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Technical Report

Measuring Soil Moisture with FD-Probes

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Measuring Soil Moisture with FD-Probes

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1 Introduction

Soils are part of the ecosphere and play an important role for life on earth. They influence the quality and composition of ground- and drinking water and provide a biotope for many animals, organisms and in particular plants (Blume et al., 2010). Soil has many important functions for plants, such as the supply of water, nutrients and oxygen. It therefore strongly affects plant growth and plant health.

The water content of soils, commonly called soil moisture, is an essential part of the soil besides minerals, organic matter and air. Soil moisture is a key variable in the process of mass and energy exchange of the interface between land surface and atmosphere (Pauwels et al., 2001, Weidong et al., 2002). For this reason, accurate information about soil moisture is very interesting for many research fields. For agricultural applications information about soil moisture is inevitable to model plant growth, vitality, yield or irrigation requirements (e.g. D'Urso et al., 2010).

Local field measurements are, however, expensive and time-consuming and provide only a limited spatial comparability. Earth observation (EO) data from the optical to the microwave domains – nowadays continuously available across wide areas – have been exploited in the last decades for the potential to retrieve soil moisture information. While crop type, soil texture, soil mineral components and organic matter may not change rapidly, soil moisture quickly responds to changing weather conditions. Moreover, vegetation coverage may disturb the spectral signal from the soil. As such, soil moisture is one of the most difficult agricultural parameters to retrieve but also amongst the most important ones. Therefore, ground-based local measurements are still required to validate the remote sensing estimates of soil moisture, which can be accomplished in the context of intensive field campaigns using appropriate measurement devices (Richter et al., 2012; Weidong et al., 2012). This field guide intents to give an overview of background knowledge, measurement practices and related information for the retrieval of soil moisture.

1.1 Definitions

Definitions of soil:

A simple definition for soil is given by Blume et al. (2010): "Soil is the biologically active part of the upper crust of the earth."

More precise is the definition from the USDA (1999): "Soil […] is a natural body comprised of solids (minerals and organic matter), liquid, and gases that occurs on the land surface, occupies space, and is characterized by one or both of the following: horizons, or layers, that are distinguishable from the initial material as a result of additions, losses, transfers, and transformations of energy and matter or the ability to support rooted plants in a natural environment."

Definitions of soil moisture (soil water content):

"*Water content* is the percental amount of water in the soil, which can be removed from the soil by drying 16 hours in a laboratory at 105°C. After this drying procedure the soil is not completely dry, but the remaining water is called hygroscopic water and is not part of the water content of the soil.

Precipitation increases the amount of water in the soil and leads to percolation. But a certain part of the water remains in the soil against gravity and is called adhesive water or *soil moisture*." (Blume et al., 2010).

Some important special terms related to soil moisture:

Saturation is the water content, when all pores of the soil are filled with water and not with air, the *Field Capacity (FC)* is the maximum amount of water that can be held in the soil. The *Permanent wilting point (PWP)* is the status, where soil water is not available for plants anymore. The *Available Water* is the range between FC and PWP and describes the amount of water which is useable for plants (Government of Manitoba, 2012).

Soil moisture is defined by volumetric soil moisture (θv) and characterizes the volume of water present in a unit volume of soil. It can be expressed by the following ratio:

$$\theta_v = \frac{V_w}{V_S} \qquad \textit{(Equation 1-1)}$$

where V_w represents the volume of water present in a given bulk volume of soil V_S. Experimental measures of soil moisture can be expressed as percentage (%) or a ratio ($m^3\ m^{-3}$), thus ranging between 0 and full saturation. The upper limit is not a priori definable, as it depends on the soil porosity of the sample being measured (Richter et al., 2012).

1.2 Areas of Application

There are various fields of interest for measuring soil moisture:

- determine need for irrigation (e.g., D'Urso et al., 2010)
- predict growing conditions for trees or plants (e.g. Lawless et al., 2008)
- get information about soil moisture percentage for geotechnical and civil engineering purposes (Eijkelkamp, 2013)
- ground reference data for various research topics
  - improve soil moisture retrieval from radar remote sensing data (Dobriyal et al, 2012)
  - modeling plant growth or yield depending on soil moisture (e.g. Place & Brown, 1987)

1.3 Measurement and Devices

There are different possibilities to measure soil moisture. The most accurate are *destructive methods*, such as the *gravimetric* method. A soil sample is taken, its weight is measured and then it is dried in the oven of a laboratory for 16 hours at 105 °C. Afterwards it is weighed again. The difference of the two measurements corresponds to the amount of water in the original sample. The advantage of this method is the high accuracy. It is used to calibrate other methods, e.g. FD-Probes (see below). The disadvantages are the time consuming soil sampling and drying. Moreover, there is only little time between taking the sample and the first weighing and drying process, because otherwise the sample starts to dry and the initial weight is lost. For monitoring purposes the method is not useful due to its destructive character (Schöninger & Dietrich, 2008).

Non-destructive methods are divided by two different measuring principles:

(1) The first principle is measuring soil suction with a tensiometer. However, these devices have a limited range, are not suited for dry conditions and time consuming. Alternative instruments are porous blocks that wet and dry according to the soil moisture. Porous blocks have a wider range than the tensiometer and are therefore more suited for long term measurements.

(2) The second principle is measuring the quantity of water in the soil. Here Time-Domain-Reflectometry-Probes (TDR) or Frequency-Domain-Probes (FD) are of use. TDR Probes are slightly more accurate than FD Probes, but more expensive as well. Both instruments are identically in their use and are of advantageous speed and simplicity.

2 Data Collection

2.1 Theory: Measurement Principle

The soil moisture sensor used at the Department for Geography is a ThetaProbe from Delta T-Devices (see Figure on cover page). This FD-probe consists of a housing for the electronics and four steel pins. It measures volumetric soil moisture by recognizing changes in the electric field caused by different dielectric constants of the soil components. The relationship between the Theta Probe output and the square root of the dielectric constant is shown in Figure 2-1. The changes are then converted into a DC voltage and are proportional to the soil water content (Eijkelkamp, 1999).

FD probes measure dielectric characteristics of the soil between the steel pins which can basically be considered as electrodes. The dielectric constant is expressed as electrical capacity, by measuring the charging time of the capacitor. The charging time again depends on the electrodes and the dielectricity of the medium (soil) between them (UMS n.d.). The dielectric constant of the soil or the *capacitor*, which equals the permittivity, finally depends on the water content (Eijkelkamp, 2013).

The dielectric constant of water $\varepsilon_{water} \approx 80$ is much higher than $\varepsilon_{soil} \approx 3$ to 5 and $\varepsilon_{air} \approx 1$. Consequently, charging time varies with the water content and is thus an indirect variable for soil moisture.

Normally an oscillating voltage with 100 MHz frequency is used to minimize the ionic conductivity (Eijkelkamp, 1999). The response time is 0.5 seconds and the accuracy for homogenous soils is 1 Vol%.

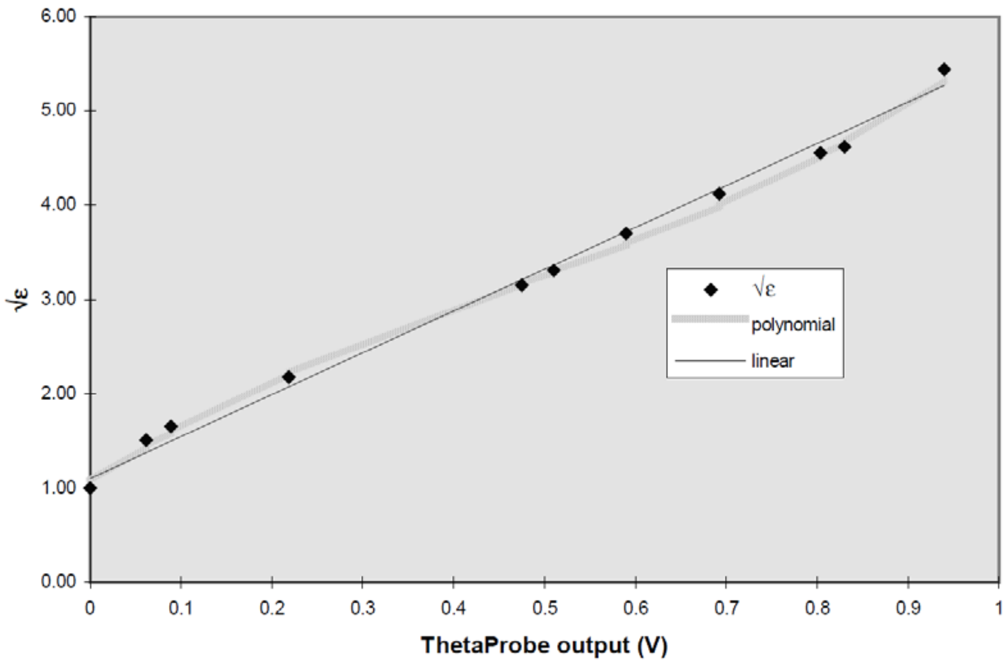

Figure 2-1: Relationship between ThetaProbe output and square root of the dielectrical constant (Eijkelkamp, 1999)

2.2 Technical Accomplishment

In the following table, an example is shown for the exact measurement procedure in the field, using a Delta-T Devices, Theta Probe (type ML2x) and the UMS console INFIELD 7.

There is no need for an extra calibration of the FD probes. It is important, however, to distinguish between mineral soil and organic soil and to be sure that the correct unit (%) is shown in the display. Normally the soil of agricultural fields is the mineral soil type.

Afterwards, the user can decide to apply a soil specific calibration if the soil composition is well known and the probe has been used for continuous measurements. If the probe is utilized in field campaigns where soil composition can differ from field to field, the standard pre-calibrations shall be sufficient. Figure 2-2 shows generalized examples for mineral and organic soils.

Measurement procedure	
(1)	Remove the yellow protective caps from both the socket at the console and the cable end of the probe
(2)	Connect the cable to the right console cable socket
(3)	Turn on the device and switch data input to “Theta P” via the F1-key
(4)	If necessary, switch the soil type between mineral and organic
(5)	Insert the probe into the soil, following a sample strategy depicted in chapter 2.3
(6)	Write down the soil moisture value into the field protocol

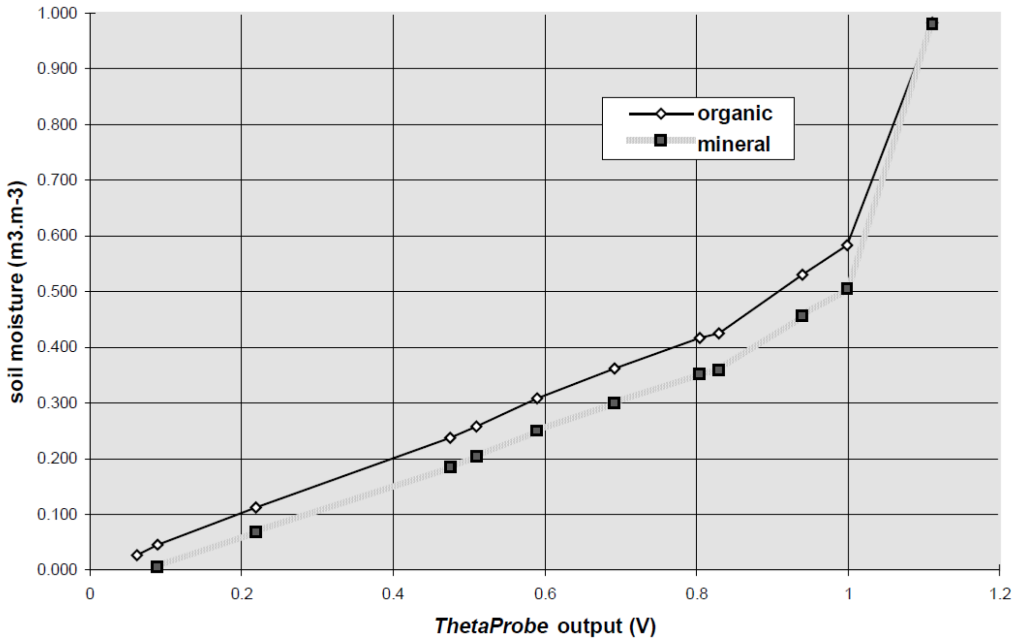

Figure 2-2: Standard calibration curves for mineral and organic soils (Eijkelkamp, 1999).

2.3 Sampling Strategy

Even if there is no explicit sampling strategy for measuring soil moisture, please note the following suggestions. There are many methods how to proceed in the field. None of them are superior to others, but once chosen, you should stick to that technique. If there is a team at work, it should agree on the same method!

Several possibilities:

- measure in a circle around you
- measure in a spiral around a point
- measure in a matrix (e.g. 3x3 samples)

For each technique measure for about 10 times and then calculate the arithmetic mean. Then go to the next sample point.

If you collect your measurements within a field campaign and over a longer period of time, think about *when* to measure. Are you interested in the soil moisture at noon, or in the morning? Try to measure always at the same time of the day to avoid misleading information. Moreover, in the protocol you should always make notes about the *weather conditions* (e.g., percentage of clouds, last precipitation, etc.).

It could further be useful to mark the sample points with a GPS to relocate the same points next time. Within the field, you should always measure within and between the rows. In potato fields, measurements should be taken between, on one side and the top of the mounds. If the sample points are distributed as clusters, determine their distance by statistical methods in a pre-study. Water content may seem to vary on very small process scale, but on a larger scale patterns might evolve.

2.4 Sources of Errors and Uncertainties

Though the measurement of soil moisture with a TDR or FD Probe is quite easy, there are some important aspects to take into account:

Potential error sources	
▪ The pins of the probe must penetrate into the soil as far as it will go!	▪ Be careful with the instrument – pins can break or bend easily!
▪ The certainty of the measurement decreases with increasing moisture. Therefore, the measurement is not suitable for wet conditions!	▪ Be extra careful if there are many stones. But at the same time focus on your sampling scheme as strictly as possible.
▪ The probe must be inserted perpendicular to the surface!	▪ Roots and earth worm holes will affect your measurement (Eijkelkamp 1999)

3 Data Elaboration

3.1 Required Software

There is no special software required to analyse soil moisture data. Standard hand held devices that can be used with the soil moisture probes often cannot store the measured data. Instead, they should be written down manually.

3.2 Data Output and Correction Methods

If the measurement was taken carefully, no extra correction methods are necessary. The best way to get reliable values is to take several samples and then calculate the mean for each sample point. The possibility of outliers contributing to the overall average soil moisture at a sample point is to exclude the highest and lowest measured value of the calculation. Note, however, that computing a trimmed average also means a manipulation of your field data.

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