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Response of the TDR sensor to moisture under different types of management of a typical Latosol in the Cerrado[1]

Resposta do sensor TDR à umidade sob diferentes manejos de um Latossolo típico do Cerrado

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ABSTRACT - The technique of Time Domain Reflectometry (TDR) is important in the evaluation of soil moisture due to being an instantaneous method, which is non-destructive, precise and little dependent on environmental factors. However, researchers have emphasised the need for continuous specific calibration for each soil-management situation. The aim of this work therefore, was to evaluate the response of a portable TDR sensor to soil moisture in a Dystroferric Red Latosol in the Cerrado, under three different systems of soil management and at three different depths in the soil profile. To do this, TDR equipment consisting of two rods, each 0.12 m in length, was used for instantaneous measurement of the volumetric water content of the soil. The depths of 0-0.12, 0.12-0.24 and 0.24-0.36 m were evaluated under three different systems: no-tillage (NT), crop-livestock integration (CLI) and conventional planting (CONV). The response of the TDR sensor varied for both the type of management and for depth. After statistical regression analysis of the data, the values for moisture as a function of the response period of the sensor, and the correlation between moisture by TDR and moisture by the gravimetric method, were highly representative. This demonstrated that the apparatus under evaluation proved to be effective in measuring soil moisture at each depth and under each management system in the specific Latosol under analysis, displaying statistical differences between the treatments.

Key words: Soil water content. Soil management. Dielectric permittivity. Cropping systems. Time domain reflectometry.

RESUMO - A técnica de Reflectometria no Domínio do Tempo (TDR) tem se destacado na avaliação da umidade do solo, por ser um método instantâneo, não destrutivo, preciso e pouco dependente dos fatores ambientais. Porém, pesquisadores têm enfatizado a necessidade de calibração específica e contínua para cada condição de manejo do solo. Portanto, objetivou-se com este trabalho avaliar a resposta à umidade do solo de um sensor portátil do tipo TDR para um Latossolo Vermelho Distroférrico do Cerrado sob três diferentes sistemas de manejo do solo em três profundidades distintas no perfil do solo. Para isso, utilizou-se um equipamento TDR composto por duas hastes de 0,12 m de comprimento cada, com medição instantânea do conteúdo volumétrico de água no solo. Avaliaram-se as profundidades de 0 - 0,12; 0,12 - 0,24 e 0,24 - 0,36 m em três diferentes manejos: plantio direto (PD), integração lavoura-pecuária (ILP) e plantio convencional (CONV). A resposta do sensor TDR variou com o tipo de manejo e profundidade. Após análise estatística dos dados por meio de regressão, observou-se boa representatividade dos valores de umidade em função do período de resposta do sensor e da correlação entre a umidade pelo TDR e umidade pelo método gravimétrico. Este fato indicou que o aparelho avaliado se apresentou eficaz na mensuração da umidade do solo em todas as profundidades e sistemas de manejo do especifico Latossolo analisado, com diferença estatística entre os tratamentos.

Palavras-chave: Conteúdo de água no solo. Manejo do solo. Permissividade dielétrica. Sistemas de cultivo. “Time domain reflectometry”.

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INTRODUCTION

Because of the difficulties involved in determining soil moisture by direct methods (e.g. gravimetric), indirect methods are generally used, where moisture is estimated by measuring a related soil attribute (MIRANDA *et al*., 2007).

Among the indirect methods of determining soil moisture, Time Domain Reflectometry (TDR), which relates moisture to the dielectric properties of the soil-water-air environment, has become prominent in recent years, and has been used by several researchers for evaluating humidity and other soil attributes (BROCCA *et al*., 2009, COPPOLA *et al*., 2011, PENNA *et al*., 2013, TOPP; DAVIS; ANNAN, 2003).

The TDR sensor quickly and accurately uses the indirect method to determine soil moisture. In addition, it depends little on environmental factors, allowing automatic collection in real time of data distributed spatially (GONÇALVES *et al*., 2011). According to Silva and Gervásio (1999), TDR establishes the dielectric constant (ε) of the soil by measuring the return time (t), i.e. the time that an electromagnetic pulse emitted by parallel conductive rods of length L driven into the ground returns to the point of emission. This dielectric permittivity of the soil, which explains the principle of sensor operation, is mainly related to the amount of water present in the substrate, given the range of ε (dimensionless) in the constituent fractions of the soil. For air, ε is almost equal to that of a vacuum, i.e. equal to one. For dry soil, ε usually ranges from 2 to 5, while for free water, the value is approximately 81 (SILVA; ANDRADE JÚNIOR; SOUZA, 2008). Gonçalves *et al*. (2011) demonstrated that these dielectric sensors provide a high correlation with residual soil moisture (θ), indicating a potential for quantitative measurements when well calibrated.

Topp *et al*. (1988) proposed a third-degree polynomial to convert the values for the soil dielectric constant into volume-based moisture, whose precision is sufficient to suggest the use of TDR without the need to calibrate for different soils. However, other researchers (ABBAS; FARES; FARES, 2011; GONÇALVES *et al*., 2011; SOUZA *et al*., 2013) have emphasised the need for continuous specific calibration for each soil under study, since ε varies according to the soil characteristics and the consequent variation in soil moisture.

Therefore, based on the hypothesis that moisture transducers are capable of detecting the presence of water in any type of soil, irrespective of the management system, the aim of this study was to evaluate the response of the TDR sensor to moisture in a dystroferric Red Latosol, typical of the Cerrado, under three different management systems, and at three different depths.

MATERIAL AND METHODS

Location of Experiment

The experiment was conducted at the Federal University of Goiás (UFG), in Jataí, in the southwest of the State of Goiás, Brazil (Figure 1), located at 17º53' S and 51º43' W, at an altitude of 670 m. The climate in the region is typical of the Savannah (Aw): mesothermic, rainy from October to April and dry from May to September. According to Embrapa (2009), the soil under study is classified as a dystroferric Red Latosol (RLdf).

Experimental Area

The experimental area consisted of three sub-areas, each of approximately 1.0 ha, cultivated with soybean (*Glycine max*) during the 2013/2014 season (first crop), under different systems of soil management. Over the years, the sub-areas have been cultivated with soybean (first crop) and maize or sorghum (second crop), under a no-tillage system (NT) since 2008 (sub-area 1); soybean intercropped with brachiaria under crop-livestock integration (CLI) since 2009 (sub-area 2); and soybean under conventional no-tillage (CONV) and harrowing at the time of planting (sub area 3). Each sub-area was divided into a regular grid containing nine cells measuring 30 x 30 m (Figures 1a, 1b and 1c), where the centre of each cell was considered the sampling control point for collection.

Sampling and Data Collection

In the three sampling sub-areas, nine samples were extracted at three depths to determine the physical attributes of the soil, such as texture (Sand, Silt and Clay), overall density (dg) and organic matter content (OM). Also, 1,926 soil moisture readings were carried out at depths of 0-0.12 m, 0.12-0.24 m and 0.24-0.36 m, using a HYDROSENSE™ portable Time Domain Reflectometry sensor (TDR), with 0.12 m long rods, which gives instantaneous readings of the non-calibrated residual volumetric moisture (θ_{TDR}) of the soil (Figures 2A and 2B).

The collections took place between 19 November 2013 and 15 January 2014, which made it possible to obtain a variation in soil moisture due to climate variability between the months under analysis.

To calibrate the TDR sensor, a methodology suggested by Abbas, Fares and Fares (2011) was used, where, at the same time as monitoring the residual moisture, six soil samples were randomly collected from each depth at five sampling control points for each management system, giving a total of 270 disturbed samples.

Figure 1 - Location of the experiment (State Geoinformation System of Goiás - SIEG, 2014) (a); satellite image of the study area (© Google Earth, 20/4/2014) and (b); sketch of the distribution of sampling points in the study areas (c). NT: no-tillage; CLI: crop-livestock integration; CONV: conventional planting

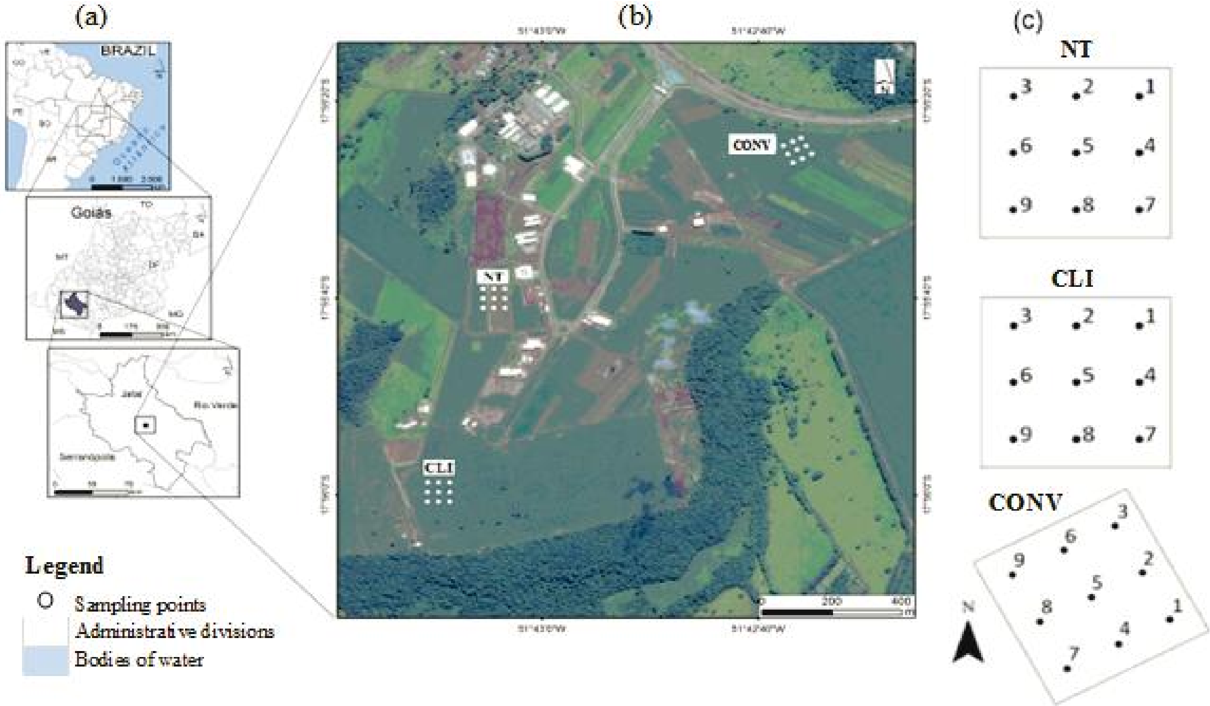


Figure 2 - Details of the TDR equipment used, with two steel rods (A) and the rods inserted into the ground during a reading (B)

From these samples, the gravimetric moisture was determined by the greenhouse method; this was later transformed into the reference volumetric moisture (θp) using bulk density. The bulk density was obtained from undisturbed samples collected from the three depths at each sample control point for each type of management, as per Ferreira *et al*. (2003) and Embrapa (1997).

Analysis of the data

All data were submitted the Shapiro-Wilk test of normality, and the Bartlett test to verify homoscedasticity (homogeneity of the variances) to meet basic ANOVA assumptions. The soil attributes, at the depths under study for each cropping system, were submitted to analysis of variance and later to the Scott-Knott mean value discrimination test at a level of 5%.

In order to calibrate the sensor, the values for residual soil moisture obtained with the TDR (θ_{TDR}) were correlated with the values for reference moisture determined by the greenhouse method (θp), generating linear equations grouped for management system and depth, as per Ávila, Mello and Silva (2010), Abbas, Fares and Fares (2011), Varble and Chávez (2011) and Souza *et al*. (2013).

The parameters of the adjusted equations were submitted to analysis of variance at a level of 5%, to attest to the validity of the linear trend and of the adjustment intercept.

RESULTS AND DISCUSSION

Soil attributes

Table 1 shows the mean values and coefficients of variation of the soil attributes evaluated in this study. A trend towards greater compaction can be seen from the values for density throughout the soil profile under the conventional management system, since the three layers of this system remained similar, whereas under the other systems, only the top layers displayed these characteristics. The higher density values seen in the profiles under evaluation may be related to the history of agricultural-machine traffic on the ground over the years, confirming the effects seen by Costa *et al*. (2003), and Assis and Lanças (2005). In the integrated crop-livestock system, the compaction of the soil is more pronounced due to trampling by the animals (ALBUQUERQUE; SANGOI; ENDER, 2001).

Differences between treatments were found for soil organic matter (OM), but with a tendency to a reduction in value for increases in depth in all the treatments under study. This observation demonstrates a profile that is characteristic of soils in general, as the deposition of dry matter is concentrated on the soil surface.

According to some authors, the calibration of moisture sensors is greatly influenced by the soil clay content. Santos, Zonta and Martinez (2010) mention abnormalities in the characteristics of the dielectric constant of water when in contact with colloidal particles (clay and organic matter), Kaiser *et al*. (2010) found that an increase in the clay and iron oxide content of the soil promoted an increase in the dielectric constant of the medium for the same volumetric moisture content, and work done by Villwock, Tavares and Vilas Boas (2004) under conditions similar to the present study (calibration of TDR probes in a dystroferric Red Latosol - RLdf) also confirms the recommendation of a specific calibration for soils with a high clay and iron content). Thus, the need for different calibrations of the TDR sensor as a function of soil characteristics becomes obvious.

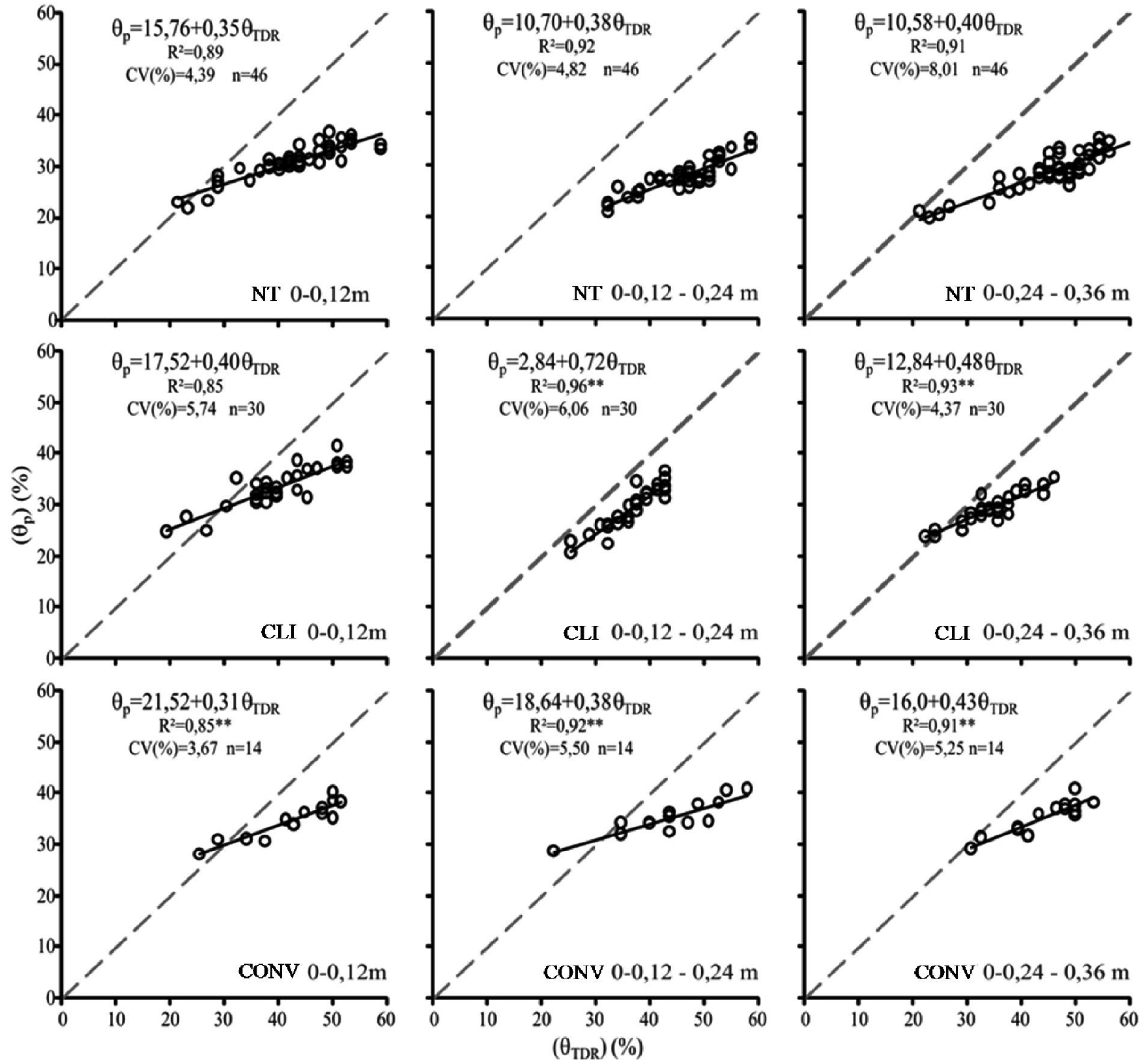
The dispersion diagrams in Figure 3 show the calibration equations adjusted for the reference humidity (θp) as a function of the volumetric moisture measured with the TDR (θ_{TDR}), grouped for the no-tillage (NT), crop-livestock integration (CLI) and conventional planting (CONV) systems at three depths. Analysis of variance of the adjustment parameters confirmed the validity of the

Table 1 - Result of the Scott-Knott mean-value discrimination test (α = 0.05, *n* = 9) for bulk density, organic-matter content and textural composition in the RLdf under study

Attribute	System	NO-TILLAGE			CL INTEGRATION			CONVENTIONAL		
	Layer (cm)	00-12	12-24	24-36	00-12	12-24	24-36	00-12	12-24	24-36
dg (g cm^{-3})	Mean	1.26 a	1.19 b	1.17 b	1.32 a	1.22 a	1.14 b	1.24 a	1.26 a	1.27 a
	CV(%)	7.98	10.23	9.69	5.46	7.98	6.92	7.69	6.23	6.73
OM (%)	Mean	3.1 b	2.7 c	2.2 d	3.4 a	3.3 a	2.6 c	3.5 a	3.4 a	2.7 c
	CV(%)	7.8	9.38	14.48	11.96	11.15	14.74	11.60	12.29	13.40
Clay (%)	Mean	45.1 c	44.3 c	48.2 b	43.1 c	46.8 b	48.3 b	57.6 a	58.0 a	58.9 a
	CV(%)	6.27	10.46	5.68	10.25	7.17	6.43	8.45	9.25	6.42
Silt (%)	Mean	28.5 a	29.4 a	25.1 b	32.0 a	27.8 a	26.5 b	26.2 b	26.3 b	23.0 b
	CV(%)	11.92	17.01	12.64	12.23	8.39	10.77	17.47	15.83	21.08
Sand (%)	Mean	26.4 a	26.3 a	26.7 a	25.0 a	25.4 a	25.2 a	16.3 b	15.7 b	18.1 b
	CV(%)	8.60	11.35	6.26	11.85	10.33	2.27	9.22	12.40	16.51

Mean values followed by the same letter on a line do not differ statistically; RLdf: Dystroferric Red Latosol

Figure 3 - Calibration equations adjusted for the reference humidity (θp) as a function of the volumetric humidity measured with the TDR (θ_{TDR}), grouped for the no-tillage (NT), crop-livestock integration (CLI) and conventional planting (CONV) systems at the three depths



linear trend (α ≠ 0) and of the intercept (β ≠ 0), thereby inferring that the equations can be used to determine residual soil moisture within the control conditions (soil/management/depth).

Similarities in the slope of the trend lines for each point can be seen for almost all the treatments, with a mean angular coefficient of 0.39, except for the CLI (0.12-0.24 m) which, besides having a higher value for R^2 relative to all the other treatments, also showed a greater variation in θ_p and a greater value for the angular coefficient (0.72), expressing a greater degree of slope for the trend line; this was the treatment that most approached the ratio of 1:1, as found by Silva and Gervásio (1999). In general, the high values for R^2 and low values for CV that were found demonstrate the high level of effectiveness of the apparatus used in measuring soil moisture for the soil and climate conditions of the region.

The results prove that the response of the TDR sensor to moisture varies with the management system and the depth, since there is a difference in the calibration curves obtained in this study. Therefore, calibration of the sensor under analysis was carried out successfully, using different equations for each management system and depth, demonstrating the effectiveness of the apparatus in measuring soil moisture in the experimental area used.

The results found in the present work were similar to those of Cardenas-Lailhacar and Dukes (2010), who developed a linear equation with $R^2 = 0.93$ to calibrate the ECH2O model from Decagon Devices, Inc., and those of Varble and Chávez (2011), who also used the linear model with $R^2 = 0.92$ when analysing a similar TDR sensor to the present study.

Lower values for R^2 were also seen at the depth of 0-0.12 m for each system, probably due to the sensor rod having less contact with the soil particles, since this layer has a greater concentration of roots and greater levels of organic matter; this favoured greater soil aeration, with a consequently greater influence on water evaporation from the soil to the atmosphere. In the field, these characteristics were more intense under the CONV system due to greater soil turning, confirmed by the lower values for density near the surface of the said management system.

Therefore, agreeing with Abbas, Fares and Fares (2011), Gonçalves *et al*. (2011) and Souza *et al*. (2013), this study reaffirms the need for the specific calibration of TDR sensors for each system under study, especially when a high degree of precision is required to determine the soil moisture.

CONCLUSIONS

Based on the above studies, it can be inferred that:

1. For greater efficiency in monitoring soil moisture by TDR sensors in a dystroferric Red Latosol typical of the Brazilian Cerrado, calibration is necessary for each management system and soil depth;
2. Using a previous calibration, the TDR can be used to monitor soil moisture.

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