Electrical Methods of Soil Moisture Measurement: A Review

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Abstract: ***Soil moisture is an important factor that is of immense importance in the field of engineering, agriculture and ecology. The permittivity of soil is dependent on the water level present in the soil. Development of weather patterns and the production of precipitation depend on soil moisture. A number of soil moisture measurement techniques are being developed by various researchers. This paper reviews the various electrical methods of measuring soil moisture, such as the dielectric method, electrical resistance method and electrical capacitance method.***

Keywords: Soil moisture, electrical methods to measure soil moisture, Irrigation, Resistivity of soil, Resistivity probe.

1. Introduction

Soil moisture is the water content in the soil. The permittivity of the soil is dependent on the water level present in the soil. Development of weather patterns and the production of precipitation depend on soil moisture [1]. Measurement of soil moisture is important for irrigation schedules. By measuring the soil water content, soil moisture can be determined.

Soil moisture is important for the plant's growth. Moist soil increases the rate of diffusion because soil water is the pathway for ion movement and thickness of water film determines the ease of nutrient movement to the root [2]. Thus, it is important to keep the soil moist to the desired level for healthy crops. Soil moisture content is measured using different electrical techniques.

2. Electrical Methods of Soil Moisture Measurement

The following techniques employ the electrical properties of the soil to measure the moisture content in the soil: Electrical resistivity and dielectric constant.

2.1 Electrical Resistivity Technique

The principle of electrical measurement of soil moisture was first reported by Whitney *et al.* in 1897 [2]. Electrical resistance technique operates on the principle that resistance between two electrodes immersed in the soil will depend on the moisture content of the soil [2]. Later, J. A. Munoz *et al.* [3] observed the electrical resistivity of natural unsaturated loess, a loosely compacted yellowish-grey deposit of wind-blown sediment. Cylindrical specimens were extracted from the ground for that purpose. The system used a precision balance to measure the change in water mass, of a metallic cylindrical mould housing the specimen of a plastic cover disk accommodating the resistivity probe as well as covering the specimen to avoid evaporation at the time of measurement. The electrical resistivity probe was used for measuring the resistivity of soil with variation in moisture. The volumetric water content increased from 5.8% to 38.5% with a decrease in resistivity from 338 Ω-m to 8 Ω-m. For dry soil, the resistivity reached values higher than 50 Ω-m. At lowest degrees of saturation, resistivity is highest and vice versa.

Sudhir *et al.* [4] used electrical resistivity method for determining the water content in the sand. Figure 1 shows the setup for measuring the electrical resistivity of sand. The oven dried sand and bore well water was used for preparing the sample. The predefined water quantity is added to sand and kept in plastic bags for 24 hours in a PVC mould in 3 layers. The mould is cylindrical, and the ends are pressed with copper plates, which behave as the outer electrodes. Two other copper rods were placed inside the specimen with a spacing of 0.0424 m. DC voltage ranging from 0 to 30V is applied to the outer plates, and the resistivity is measured. One 2K resistance is inserted in series with the specimen to measure the current. At a low water content of 1.02%, the resistivity is undetermined. For 30V DC supply, electrical resistivity value varied between 49.723 to 297.666 Ω-m and the mean is 140.913. The analysis showed that the ER increases with a decrease in moisture content.

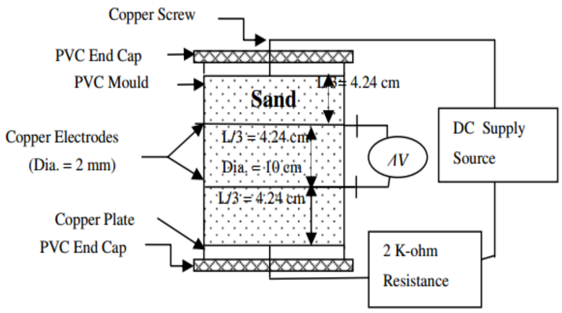

Figure 1: Setup for measuring electrical resistivity of sand [4]

Soil sample extracted from the field may not have the same resistivity as that of the field because of their degree of compaction. However, the moisture content in them would remain the same, if kept in a sealed container. W. John McCarter [5] found the electrical resistivity characteristics for compacted clays. Figure 2 shown below is the setup for measuring the resistance of the compacted clay.

The sample was compressed into a conductivity cell. The electrical resistance is measured by Terrameter. The two-electrode model of electrical resistivity measurement is used over the four-electrode model as it nullifies the uncertainty over the cross-sectional area and electrode sample coupling. After testing, the clay is remixed and compacted to ensure the moisture remains constant. At saturation, the moisture content remained constant. The resistivity dropped as the volumetric water content is zero and increasing the same showed change in resistivity. Similarly, it has been observed that increasing the degree of saturation also decreases the resistivity. Resistivity is thus a function of moisture content and degree of saturation.

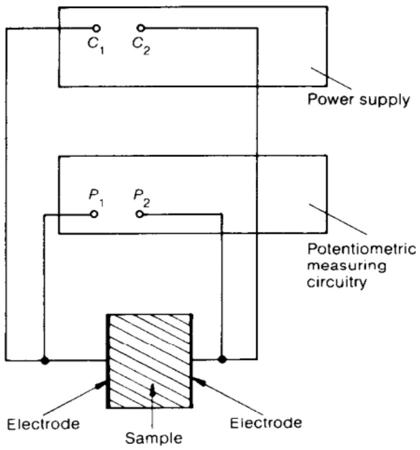

Figure 2: Schematic diagram of sample resistance measurement [5]

The soil water content of maize farm with sandy loam soil is investigated using a vertical sounding technique [11]. The electrodes used were made of copper wires supported by wood. Copper wires are the conducting medium and wood supported wires in the ground. The electrodes were connected to 40m long cable with an electrode separation of 0.2m. The electrodes are inserted into the ground close to the plants. The jumpers connected to the copper part of electrodes through cable take-outs are connected to WWEN32S protocol. The resistivity obtained was in the range of 40-60 Ω-m for the sandy loam soil.
A clear relationship exists between the soil moisture and soil resistivity, which makes the electrical resistivity method simple and reliable.

2.2 Dielectric Technique

Time Domain Reflectometry (TDR), capacitance technique and Frequency Domain Reflectometry (FDR) are the techniques that use the dielectric property of the soil for measuring soil moisture content.

2.2.1 Time Domain Reflectometry (TDR)

The apparent dielectric constant is measured by measuring within the time region the round trip rate of electromagnetic waves at a constant frequency (a high frequency from 30 MHz to 3 GHz) to and from metal electrodes buried in the soil. The cable tester produces high-frequency electromagnetic pulses and monitors reflected waves, rods inserted into the soil, the cable connecting the tester and rods. [6].

Spatial variations play a key role in the Terroir effect. Terroir effect involves the environmental factors affecting a crop's epigenetic qualities. Spatial variation in soil water is barely considered while measuring with TDR. TDR measures a small volume of soil, so no information of lateral spatialization is observed [7].

2.2.2 Capacitance Technique

The moisture content can be measured by measuring the dielectric constant, which can be measured by capacitance. The dielectric constant of water is 81 (approx.), 3 to 5 (approx.) for dry soil, and 1 (approx.) for air. The capacitance method is used for measuring the moisture content of soil; because, the dielectric constant increases with an increase in the water content. Capacitance, C is directly proportional to the dielectric constant, K_d.

$$C = G_C K_d$$

Where G_c represents the shape factor that is dependent on the size and shape of the capacitance sensor and the distance between the electrodes [6]. Figure 3 below shows the schematic diagram of soil moisture measurement using capacitance method. The capacitance sensor consists of two electrodes, which are to be immersed in the soil. The two electrodes form the capacitor and soil act as the dielectric material. Change in the frequency of the oscillator indicates a change in soil moisture [10].

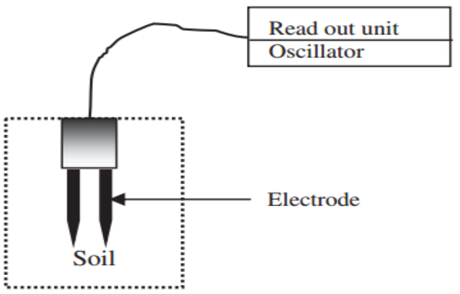

Figure 3: Schematic diagram of soil moisture measurement using capacitance technique [10]

T. J. Dean *et al.* [8] used the bridge method with 30 MHz, which required manual balance to measure the dielectric constant. The probe is directly inserted into the soil surface layers. The calibration is done by the gravimetric method. The sensor inserted in the access tube measures the capacitance of the electrodes with a dielectric comprising of moist soil surrounding the access tube. Aluminium probes are installed to minimize the soil disturbance and possibility of air gap around the access tube. For a capacitance probe, the air gap is significant because of its sensitivity. For that purpose, a steel rod was used to set up an annular gap tapering. Thus, the technique can tolerate air gaps while installing the access tube without prejudice to accuracy.

Measurement of frequency is one of the factors affecting the sensitivity of the capacitance sensor measurement. Kizito *et al.* [9] constructed a moisture probe with 5.2 cm long pongs. Sensor performance was obtained by partial vertical immersion of sensor pongs in known salt solutions. The sensitivity of the probe with changing salinity decreased with the increase in frequency. Further increase in frequency did not reduce the sensitivity any further.

2.2.3 Frequency Domain Reflectometry (FDR)

FDR measures the interference waves produced when electromagnetic waves emitted on continuous frequencies (100 MHz to 1.7 GHz) in the frequency region as they complete a round trip at the sensor rod inserted in the soil, allowing the determination of the dielectric constant from peak features [6]. Figure 4 shows the schematic diagram of FDR for soil moisture measurement. The FDR has the same working principle as that of the Capacitance Technique.

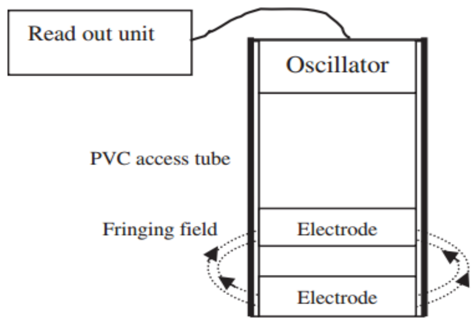

Figure 4: Schematic diagram for soil moisture measurement using FDR [10].

FDR probe is better in soils having volumetric moisture content lesser than 5% and hence, its sensitivity is high for volumetric moisture content measurement in relatively dry soil. Earlier researches showed that FDR probe shows erroneous results, being sensitive to air gaps between soil, the access tube and the probe [10].

3. Conclusion

The researchers have developed various electrical techniques viz., Electrical Resistivity (ER) technique, the capacitance technique, FDR, TDR for measuring soil moisture. Electrical Resistivity technique is used for spatial measurement of soil water. For monitoring soil water content by ER technique, calibration can be performed both in the field and in the laboratory. The TDR and electrical resistivity method can be used in the field to find ER and Soil Moisture relationship. The soil moisture results will be different for different techniques depending on the factors like salinity, soil type, temperature etc.

References

[1] "Soil Moisture", *Marshall Space Flight Center Earth Science Office, NASA*, Dec. 30, 1999. [Online]. Available: https://weather.msfc.nasa.gov/landprocess/ (Accessed: 12 Feb. 2017)

[2] A. I. Johnson, "Methods of Measuring Soil Moisture in the Field", *Geological Survey Water-Supply Paper 1619-U, Contributions To The Hydrology of The United States*, U.S. Department of The Interior, U.S. Geological Survey, U.S. Government Printing Office,

Washington,1962. Retrieved from https://pubs.usgs.gov/wsp/1619u/report.pdf

[3] J. A. Muñoz-Castelblanco, J. M. Pereira, P. Delage and Y. J. Cui, "The Influence of Changes in Water Content on the Electrical Resistivity of a Natural Unsaturated Loess", *Geotechnical Testing Journal*, Vol. 35, Issue 1, 2012, pp. 11-17. Doi: https://doi.org/10.1520/GTJ103587

[4] S. Bhatt and P. K. Jain, "Correlation between electrical resistivity and water content of sand - a statistical approach", *American International Journal of Research in Science, Technology, Engineering & Mathematics (AIJRSTEM)*, Vol. 6, Issue 2, 2014, pp. 115-121. Retrieved from http://iasir.net/AIJRSTEMpapers/AIJRSTEM14-342.pdf

[5] W. J. McCarter, "The electrical resistivity characteristics of compacted clays", *Geotechnique*, Vol. 34, Issue 2, June 1984, pp. 263-267. Retrieved from https://www.researchgate.net/publication/245410154

[6] M. Inoue and T. Shimizu, "Experimental Set-up to Continuously Monitor Water Flow and Solute Transport in Unsaturated Large Weighing Lysimeters", *Research Paper in Annual Report of Arid Land Research Center, Tottori University*, 1997, pp. 1-14. Retrieved from https://www.alrc.tottori-u.ac.jp/english/achievements/annual/1997-1998/paper.pdf

[7] L. Brillante, O. Mathieu, B. Bois, C. van Leeuwen and J. Lévêque, "The use of soil electrical resistivity to monitor plant and soil water relationships in vineyards", *Soil*, Vol. 1, March 2015, pp. 273-286. Doi: https://doi.org/10.5194/soil-1-273-2015

[8] T. J. Dean, J. P. Bell and A. J. B. Baty, "Soil moisture measurement by an improved capacitance technique, Part I. Sensor design and performance", *Journal of Hydrology*, Vol. 93, Issues 1-2, 1987, pp. 67-78. Doi: https://doi.org/10.1016/0022-1694(87)90194-6

[9] F. Kizito, C. S. Campbell, G. S. Campbell, D. R. Cobos, B. L. Teare, B. Carter and J. W. Hopmans, "Frequency, electrical conductivity and temperature analysis of a low-cost capacitance soil moisture sensor", *Journal of Hydrology*, Vol. 352, Issues 3-4, May 2008, pp. 367-378. Doi: https://doi.org/10.1016/j.jhydrol.2008.01.021

[10] S. Lekshmi S. U., D. N. Singh and M. S. Baghini, "A critical review of soil moisture measurement", *Measurement*, Vol. 54, August 2014, pp. 92-105. Doi: https://doi.org/10.1016/j.measurement.2014.04.007

[11] I. S. Jakalia, A. A. Aning, K. Preko, N. Sackey and S. K. Danuor, "Implications Of Soil Resistivity Measurements Using The Electrical Resistivity Method: A Case Study Of A Maize Farm Under Different Soil Preparation Modes At KNUST Agricultural Research Station, Kumasi", *International Journal of Scientific & Technology Research*, Vol. 4, Issue 1, January 2015, pp. 9-18. Retrieved from https://www.researchgate.net/publication/306264655