

Construction and calibration of Time Domain Reflectometry probes for assessing soil humidity in dystrophic red latosol

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Abstract

Among the indirect methods of assessing soil moisture, Time Domain Reflectometry (TDR) stands out, which uses the soil dielectric constant to provide volumetric moisture efficiently, quickly and non-destructively. Despite a practical and precise method, TDR has a high cost due to the probes and its Data Logger. In view of this, the present work aims to build and calibrate TDR probes to assess moisture in a Dystrophic Red Latosol. The present work was carried out in the experimental area of the hydraulics laboratory of the Federal University of Grande Dourados (UFGD), located in Dourados-MS, at latitude 22° 12 'south, longitude 54° 59' west and altitude of 434 meters. Each probe built consisted of 3 stainless steel rods ($\varnothing = 3 \text{ mm}$; $L = 230 \text{ mm}$) RG 98 cable with 90% mesh and 50 ohm impedance, 4.7 pF ceramic capacitor and BNC connector. The construction procedures followed the following steps: 1- Making the cable, 2- Preparing the rods, 3- Welding the rods to the wires, 4 -Operating test and 5 - finishing phase. After construction, they were calibrated with the characteristic soil of the Region, proceeding with the Probe Reading in two depths (10 and 30 cm) and simultaneous collection of deformed soil samples to determine the moisture based on mass in Laboratory. Subsequently, calibrations with cubic polynomial adjustment were performed. The results showed adjustments with high determination coefficients, and the probes developed showed satisfactory performances.

Keywords: *Irrigation management; capacitive sensors; water use efficiency; time domain reflectometry; moisture profiles*

1. Introduction

Irrigated agriculture represents the use of more than 70% of the world's fresh water, with competition for domestic and industrial use of intense water, so to ensure global food security, water use in agriculture must become sustainable (Du et al., 2015). Due to the increase in the world population, associated with intense capitalist exploitation, water resources are being degraded, making water a limiting factor for the development of a region (Gomes Filho et al., 2020). Thus, knowledge of soil moisture is of fundamental importance in the management of any irrigation system, in order to replenish the necessary amount of water (Gheysari et al., 2017). Therefore, because irrigated agriculture requires large volumes of water, devices capable of accurately assessing local water conditions can be of great help.

Irrigation brings great benefits, such as increased production, less dependence on climatic factors, decreased production risks, in addition to making unproductive areas productive. However, when we use irrigation inappropriately, it can cause harm and environmental damage such as leaching of nutrients,

unnecessary expenses with electricity and soil compaction, reducing the production and useful life of the forage. Thus, knowledge of the dynamics of water in the soil becomes a fundamental factor for success and sustainable production (Souza et al., 2016).

According to El-Naggar et al. (2020) there are two techniques for measuring the water condition of the soil, the direct and indirect techniques. The direct ones consist of the removal of water from the soil matrix for later measurement. Indirect techniques are well adhered to irrigation systems and use the physical and chemical properties of the soil such as electrical conductivity, dielectric constant, thermal capacity, H content or magnetic susceptibility to determine soil moisture. Among the indirect methods, Time Domain Reflectometry (TDR) stands out, which uses the soil dielectric constant to provide volumetric moisture in an efficient, fast and non-destructive way.

The apparent soil dielectric constant (K_a) expresses the electrical permittivity that the air-soil-water system has when it is affected by an electric field. In this system, water, air and soil have different electrical permittivities. For air, K (dielectric constant) is practically 1, for dry soil, it varies from 2 to 5, while for water (20 °C) its value is approximately 81. Thus, due to the great influence of water conductivity in relation to the other components of the soil system can be found through the dielectric constant of the system the volumetric humidity (Souza et al., 2016).

The TDR technique basically consists of measuring the propagation time of an electromagnetic pulse at the beginning of its probe nailed to the ground until the end of it. The pulse is emitted by a device and travels through a 50 OMHS impedance coaxial cable until it reaches the transmission rods (probe) it undergoes a reflection continuing the route until the end of the rods, where it is reflected and the pulse emitter returns. This time and the speed of the pulse are closely linked to the dielectric constant of the soil. The values of the apparent dielectric constant are converted into volumetric humidity units through equations inserted in commercialized TDR equipment.

The use of TDR provides a series of advantages, such as speed in obtaining volumetric humidity (Tommaselli and Bacchi, 2001), allows the removal of accurate readings without affecting or destroying the region that was sampled, the readings can have great repeatability without changes, the emission of ionizing rays does not occur and, in addition, the equipment is easy to connect to data collection devices. Sanches et al (2020), on the other hand, indicates that the equipment has possibilities to carry out measurements vertically from the soil profile in the same way as horizontally and maintaining the same precision. Other authors cite advantages such as ease of operation and security provided to the operator (Miyata et al., 2020). Finally, because TDR is a method that uses GHz operating frequencies, it is more suitable for soils with greater electrical conductivity than Reflectometry in the frequency domain (FDR) that works with MHz frequencies, since the soil ions that interfere with the measurement of the apparent dielectric constant are less influenced by GHz frequencies (Souza et al., 2013).

However, TDR devices have a high acquisition cost (Tommaselli and Bacchi, 2001), as well as their probes coupled to them to transmit the pulse. Another disadvantage is that these devices have universal and unique equations that transform K_a into volumetric units for different types of soil, which generates limitations to some types of soil and to ensure accuracy, calibration must be performed, that is, to develop an equation for the studied soil. As done by Topp et al. (1980), who developed an equation that has been used for several studies showing that it is adequate for determining the water condition of the soil.

Tommaselli and Bacchi (2001) performed the calibration of the TDR Trase system for 5 soil textures (Neossolo, Argilossolo, Latossolo and Nitossolo) and realized that the equation of Topp et al. (1980) was not accurate for different types of soil. Thus, a series of researchers carried out the calibration for the reality of the soils present in Brazil. Coelho et al. (2016), verified the equations of two equipments (Trase and TDR 100) for 3 types of soil (Eutrophic Red Latosol, Fulvic Latosol, Cohesive Dystrophic Yellow Latosol) and realized that the equations provided by these devices presented terrible performances and that the equations cubic meters developed in their calibrations were the ones that most fit the reality of Brazilian soils. However, they continued to see limitations regarding the use of the equation in the TDR for soils with high levels of organic matter, expansive soils, saline soils and soils containing magnetic minerals such as magnetite (Vaz, 2008).

Therefore, in view of the importance of Reflectometry in the Domain of Time for the conservation of water resources, the lack of conformity of the equations provided by these devices, the high cost of their probes and the large amount of magnetic minerals forming the soil of our region, the present work has as objective the construction and calibration of TDR probes for moisture assessment in a Dystrophic Red Latosol.

2. Material and Methods

The present work was conducted in the experimental area of the hydraulics laboratory of the Federal University of Grande Dourados (UFGD), located in Dourados-MS, at latitude 22 de 12 'south, longitude 54 de 59' west and altitude of 434 meters with the ground classified as Distrossic Red Latosol (EMBRAPA, 2018). The construction and calibration steps are presented below.

2.1. Probe Construction

Each probe built consisted of 3 stainless steel rods ($\varnothing = 3$ mm; $L = 230$ mm) RG 98 cable with 90% mesh and 50 ohm impedance, 4.7 pF ceramic capacitor and BNC connector. The procedures for making the probe were as follows:

- a) Making the Cable: The RG 98 cable was cut into lengths of three and eight meters, one of its ends was stripped in 2 cm to insert the BNC connector (Figure 1.a). The other end was blasted at 4 cm from its first face (cover) then the mesh was cut into two parts rolled up, both separated to create 2 threads. The second face (conductor and insulator) was blasted 0.5 in its final part and the rest remained with the insulator (Figure 1.b).
- b) Preparation of the stems: The stems were left with their sharp non-bridge ends in hydrochloric acid solution for 24 hours (Figure 1.c). After that period they were washed in running water and sanded on the ends that received the acidic solution so that in this way they do not cause problems with the weld.
- c) Welding the rods to the wires: This process 3 rods were welded with the second end of the cable. For this, we welded the 2 wires from the mesh one on each side rod with Sn 60/40 tin alloy and soldering iron for approximately 60 seconds, the last wire (inner conductor) is soldered on the inner rod (Figure 1.d). With the cable already close to the rod and these rods spaced 22 mm apart (Figure 1.e), we soldered the 4.7 pF ceramic capacitor, with one pole present on an external rod and another on the internal rod.
- d) Function test: After formation of the probe skeleton (Figure 1.e), we use the multimeter to check if the

circuit is not interrupted by loose wires, touching or due to incomplete fusion of the weld.

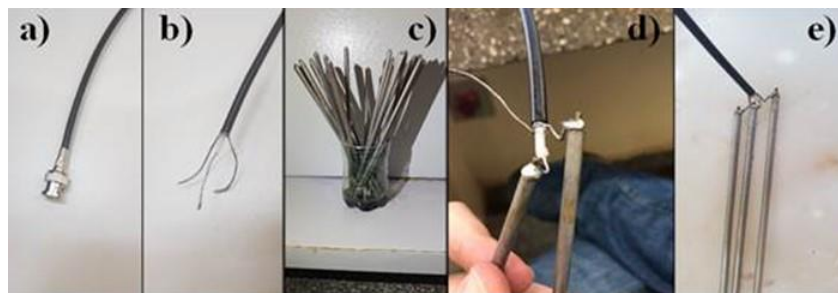


Figure 1. Probe preparation procedures. Dourados, 2020. 1.a) End of the cable connected to the BNC connector, b) End of the cable intended for the rods, c) HCl rods, d) Conductor welded to the interior rod, e) End of the already welded rods spaced in 22 mm.

e) Finishing phase: The finishing phase was responsible for providing resistance to the probe through a protective layer made with the resin and hardener solution, improving the handling and durability of the equipment. This phase was divided into 6 procedures:

Preparation of the solution: Each probe formed by 3 rods required 24 cm³ of the solution or total mixture formed by Epoxy hardener type 3154 (Figure 2.a) and Epoxy resin 2119 (Figure 2.b) according to the equation 1:

$$MT = 0.75Mr + 0.25Me \tag{1}$$

where,

MT = total mixture (final solution);

Mr = resin material (2);

Me = hardener material.

Homogenization of the solution: The solution or total mixture was stirred for about 30 minutes until the material was homogeneous

Installation of the probe skeleton in the U structure: The rods were placed in a structure (Figure 2.c) prepared to receive the solution and direct the mixture to the correct location

Stem checking: Stems when added to the structure may undergo some changes in their arrangement. In this way, we visualize the arrangement of the rods and each wire so that there is no difference in height between the rods and twisting of the wires.

Application of the resin to the stems: With the solution already prepared, homogenized and the stems already added to the structure, it was applied the solution to the structure.

Stiffening: After application to the structure, the material was kept in an environment at 20 ° C for 48 hours.

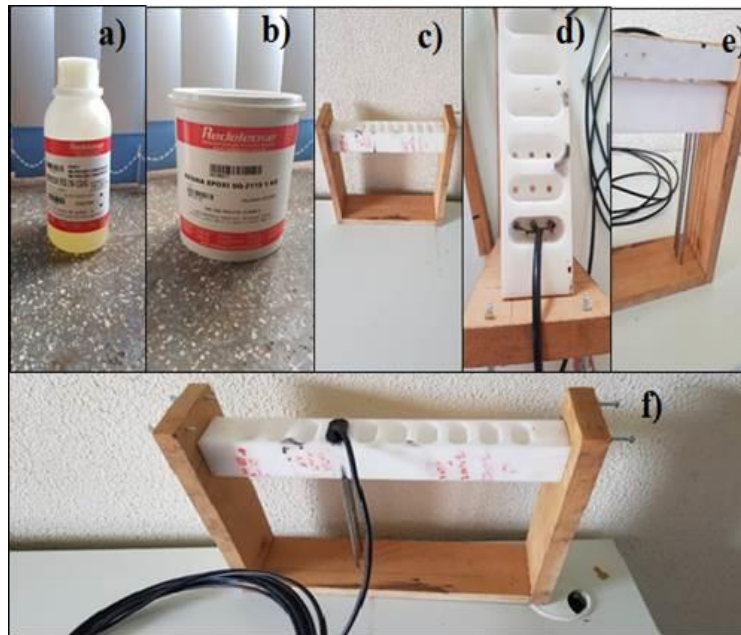


Figure 2. Finishing phase. Dourados, 2020. 2.a) Hardener, b) Resin, c) U-shape, d) Wire checking, e) Rod height check, f) Stiffening rods.

After 4 hours the skeleton of the probe was removed from the structure in one and the final result of the confection was obtained, Figures 3 show the result and dimensions.

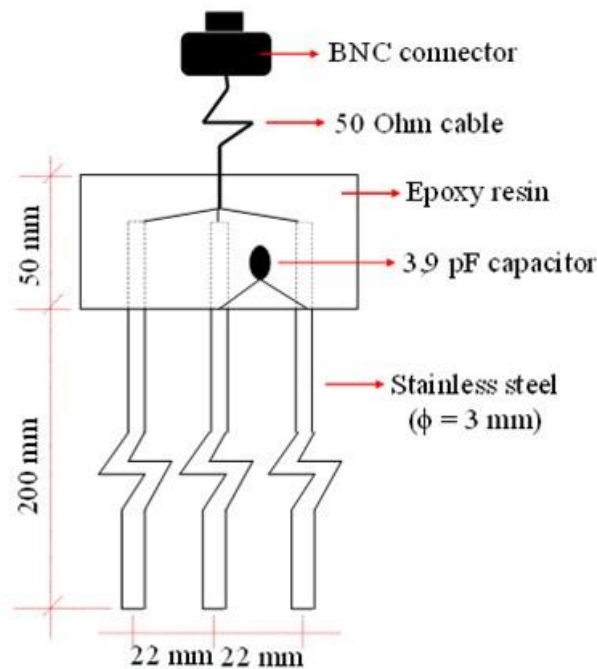


Figure 3. Probe dimensions.

2.2. Field Calibration Tests

To start the calibration, a trench 50 cm wide, 50 cm long and 50 cm deep was made as shown in Figure 4.a. In this trench we took 6 unformed samples with the aid of a volumetric ring coupled to a castel (Figure 4.b) at depths of 10 and 30 centimeters. After that, in the laboratory, the excess soil was removed, so that the

soil only fills the volume of the rings and in order to avoid any loss of soil, a thin tissue was placed, attached by elastic at the ends of the 6 rings.

Thus, with the rings already prepared, they were taken to the saturation tray and remained 24 hours inserted in a tray with water until their average height (Figure 5.a). Subsequently, they were removed from the trays to obtain the wet soil mass and placed in the greenhouse at 105°C for 24 hours (Figure 5.b). After 24 hours in the greenhouse, the rings were removed and taken to the scale informing the dry soil mass. Once the mass of the dry soil was obtained and the volume of the volumetric rings was known, we arrived at the density value of each depth through the universal density equation.



Figure 4. Field procedures. Dourados-MS, 2020. 4.a) Hardener, b) Resin.

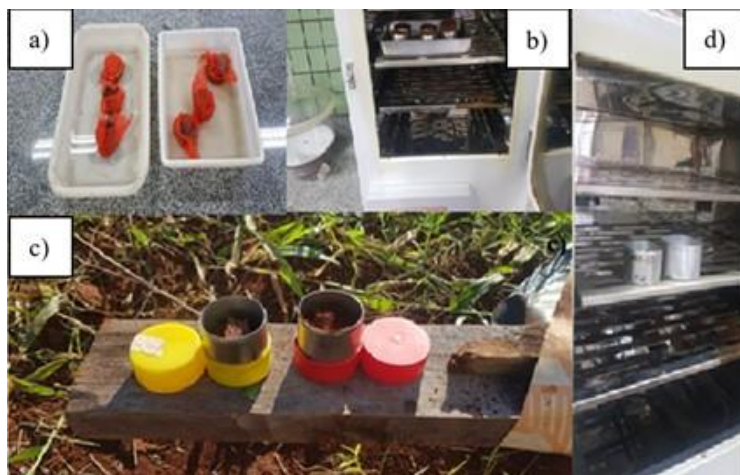


Figure 5. Laboratory procedure. Dourados-MS, 2020. 5.a) Volumetric rings in the saturation tray, b) Volumetric rings inside the greenhouse, c) Containers for transporting deformed samples, d) Deformed samples in the greenhouse.

Calibration was performed using the artisanal probe at two depths in the trench, the first 10 cm deep and the second 30 cm deep as shown in (Figure 6).



Figure 6. Probe driven at depths of 10 and 30 cm. Dourados-MS, 2020.

Soil samples to determine the exact water content in the soil were taken next to the probe and followed the standard greenhouse method, since it has simplicity, practicality and precision, being widely used in equipment and method calibrations (Buske et al., 2013). After taking the samples, they were formed in containers (Figure 6.c) taken closed to the laboratory.

Then, in the laboratory, they were weighed in a metallic container of known weight with a precision scale (4 decimal places). After that, they were taken open inside the metallic container to the greenhouse at 105°C (Figure 6.d), until they reached constant mass and with that weighing and that of the metallic container used without the soil.

So the soil moisture was obtained according to the equation 2:

$$\text{Moisture\%} = (M1-M2) / (M2-M3) \times 100 \quad (2)$$

where,

M1 = weight of wet sample;

M2 = dry sample weight;

M3 = weight of open metal container.

However, the value indicated in the TDR is based on volume like this, with the density values obtained with an unformed sample in a volumetric ring at the depths of the probes and based on the volumetric cylinder method we acquire the soil density and, therefore, the volumetric humidity as equation 3:

$$\text{Volumetric Humidity} = U \times Ds \quad (3)$$

where,

U = actual humidity;

D_s = soil density in g / cm^3 .

Having obtained the values of volumetric humidity of the samples and the apparent dielectric constant presented in the equipment, it was possible to establish the calibration curve by adjusting a cubic polynomial equation using a dispersion diagram and coefficient of determination (R^2), using spreadsheets such as Microsoft Excel®.

3. Results and Discussion

The volumetric humidity obtained by the standard greenhouse method (gravimetric) ranged from $0.1295 \text{ cm}^3 / \text{cm}^3$ to $0.2933 \text{ cm}^3 / \text{cm}^3$ at a depth of 10 centimeters and $0.1280 \text{ cm}^3 / \text{cm}^3$ to $0.3126 \text{ cm}^3 / \text{cm}^3$ at a depth of 30 centimeters. In Figure 7, the cubic polynomial adjustment is presented to determine the volumetric humidity as a function of the apparent dielectric constant (K_a) at a depth of 10 centimeters.

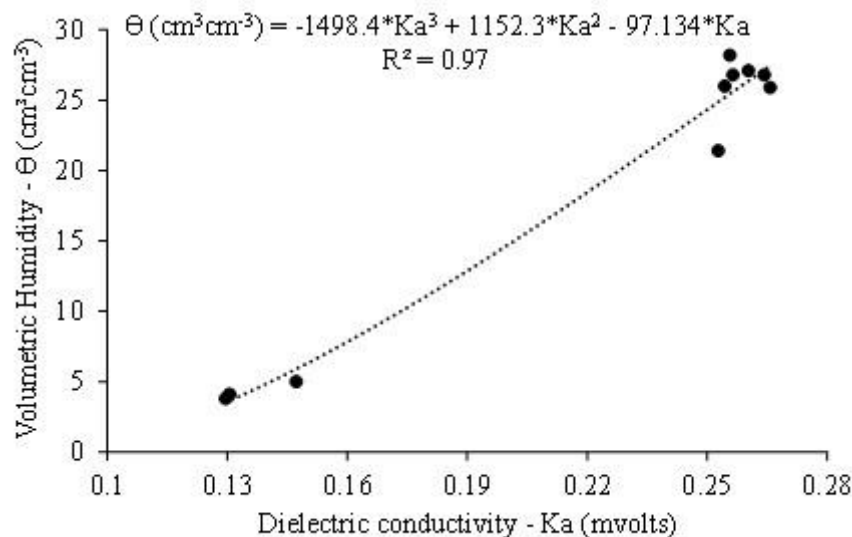


Figure 7. Water content at a depth of 10 centimeters as a function of the dielectric conductivity (K_a).

When studying hydraulic characterization of domestic taps Gomes et al. (2020) performed potential adjustments using adjustment equations with $R^2 = 0.99$, and thus managed to explain the different flow amplitudes for the tested models.

The coefficient of determination of $R^2 = 0.99$ approaches the unit (1.0) indicating the cubic polynomial equation ($6835.7 * K_a^3 - 5169.4 * K_a^2 + 1315.5 * K_a - 90.84$) for calibrating the TDR equipment. in a Dystrophic Red Latosol at a depth of 30 centimeters, Figure 9. Based on previous work, this one of the cubic polynomial model has been justified, for example, Villwock et al. (2004), in which the calibration equation model that had a coefficient of determination closest to 1 was the cubic polynomial model.

For Batista et al. (2016), the cubic polynomial equations had a calibration coefficient close to the ideal for 5 soil types with different textural classes. Regardless of the soil with a clayier texture having shown less efficiency in the cubic model, it still had a good calibration adjustment.

For Amaral et al. (2019), in its calibration performed in a typical dystrophic Red-Yellow Clay soil field,

the cubic polynomial model was the one that presented the best fit for determining the volumetric moisture obtained through the gravimetric method as a function of the dielectric constants of the soil.

In Figure 8, the cubic polynomial adjustment is presented to determine the volumetric humidity as a function of the apparent dielectric constant (K_a) at a depth of 30 centimeters.

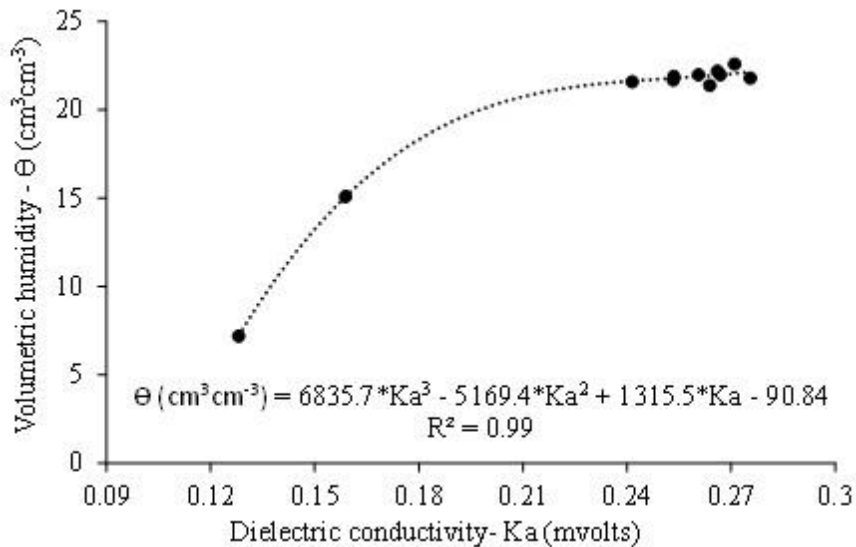


Figure 8. Water content at a depth of 10 centimeters as a function of the dielectric conductivity (K_a).

4. Conclusion

Based on the results presented, it was possible to observe that the cubic polynomial adjustments presented satisfactory results for the developed probes. Thus, artisanal probes built can be a great option for the management of irrigators due to the low cost in relation to the manufacturer's industrial probes. Reflectometry in the Time Domain is a tool that can be indicated to assess the dystrophic red latosol moisture.

5. Acknowledgement

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