

Ndoor Calibration of Volumetric Water Content of Farmland Clay Measured by TDR in A Certain Area of Henan Province

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Abstract

Due to the change of water content of farmland clay soil has a direct impact on grain yield and quality, and the TDR method will have a large error in measuring the water content of clay soil. In order to improve the accuracy of TDR measurement of volumetric water content of farmland clay soil, YT-DY-0101 soil moisture meter was used to calibrate the clay soil with different volumetric water content. The test results show that the fitting curves of the same type of TDR are different, and each TDR needs to be calibrated separately. When the volumetric water content of cohesive soil is low ($11.07 \text{ cm}^3 \cdot \text{cm}^{-3}$), the results of direct measurement by TDR are closer to the true value; with the increase of volumetric water content of soil samples, the accuracy of TDR fitting curve is high, but the results are still large or small for clay with different volumetric water content. When the volumetric water content of clay sample increases to $44.03 \text{ cm}^3 \cdot \text{cm}^{-3}$, the accuracy of TDR fitting curve is the highest.

Keywords

TDR; Clay soil; Volume water content; Calibration.

1. Introduction

The distribution of soil water content will directly affect the properties of soil, and ultimately affect the yield and quality of crops [1]. Clay soil is one of the main types of farmland soil in China, which has the characteristics of strong water and fertilizer retention capacity, large dry capacity, and poor permeability. Therefore, it is of great practical significance to accurately measure the moisture content of farmland clay soil.

At present, there are three main methods to measure soil water content. The first method is drying method. After evaporation of water in soil by drying oven ventilation, the soil water content is calculated by the difference between the quality before and after drying. The second is the alcohol combustion method, the basic principle is the same as the drying method; the third method is based on TDR (Time-Domain-Reflectometry, time-domain reflectometry, hereinafter referred to as TDR), and the soil water content is inversely calculated by directly measuring the physical parameters related to water in the soil. The first two methods have similar operation processes, but both have shortcomings such as tedious operation, long test cycle, inability to conduct in-situ measurement, and poor timeliness. Although the TDR method is simple in operation and rapid in measurement, when measuring the clay soil with large clay content and heavy texture, the electromagnetic wave energy loss is large and the reflection information is fuzzy, which will lead to a large deviation from the actual water content. Therefore, it is necessary to correct the water content deviation of clay soil by calibrating the TDR [2–4].

In this paper, the viscous soil of a farmland in Henan Province was taken as the research object, and the soil columns with different mass water contents were configured. Several TDR measurements of the same type were used. The data were recorded and entered by Grapher software.

2. Test Principle and Instrument

On the TDR method to measure soil water content, domestic and foreign scholars have carried out a lot of experiments and exploration. Alessandro Tarantino et al. proposed an empirical equation to estimate soil volumetric water content based on the dielectric constant and bulk conductivity measured under different compaction conditions, combined with the dielectric constant obtained by Topp equation and the dielectric constant obtained by TDR, CT and TP mixed model[5]. M. Menziani proposed a new idea to verify the accuracy of soil volumetric water content by combining the established physical model of soil hydrological and thermal parameters with the TDR measurement technology[6]. Liang Liu et al take the northeast black soil area farmland soil as the research object, using TDR method to 'from wet to dry' soil column indoor calibration, obtains to the single and the mixed medium TDR method soil moisture calibration curve can obtain the high accuracy conclusion[7]. Huashan Wu used TDR method and drying method to determine the water content of different soils in Yangzhou, and proved that the measured value of TDR method at the density of 1.3 g / cm^3 was the closest to the true value[8]. Yueru Wu conducted indoor calibration tests on soil samples in the upper reaches of Heihe River based on the principle of TDR determination of soil water content, and obtained the relational expression of TDR determination of soil volumetric water content with good correlation[9].

It can be seen from the above experimental studies that although many scholars have done many studies on the accuracy of TDR measurement of water content, there are few studies on the calibration of volumetric water content of farmland clay measured by TDR. To improve the TDR method.

2.1. Test Principle

The soil volumetric water content measured by TDR method is calculated by the dielectric constant of soil. As shown in Figure 1, the TDR volumetric water content measurement system is mainly composed of four parts : test probe, probe, cable and data acquisition instrument.

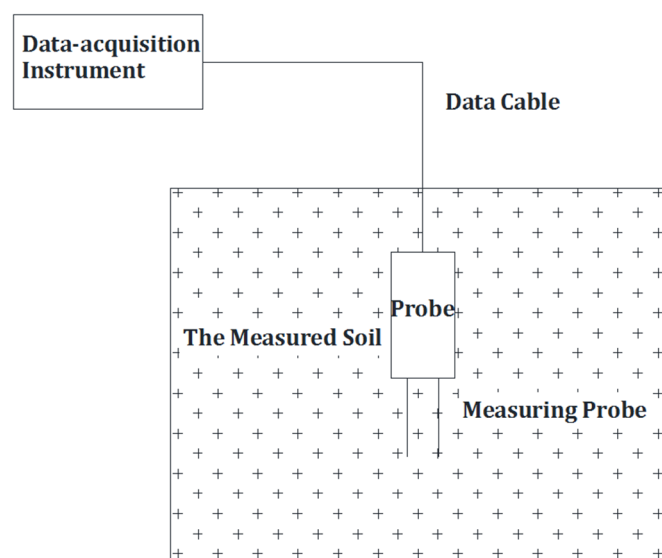


Figure 1. TDR volumetric water content measurement system

TDR emits high-frequency pulse signal in the measurement process, which is transmitted into the probe through the cable, and enters the soil by measuring the probe. The dielectric constant is obtained according to the time when the electromagnetic wave is reflected to the end of the probe in the soil. When the frequency is 1MHz ~ 1GHz, the dielectric constant k :

$$k=(c/v)^2=(ct/2L)^2 \quad (1)$$

Formula (1) : the dielectric constant of the measured soil ; for electromagnetic wave propagation velocity in vacuum ($3 \times 10^8 \text{m} \cdot \text{s}^{-1}$) ; the propagation velocity of electromagnetic wave in the measured soil ; the time needed for electromagnetic wave to travel in the soil ; measure the length of the probe for the TDR.

The size of dielectric constant essentially reflects the energy consumption of electromagnetic wave in the process of propagation in different media, which is an inherent property of the medium itself. When the temperature of water is 20°C, the dielectric constant is 80 ; the dielectric constant of general solid is 2~5 ; at a standard atmospheric pressure, the dielectric constant of air is 1. Soil is a complex three-phase body composed of solid, liquid and gas, in which the dielectric constant of water accounts for the largest proportion, and the soil water content can be speculated by measuring the dielectric constant k of soil.

Topp et al. measured bulk water content of most soils by TDR[10], and summed up the empirical formula between bulk water content and dielectric constant.

$$\theta = 5.3 \times 10^{-2} + 2.92 \times 10^{-2} K - 5.5 \times 10^{-4} K^2 + 4.3 \times 10^{-6} K^3 (\theta \leq 0.6) \quad (2)$$

In Formula (2) : θ is the volumetric water content of the measured soil, cm^3/cm^3 ; K is the dielectric constant of the measured soil.

Early Toop believed that the soil volumetric water content measured by TDR method was not affected by physical factors such as soil texture, bulk density, and temperature. However, when the error requirement was less than $0.05 \text{ cm}^3 \cdot \text{cm}^{-3}$, various factors would affect the accuracy of the measurement results. For clayey soil with large clay content and dense texture, due to its strong water retention, electromagnetic waves may cause the reflection signal to be blurred during propagation, resulting in inaccurate measurement. Therefore, it is necessary to calibrate the TDR of the measured clay in advance.

2.2. Test Apparatus

The TDR soil moisture meter model used in the test is YT-DY-0101, as shown in Figure 2. The measuring probe is 12cm long, the distance between the needles is 2.5cm, the probe diameter is 5cm, and the length is 18cm. Four TDRs of this model were used in this experiment, and the basic parameters are shown in Table 1.



Figure 2: YT-DY-0101 TDR moisture meter

Table 1. Main technical indexes of YT-DY-0101 TDR moisture meter

Range%	Resolution%	Precision%	Measuring range	Repeated precision%
0~100	0.01	±2	90 % effect in a 70×30 mm φ diameter cylinder around a central probe	±0.2

3. Experimental Scheme

3.1. Preparation of Experimental Soil Samples

The soil samples were collected from a farmland in Jiaozuo, Henan Province. The density, optimal water content and particle distribution were tested according to the 'geotechnical test method standard' (GBT50123-2019). The results are shown in the table. It can be seen from the table that the proportion of particles with diameter ≤0.075mm in the test soil sample is 56.63%, which is a typical cohesive soil.

Table 2. Basic physical indexes of soil samples

Soil particle density /(g·cm ⁻³)	Maximum dry density /(g·cm ⁻³)	Optimum moisture content /%	Soil particle composition /%		
			≥0.25mm	0.075~0.25mm	≤0.075mm
2.67	1.7	19	24.2	22.08	56.63

Drying method is used to measure the mass water content of original soil sample, and the formula is converted to volume water content.

$$\Theta_w = (\rho_d / \rho_w) w \quad (3)$$

In Formula (3), is volumetric water content, cm³/cm³ ; is the dry density of the measured soil, g/cm³ ; water density, g/cm³.

The process of configuring the soil sample to be measured is as follows :

- 1) Firstly, the initial soil sample is fully mixed and stirred, and the soil is taken at different positions of the soil sample. The average initial mass water content of the soil sample is 6.7 %, and then the soil sample is divided into five parts.
- 2) According to the mass water content of the initial soil samples, water was added to each soil sample, and the soil samples with mass water content of 6.7 %, 11.7 %, 16.7 %, 21.7 % and 26.7 % were configured.
- 3) The soil sample to be tested was covered with plastic film and kept at room temperature for 24 h to ensure the uniform distribution of water in the soil sample.

3.2. Experimental Process

The test process is as follows:

- 1) According to the fixed density of 1.5g/cm³, the soil samples with different water content were weighed and rammed into the cylindrical plastic bucket (bucket diameter 100mm, height 200mm). During the period, a soil sample was rammed to a certain height and sealed with plastic film, and then the next soil sample was made.

2) After standing for 2h, as shown in Figure 3, the plastic film on the top of the soil sample was removed, and the TDR was vertically inserted into the soil sample to read the measured value. After measuring the three different positions of the same soil sample, the mean value was taken as the volume water content of the soil sample corresponding to the TDR.

3) After a single soil sample measurement, the film was covered again, and the TDR measurement probe was cleaned and wiped, and then the next soil sample was measured. Five soil samples were grouped after the end of the measurement. In this loop, four sets of TDR measurements are performed.

4) At the end of the measurement, the soil samples without TDR insertion were sampled by ring knife, and then put into the oven (105°C, 24h) to determine the actual mass water content.



Figure 3. TDR measurement of volumetric water content of single soil sample

4. Results and Analysis

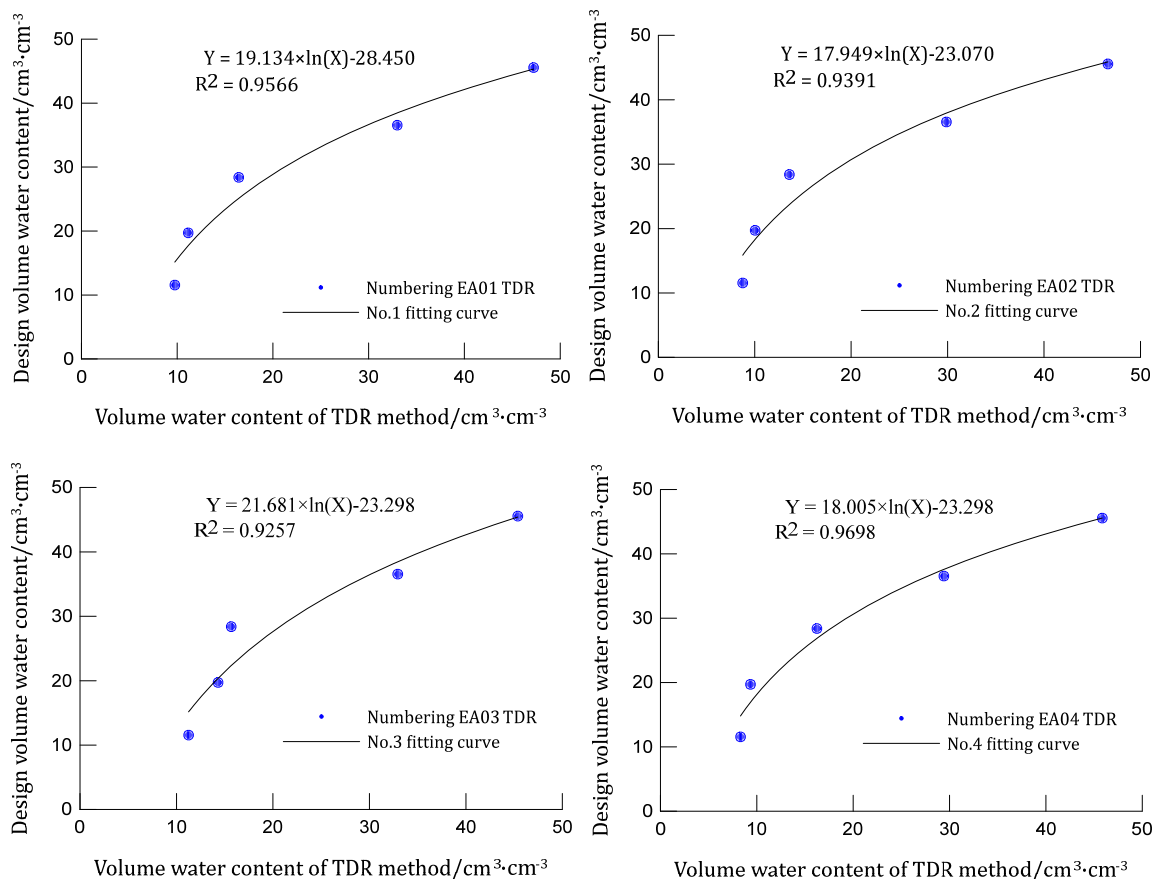


Figure 4. Water content fitting curve of EA01, EA02, EA03, EA04 TDR

Five soil samples with water content and four TDRs were numbered. The soil samples with mass water content of 6.7%, 11.7%, 16.7%, 21.7% and 26.7% were numbered as 1, 2, 3, 4 and 5, and the four TDRs were numbered as EA01, EA02, EA03 and EA04, respectively. The measured data of drying method and TDR method were input into the main standard system with the volumetric water content of TDR method as X axis drawn by Grapher, and the volumetric water content of Y axis was designed. The fitting curves of four groups of data were obtained by logarithmic function.

According to Figure 4, the correlation coefficient R^2 of the fitting curve of the four TDR moisture meters is between 0.9257 and 0.9698 when measuring clay soil with mass water content of 6.7%~26.7%, and the correlation coefficient of different TDR moisture meters is 0.0441. It can be seen that although the TDR method has relatively high accuracy in measuring cohesive soil, there are still differences between TDR moisture meters. Therefore, it is necessary to calibrate each TDR moisture meter separately before the test.

According to the fitting value of the fitting curve and the designed volumetric water content, the relative error of the fitting curve for the measurement of cohesive soil with different design volumetric water content is obtained, see Table 3 to Table 6.

Table 3. Measurement and fitting results of each moisture content of EA01 TDR (unit : cm³ / cm³)

Soil sample number	Design mass water content	Mass moisture content measured by drying method	Design volume water content	Volumetric water content measured by TDR	Fitting values	Fitting relative error / %
1	6.70	6.50	11.05	9.76	15.15	37.07
2	11.70	11.10	18.87	11.16	17.71	6.13
3	16.70	16.20	27.54	16.43	25.12	8.77
4	21.70	21.30	36.21	36.99	40.65	12.28
5	26.70	25.90	44.03	47.22	45.33	2.96

Table 4. Measurement and fitting results of each moisture content of EA02 TDR (unit : cm³ / cm³)

Soil sample number	Design mass water content	Mass moisture content measured by drying method	Design volume water content	Volumetric water content measured by TDR	Fitting values	Fitting relative error / %
1	6.70	6.50	11.05	8.76	15.87	43.65
2	11.70	11.10	18.87	10.04	18.34	2.82
3	16.70	16.20	27.54	13.59	23.77	13.69
4	21.70	21.30	36.21	33.88	40.16	10.91
5	26.70	25.90	44.03	46.63	45.89	4.23

Table 5. Measurement and fitting results of each moisture content of EA03 TDR (unit : cm³ / cm³)

Soil sample number	Design mass water content	Mass moisture content measured by drying method	Design volume water content	Volumetric water content measured by TDR	Fitting values	Fitting relative error / %
1	6.70	6.50	11.05	11.25	15.17	37.27
2	11.70	11.10	18.87	14.31	20.39	8.03
3	16.70	16.20	27.54	15.67	22.36	18.82
4	21.70	21.30	36.21	36.94	40.94	13.07
5	26.70	25.90	44.03	45.38	45.41	3.13

Table 6. Measurement and fitting results of each moisture content of EA04 TDR (unit : cm³ / cm³)

Soil sample number	Design mass water content	Mass moisture content measured by drying method	Design volume water content	Volumetric water content measured by TDR	Fitting values	Fitting relative error / %
1	6.70	6.50	11.05	8.30	14.81	34.02
2	11.70	11.10	18.87	9.34	16.92	10.31
3	16.70	16.20	27.54	16.23	26.88	2.38
4	21.70	21.30	36.21	33.41	39.88	10.13
5	26.70	25.90	44.03	45.85	45.58	3.52

From table 3 to table 6, it can be seen that the water content of five soil samples measured by drying method is highly consistent with the designed water content, indicating that the water content configuration of the test soil samples is accurate. It is also easy to know that although the fitting curves of four TDR moisture meters have high correlation coefficients, the fitting curves have different fitting accuracy for clay soils with different moisture contents.

When the designed volumetric water content of clay soil is 11.05 cm³ · cm⁻³, there is a large fitting error between the fitting values of the four TDR moisture meters and the designed volumetric water content, and the error range is 34.02 cm³ · cm⁻³ ~ 37.27 cm³ · cm⁻³, which is larger than that of the drying method. At this time, the measured value range of TDR was 8.30 cm³ · cm⁻³ ~ 11.25 cm³ · cm⁻³, which was obviously closer to the design volumetric water content of 11.05 cm³ · cm⁻³. Therefore, when the TDR method is used to measure the cohesive soil with low volume water content, the measured value of direct reading TDR is closer to the real value.

When the volumetric water content of soil samples increased to 18.87 cm³ · cm⁻³ ~ 36.21 cm³ · cm⁻³, the fitting relative error of the four TDR fitting curves was small. The fitting relative error of EA01, EA02 and EA03 TDR for soil samples with volumetric water content of 18.87 cm³ · cm⁻³ is the smallest, while the fitting curve of EA04 is the highest for soil samples with volumetric water content of 27.54 cm³ · cm⁻³. When the designed volumetric water contents of the measured soil samples were 18.87 cm³ · cm⁻³ and 27.54 cm³ · cm⁻³, the fitting values of the four TDR fitting curves were basically small (except 18.87 cm³ · cm⁻³ corresponding to EA03 fitting curve); when the designed volumetric water content is 36.21 cm³ · cm⁻³, the fitting values of the four TDR fitting curves are larger.

When the volumetric water content of the tested soil sample is 44.03 cm³ · cm⁻³, the fitting values of the four TDR fitting curves are the most accurate, and the fitting relative errors are less than

4.23%. This is because with the increase of soil water content, the dominant position of water dielectric constant in soil is more obvious, and the accuracy of fitting curve is higher.

5. Conclusion

(1) Different TDR moisture meters of the same model may have differences in the measurement of clay samples with the same mass moisture content. Therefore, each TDR needs to be calibrated separately before the test.

(2) For clay soil with low water content, the direct measurement results of TDR are closer to the true value ; with the increase of water content, the accurate value of TDR fitting curve increases, but according to the different water content of soil samples, the fitting value will appear larger or smaller results.

(3) When the volumetric water content of cohesive soil samples increases to $44.03 \text{ cm}^3 \cdot \text{cm}^{-3}$, the accuracy of the fitting curve of TDR reaches the maximum.

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