance probe. The linear models being obtained (y = a + b x), potential (y = axB) and quadratic ($y = a + bx + cx^2$). The Shapiro-Wilk coefficients of determination (R^2) normality test was performed. Mean squared errors (MSE) and root mean square error (RMSE). The final model was selected based on the combination of the highest R^2 at a significance level of 5% the lowest MSE the lowest RMSE.

Regression analysis was performed with SPSS® version 20 software and graphs with SigmaPlot® version 12.5 software.

RESULTS AND DISCUSSION

Soil is a "receiver, collector and delivery" of water for crops. Knowing the changes in moisture in the soil profile is a key factor not only in determining water consumption and availability for crops but also for research, agricultural production and efficient use of water.

The models obtained from the FDR calibration for different soil depths are shown in Table 2 and Figure 1.

The regression coefficient showed an excellent fit for all models (>0.9). For both soil profiles the quadratic model presented the best fits. It minimized the mean square error and provided greater adjustment of the regression coefficient and greater normality test. The methodology used provided satisfactory results, performing multiple repetitions on the same sample.

About the mean square error (MSE), the values observed for the quadratic model were 0.0128 and 0.0062 for the soil profiles of 0 - 10 and 10 - 20 cm respectively.

Table 2. Capacitance probe (FDR) calibration models for TypicHapluderts soil.

Model	Parameter			R^2	MSE	RMSE	Normality Test (Shapiro-Wilk)
	A	b	c				
0 - 10 cm							
F=a*x+b	0.0617	-1.5870		0.98	0.0177	0.13	0.84
F=a*x^b	1.145e-5	3.0584		0.98	0.0153	0.12	0.89
F=a*x^2 – b*x + c	0.057	-0.3766	6.840	0.99	0.0128	0.11	0.94
10 – 20 cm							
F=a*x+b	0.0186	0.1720		0.93	0.0101	0.10	0.88
F=a*x^b	0.0562	0.7699		0.93	0.0102	0.10	0.87
F=a*x^2 – b*x + c	0.0036	0.2620	5.612	0.97	0.0062	0.08	0.91

R^2: Coefficients of determination, MSE: Mean Squared Errors, RMSE: Root Mean Square Error.

In a study carried out by Oliveira et al. (2020) similar results were found in different soil layers. Inindividual profiles an improvement was observed in most of the correlation coefficients and a minimization of the mean square error, obtaining high coefficients of determination for depths of 10 - 60 cm (R^2>0.93).

Nonetheless, the equation that best fit was the potential.In the research by Morlaet al. (2016), the adjustment levels obtained from the regression coefficient in the range from

0.69 to 0.88 and the average coefficients from 0.80. In all the fitting equations were statistically significant ($p<0.05$). Based on this, we can conclude that the use of calibration equations makes it possible to improve the level of adjustment of the data measured with the probe and those obtained by the gravimetric method.

Thus, it was possible to reduce by more than half the level of average error in relation to that presented by the manufacturers (standard), which allowed to obtain greater accuracy of the readings with the probe. Calibrations performed on different soil types around the world report levels of regression coefficient adjustments ranging from 0.58 to 0.99.

Unlike this study, Pizetta et al. (2017) when calibrating a FDR-capacitive sensor, observed that linear equations were the ones that best fit for the studied soil classes (Red DistrophicOxisol, Red DistroferricOxisol and Eutrophic Red Nitosol). Even though the adjustment factor was less than 0.72 for all soil classes, attributing the sensor's poor performance to the considerable clay content.

It is observed that the clay content present in the studied soil is close to the clay content of the author's soils. However, the organic matter content of this research is higher. That is. 5.2%.

While in the three soil classes the author presented values between 2.23 and 2.87%. In consequence, the difference between the curve fit can also be attributed to the organic matter content present in the soil, as it is known that this has a great influence on the storage of water in the soil and as highlighted by (Böhme et al., 2013), soils with high water contents can influence the measurements of capacitive sensors.

In a dystrophic Red Latosol, Júnioret al. (2018) analyzing the EC-5 capacitive sensor at different soil densities observed that the current volumetric moisture (θa) was overestimated by the calibration provided by the manufacturer.

In the same way, the overestimation of θa increased with the increase in soil water content above the values of 0.20 mm/10cm, the lower water content in the soil, the best is the manufacturer's default calibration

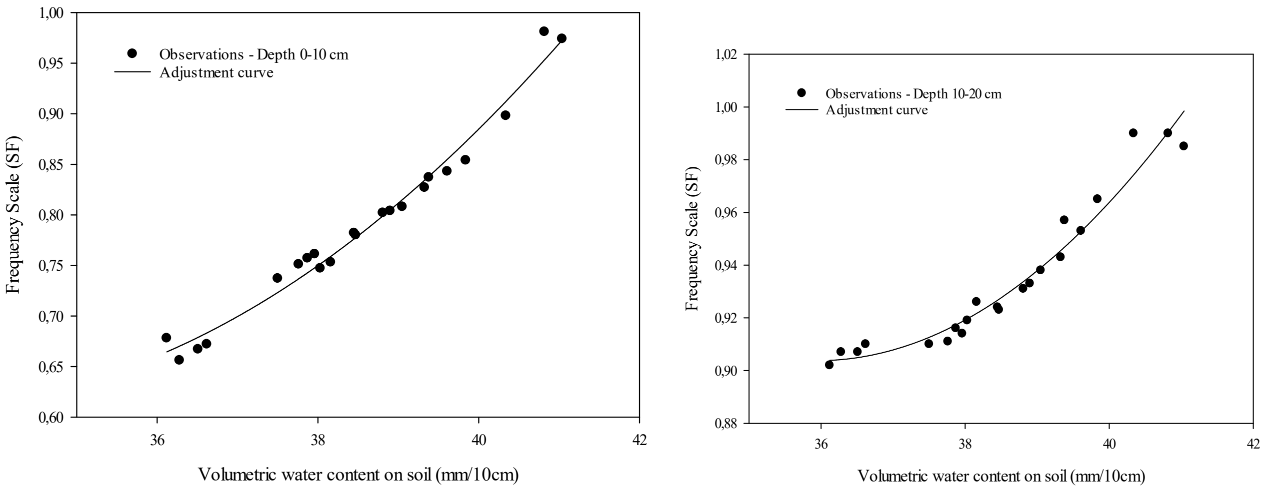

Figure 1. FDR calibration curve for the depths of 0 - 10 and 10 - 20 cm in the quadratic model.

CONCLUSIONS

The model that showed greater precision and better fit for monitoring soil moisture content using the FDR capacitance probe in a TypicHapluderts soil, for the two profiles under study, was the quadratic model.

With a low-cost implementation, we apply the weighing lysimetry method, accurately estimate soil moisture using undisturbed samples in the laboratory, obtaining satisfactory results. Using a low-cost implementation weighing lysimetry method.

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