Soil Moisture Measurements with an Improved Time Domain Reflectometry System

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Abstract

A new time domain reflectometry (TDR) technique for measurement of volumetric soil moisture content is presented. TDR determines the dielectric constant which is, in moist soils, mainly a function of water content. The new system was calibrated with different soils and soil-like materials ranging from fine sand to heavy clay. The dependence on soil type was only small, so that a universal calibration function could be established. Absolute accuracies of 1.9 per cent by volume were reached for a loessial soil; the repeatability was 0.5 per cent by volume. Higher deviations were found for materials with high specific surfaces such as clays and soils with high organic content, and which thus require specific calibrations. The measurements were also limited by a bulk soil electrical conductivity exceeding 2^{ms} cm^{-1}.

Introduction

Water content measurements are the crux of many hydrological studies. The standard methods, such as oven-drying and determining the loss in weight, tensiometry techniques, neutron moderation, or gamma reduction, have a lot of disadvantages. Some of the main problems are, for example, the destruction of the test site, high working and maintenance costs, the use of hazardous radioactive sources, or the lack of automatic data acquisition.

The relatively new time domain reflectometry (TDR) technique (Topp et al. 1980) avoids these disadvantages and is, therefore, gaining more and more acceptance.

Method

Conventional TDR

TDR is an indirect measurement method, the determination of volumetric water content being based on the reflection of a high-frequency electromagnetic pulse on metallic rods. Figure 1a shows a schematic diagram of a TDR system for water content determinations. An electromagnetic pulse is generated in the TDR device and is sent via a coaxial cable to a probe embedded in the soil. At every discontinuity on the path of the pulse, reflections occur (Fig. 1b), so that a trace with the reflection coefficient as a function of time can be displayed (Fig. 1c).

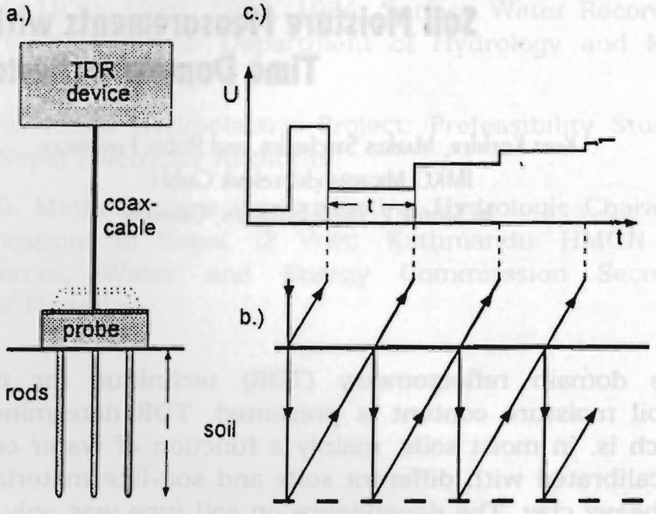

Figure 1: Schematic Diagram of TDR System (a) Voltage Reflection Pattern, (b) Idealised Trace, and (c) for Conventional TDR-systems (changed after Topp et al. 1994)

According to equation (1) the velocity, c, of the pulse in non-magnetic materials (magnetic permeability $\mu_r = 1$) yields the dielectric constant, ε_r, which in soils is mainly a function of the water content (c_0 denotes the velocity of light in free space).

$$c = c_0 / \sqrt{\varepsilon_r \cdot \mu_r} \qquad (1)$$

Graphical evaluation yields the transit time, t, on the rods from the displayed TDR trace (Fig. 1c) and with the known length, l, of the rods, the velocity, c, can be determined. With the dielectric constant, the water content can then be determined by an established calibration function.

This conventional TDR method and the devices, originally developed for electrical engineering to detect cable damage and adopted by soil scientists for water content determinations, are not very convenient for field applications. The expensive, complex, and heavy hardware; high pôwer consumption; and the need for graphical waveform interpretation pose several problems.

TRIME-TDR technique

We have developed a new TDR technique (Stacheder et al. 1994), the 'TRIME method' (TDR with intelligent micromodule elements), that avoids the need for high-frequency (HF) pulse generators, sampling oscilloscopes, or cable testers. The use of sophisticated application-specific analog and digital integrated circuits (ASIC) and new waveform-processing hardware and algorithms allows the production of devices with small dimensions (Fig. 2a) and the construction of probes that are independent of coaxial cable length (Fig. 2b).

Measuring time and power consumption are considerably reduced. The new probes can be interlinked by a digital two-wire bus and located along a serial data network up to 3km in length. The measurement values can be logged by a PC or the probes can be connected to a datalogger. Also, the use of small rod probes (0.05m) to measure water content < 5 per cent by volume and the construction of a TDR tube probe (Fig. 2c) that allows the measurement of water content profiles in the soil via a glass fibre access tube are possible.

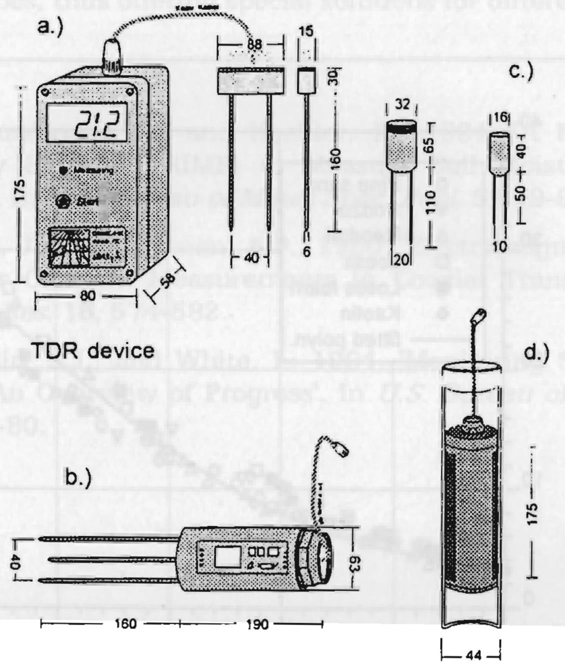

Figure 2: (a) Dimentions (mm) of TRIME Device, (b) Intelligent Rod Probe, (c) Smallest Rod Probe, and (d) Tube Probe with Access Tube

Results

The new technique was tested with several soils, ranging from fine sand to heavy clay (Table 1). The reference method for water content determinations was the thermogravimetric technique, which establishes the loss in weight of a moist sample dried in an oven at 105°C until of constant weight.

Figure 3 shows the relationship between the dielectric constant and the water content. The dependence on soil type was only small, so that a polynomial function could be fitted to the measured values. The mean absolute accuracy for water content determinations with this universal function was 1.9 per cent by volume for a loessial soil; the new system had a repeatability of 0.5 per cent by volume.

Table 1 Characteristics of Materials Used for Soil Water Content Determinations

Material	Organic content [per cent]	Texture [per cent] Clay (< 0.002mm)	Silt (0.002-0.05mm)	Sand (0.05-2mm)	Bulk density range [g/cm^3]
Fine Sand	-	-	2	98	1.4-1.6
Podzol	1.4	19	24	56	1.4-1.6
Rendoll	12.8	6	66	28	0.7-1.2
Loess	0.4	14	78	8	1.4
Loess Loam	4.9	19	61	20	1.0-1.5
Kaolin	3.4	38	60	2	1.0-1.4

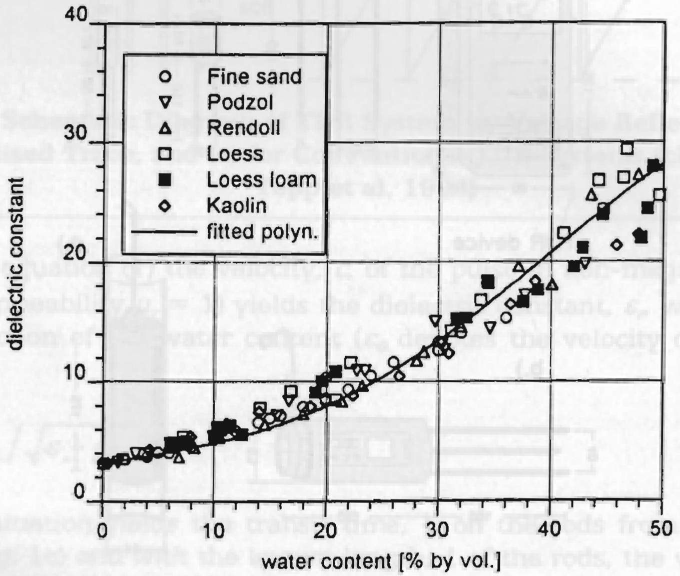

Figure 3: Relationship between Volumetric Water Content and Dielectric Constant for Different Soils Determined with a TRIME Two-Rod Probe

Yet materials with high specific surfaces, such as clays or soils with high organic content (> 10 per cent), show a more pronounced deviation from the universal calibration function. This is due to a different dielectric behaviour of the bound water fraction, so that these materials may therefore afford special calibration functions.

Another limiting factor in the use of TDR is the bulk soil electrical conductivity which may lead to significant attenuation of the transmitted signal. It was found that the TRIME rod probes could be used for water content measurements in soils with bulk soil electrical conductivities not exceeding 2^{ms} cm^{-1}.

Conclusion

The TDR technique is a powerful new tool for the determination of water content in soils. It has the advantage of quick, reliable, and non-destructive measurements.

The new TRIME system offers additional possibilities, especially for field use and for *in situ* long-term monitoring of water content and automatic data acquisition. Furthermore, the new system allows the construction of a broad variety of different probe types, thus offering special solutions for different problems.

References

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