APPLICATION OF THE TDR TECHNIQUE IN TROPICAL SOIL

SOUZA, C. F.; MATSURA, E. E.; TESTEZLAF, R.
UNICAMP/FEAGRI – DEPARTAMENTO DE ÁGUA E SOLO
Cx. Postal 6011, 13081-970, Campinas-SP-Brazil
e-mail: cfsouza@agr.unicamp.br

One recent technology developed to estimate soil water content is TDR technique (Time Domain Reflectometry), where the determination of a calibration curve is recommended (volumetric water content ($\theta$) versus apparent dielectric constant ($\varepsilon_b$)) for each soil type. This limitation is more pronounced intensified in tropical soils; because of the available equations in the literature seemingly do not consider the differences of this type of soil, mainly the presence of free iron oxide. Silva (1998) concluded that it could affect the magnetic field created by electric pulse, and consequently affect the time of displacement of the emitted wave. The objective of this work is to study the limitations to develop a Dusky Red Latosol calibration equation. It was used two methodologies to determine the calibration equation: the first one, described by Tommaselli (1997), for laboratory condition using deformed soil sample, and the second for field condition. The advantages and disadvantages of each procedure were analyzed and important recommendations were given. The found calibration equations were compared with the Topp et al. (1980) equation. The results showed that the joining of the laboratory and field experimental data help to explain satisfactorily the water content variation when compared with water content determined by gravimetric method.

INTRODUCTION

The knowledge of soil water content is important for agriculture, mainly the determination of its variation in the soil profile to optimize the irrigation management. The tendency to use TDR technique to measure the soil water content is relatively new in Brazil. Its outstanding advantages are accuracy, speed, reproducibility, good theoretical basis, a well-defined and selected sampled volume, and the fact that $\theta$ and salinity are measured in exactly the same volume. The method is based on the sensitive effect of the $\theta$ in the microwaves pulses propagation speed in conductive cables in soil, caused by the large differences in the relative dielectric permittivities of water ($81$), air (1), and soil particles (3-5). It is necessary, basically, a cable test and a sensor with metallic rods tied by coaxial cable.

In TDR, the propagation velocity of a high-frequency electromagnetic signal is determined by:

$$v = \frac{c}{\sqrt{\varepsilon_b}}$$

Where $v$ is the propagation velocity, $c$ is the propagation velocity of electrical signals in vacuum or free space ($3\times10^8$ m/s), and $\varepsilon_b$ is the apparent dielectric constant of the soil. In the application of TDR to soil water measurement, a fast rise-time voltage pulse travels in the soil guided by a transmission line or wave guide of length, $L$, and the pulse reflects back from the end. By determining the travel time, $t$, of the pulse sent throughout the transmission line, is possible to obtain the velocity during the two-way travel as $v = 2L/t$. Combining the two mathematical expressions the $\varepsilon_b$ of the measured soil can be calculated by:

$$\varepsilon_b = \left(\frac{ct}{2L}\right)$$

The TDR technique is an indirect form to determine the water content; thereby it needs a calibration curve to convert apparent dielectric constant to water content. Topp et al. (1980) proposed an empirical method for the relationships between apparent dielectric and water content based on a third-order polynomial fitted:

$$\theta = -5.3 \times 10^{-2} + 2.92 \times 10^{-2} \ast \varepsilon_b - 5.5 \times 10^{-4} \ast \varepsilon_b^2 + 4.3 \times 10^{-6} \ast \varepsilon_b^3$$

According to authors, this equation can be used as a universal calibration curve for TDR water content determination. But, this equation fitted well with the experimental data for some soil. However, it did not fit for fine-textured mineral soils, organic soils, and clays (Dirksen & Dasberg, 1993; Jacobsen & Schjonning, 1993). Dirksen & Dasberg (1993)
found that two Brazilian ferralsols had calibrations substantially different from that of Topp et al. (1980); they attributed this result to the presence of gibbsite.

The results showed by Robsinson et al. (1994) would indicate that soil mineralogy might well have a substantial influence on calibrations of apparent dielectric constant \( \varepsilon_b \) versus water content. The presence of 15 % goethite is unlikely to alter estimations of \( \theta \) achieved through Topp’s equation. The presence of 15 % hematite may increase to determined \( \theta \) from Topp’s equation in both dry and wet conditions by about 6 %.

High clay content leads to a higher specific surface area, and because layers of water molecules around the soil particles are thought to have a restricted rotational freedom, the \( \varepsilon_b \) of these molecules is lower than that of bulk water (Roth et al. 1990).

These phenomenons are usually explained by an increase in the content of bound water with increasing content of free iron oxide, organic matter and clay, since the \( \varepsilon_b \) of bound water is much lower than the \( \varepsilon_b \) of free water. Grohmann (1970) showed that the specific surface for Dusky Red Latosol presented decreased of 50% when the free iron oxide and organic matter were removed.

Ponizovsky et al. (1999) describe that the term “bound water” is in use, the term “confined water” is employed hereafter to designate the portion of soil water that is close to soil particles, is affected by the surface forces, and thus has a \( \varepsilon_b \) distinctly different from that of free water. The relative dielectric constant (\( \varepsilon \)) of free water is \( \varepsilon = 81 \) at 18°C, and it decreases by 0.37 per 1°C (Wobschall, 1977). The lower limit of the \( \varepsilon_b \) of the tightly bound water is likely to be similar to that of ice, or \( \varepsilon = 3.2 \).

This limitation is more pronounced in tropical soils because of the available equations do not consider the differences of these soils, mainly the presence of iron oxide. Silva (1998) concluded that it could affect the magnetic field created by electric pulse, and consequently affect the time of displacement of the emitted wave. The objective of this work is to study the limitations to developed a Dusky Red Latosol calibration equation. It was used two methodologies to determine the calibration equation: the first one, described by Tommaselli (1997), for laboratory condition using deformed soil sample, and the second for field condition.

**MATERIALS AND METHODS**

Experiments were conducted in the Hydraulic, Irrigation and Drainage Laboratory of the Agricultural Engineering College (State University of Campinas/Unicamp). It was used two methodologies to determine the calibration equation: the first one, described by Tommaselli (1997), for laboratory condition using deformed soil sample, and the second for field condition. The \( \varepsilon_b \) was measured by Trase System I, model 6050X1 (Soilmoisture Equipment Corp., Santa Barbara, CA, USA). Parallel steel 3-wire probes (200 mm length and 3 mm diameter) were used in the experiments. The interpretation of the TDR waveforms was done by internal automatic software of the Trase System I.

The soil type studied was Dusky Red Latosol, and some soil physical and chemistry characteristics are presented in Table 1.

<table>
<thead>
<tr>
<th>Physical</th>
<th>Depth (m)</th>
<th>Bulk density (Kg/m³)</th>
<th>Total porosity (%)</th>
<th>Texture (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-0.25</td>
<td>1240</td>
<td>53.2</td>
<td>56  9  35</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chemistry</th>
<th>Depth (m)</th>
<th>PH</th>
<th>P</th>
<th>O. M.</th>
<th>F₃O₂</th>
<th>H+Al</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>S</th>
<th>CTC</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-0.25</td>
<td>5.7</td>
<td>120</td>
<td>3.9</td>
<td>21.3</td>
<td>2.8</td>
<td>0.4</td>
<td>7.9</td>
<td>2.0</td>
<td>10.3</td>
<td>13.1</td>
<td>79</td>
</tr>
</tbody>
</table>

Lucarelli, 1997

The methodologies used to determine calibration equation are described below.

---

1 Reference to registered mark does not constitute endorsement for the authors.
Laboratory condition methodology

Air-dry soil sample was grounded and then passed through a 2 mm sieve. The sample was divided in two parts and strewn in a thin layer on the plastic plate and brought to the desired water content using a water spray. Then, the sample was thoroughly mixed and placed into cylindrical plastic recipient of 0.18 m in diameter and 0.25 m in height. The recipient was tightly shut and left in rest for 24 hours to reach equilibrium between water and solid phases. Thereafter, the apparent dielectric constant of the sample was measured by means of the TDR technique. The recipient was weighed. The weight of sample was used to estimate the water content and bulk density. Finally, the soil sample was removed from the recipient, divided in two parts and strewn in a thin layer again, and brought to new water content (Tommaselli, 1997).

Field condition methodology

The experiment was conducted during the period of low pluviometric precipitation in Campinas-SP (June to September), with duration of around 70 days. It was selected inside the experimental field of Feagri/Unicamp an area of 25 m² and irrigated until reaching approximately the field capacity of the soil. This area was representative of the soil in study and its characteristics were showed in the Table 1. Thus, using 3-wire TDR probes, installed in the depth of 0–0.20 m, apparent dielectric constant was measured for different values of soil water content. Simultaneously, it was collected around of the installed probes 5 soil samples to determinate of the water content through of the gravimetric method.

Validation of the equations

The estimated equations were compared with gravimetric method, determining the wetting front in drip irrigation. The experiment was accomplished inside of two soil columns (0.9 m of length and 0.6 m of diameter) filled with soil (Dusky Red Latossol). Each recipients were irrigated (15 mm of depth) with an emitter of rate 2 and 4 L/h, separately. For wetting front measurements it were installed inside the recipients 10 TDR multi-wire probes with 3 segments of 0.20 m and spaced 0.08 m, described by Souza et al., 1999. The wetting front was monitored and measured by the probes, and soil samples were collected after 48 hours to estimate the water content by gravimetric method.

RESULTS AND DISCUSSION

In Table 2 is presented the experimental data obtained by both procedures. In this table is possible to verify that in both methodologies the desirable range of soil moisture values was not obtained.

<table>
<thead>
<tr>
<th>θ (m³/m³)</th>
<th>ε₀</th>
<th>θ (m³/m³)</th>
<th>ε₀</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.027</td>
<td>2.8</td>
<td>0.276</td>
<td>16.3</td>
</tr>
<tr>
<td>0.043</td>
<td>3.2</td>
<td>0.283</td>
<td>16.8</td>
</tr>
<tr>
<td>0.063</td>
<td>3.8</td>
<td>0.286</td>
<td>18.1</td>
</tr>
<tr>
<td>0.094</td>
<td>4.5</td>
<td>0.349</td>
<td>19.2</td>
</tr>
<tr>
<td>0.109</td>
<td>5.1</td>
<td>0.327</td>
<td>19.9</td>
</tr>
<tr>
<td>0.126</td>
<td>5.5</td>
<td>0.317</td>
<td>20.2</td>
</tr>
<tr>
<td>0.151</td>
<td>5.9</td>
<td>0.317</td>
<td>20.3</td>
</tr>
<tr>
<td>0.173</td>
<td>6.5</td>
<td>0.363</td>
<td>24.4</td>
</tr>
<tr>
<td>0.206</td>
<td>8.7</td>
<td>0.392</td>
<td>25.8</td>
</tr>
<tr>
<td>0.224</td>
<td>11.0</td>
<td>0.425</td>
<td>27.0</td>
</tr>
<tr>
<td>0.232</td>
<td>14.1</td>
<td>0.398</td>
<td>27.4</td>
</tr>
<tr>
<td>0.271</td>
<td>15.2</td>
<td>0.419</td>
<td>29.8</td>
</tr>
</tbody>
</table>

Bold letter data were obtained in laboratory condition and others in field conditions

In the laboratory procedure, it was difficult to make apparent dielectric constant readings for water content values above 0.20 m³/m³ due to the occurrence soil compaction. This problem happened due to the high clay concentration (56%) and porosity (53.2%). The Dusky Red Latossol collapsed its structure due to soil compaction phenomenon. The critical water content for the soil compaction was above 0.20 m³/m³ for the soil-deformed samples used in the study. This effect was caused...
for the compression of an unsaturated soil during which an increase of the bulk density of soil occurs as a consequence of the reduction of its volume, due to the expulsion of the air caused by inadequate management.

The field methodology showed some readings problems for soil water content values below 0.21 m$^3$/m$^3$. Apparent dielectric constant readings decreased abruptly for a range below this point, where it was visible the soil water content presence. The observed results indicated that soil mineralogy has a substantial influence in the apparent dielectric constant readings. It is believed that the largest influence was caused by the high presence of iron oxide and clay, which increases the specific surface activity effect of the particles of the soil in the water retention. This phenomenon reduces the free water in the soil, which consequently promotes low apparent dielectric constant values.

The difficulties found in both procedures (lab and field conditions) showed that the calibration curve determination is not an easy task, but involves a series of details that could result in imprecise results. Thus, it was decided to check the possibility to join the experimental data of the used methodologies, (Table 2). It was adopted the third-order polynomial model, because it is observed in the literature a superiority of this mathematical model when compared with others models, which presented the largest correlation coefficient values for clay soils. Tommaselli (1997) observed that third-order polynomial term of $\theta$ leaves to be important when soil texture becomes thicker.

Using the results presented in Table 2, it was possible to estimate the equation represented by Figure 1, which was compared with Topp’s equation. The estimated water content by Topp’s equation was underestimated by 20 % and overestimated by 10% for the great differences when compared with gravimetric method. The comparison confirms the tendency observed by Tommaselli (1997) and Silva (1998). The authors observed that Topp’s equation could underestimate or overestimate water content for Brazilian conditions soils.

![Figure 1. Calibration equation found for studied conditions.](image)

The precision of the found equation were tested in a laboratory experiment determining the wetting front evolution and comparing with wetting front determination using gravimetric method (Figure 2). The results were satisfactory.
The experiment showed that the determination of the calibration equations for clay soils should be accomplished carefully, mainly when these soils contain high free iron oxide concentration. The possibility to make calibrations in laboratory conditions using for soil-deformed samples was discarded. For calibrations, which the objective is the irrigation management the equation obtained in field conditions is recommended, because the moisture storage range could be estimated.

CONCLUSION

The Topp’s equation known as universal was inadequate for the studied soil type, because when compared underestimated or overestimated observed water content.

It was difficult in lab conditions to obtain a TDR calibration curve that contains the total range of the water content used for irrigation management, using soil-deformed samples.

In field conditions, the soil bounded water affects abruptly the readings of the apparent dielectric constant.

When the experimental data for lab and field methodology were joined the results obtained were more satisfactory, even when used for water content measurements in air-dry soil conditions.

More studies using non-deformed soil samples in laboratory to determine the calibration curve are recommended.

REFERENCES


