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Research Article

MOISTURE CONTENT MEASUREMENT OF CLAY LOAM SOIL BY DIELECTRIC CONSTANT

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ABSTRACT
Change in dielectric constant of clay loam soil was investigated as a function of moisture content. A parallel plate capacitor was used to measure the dielectric constant of soil. Results showed that the dielectric constant highly depended on moisture content. Within the range of moisture content values, 5–32% wet basis, dielectric constant was found to be 3-16.8. Second - order polynomial Model (R^2 = 0.976) was developed between moisture content and dielectric constant of soil.

Keywords**:** *Soil; Moisture Content; Dielectric Constant, Modeling*

INTRODUCTION
Soil moisture (water) is an inevitable part of the three phase system of the soil, which comprises of soil minerals (solids), moisture and air.
Hence, soil moisture content has quite significant influence on engineering, agronomic, geological, ecological, biological and hydrological behavior of the soil mass (Dobriyal *et al*., 2012; Susha *et al*., 2014). Also, moisture content has a major role to play as far as the plant growth, organization of the natural ecosystems and biodiversity is concerned (Jung *et al*., 2010; Mittelbach *et al*., 2012).
The traditional method for measuring moisture content uses an oven which leads to high accuracy but because it is time-consuming and involves a complicated procedure, it is not suitable for field use. Various techniques for indirect testing methods have been studied for replacing the traditional oven method at home and abroad, e.g. the use of conductance, capacitance, X-rays, neutrons, and microwaves (Zhang *et al*., 2013; Rao and Singh, 2011; Susha *et al*., 2014; Mittelbach *et al*., 2012; Fityus *et al*., 2011). These techniques, except for the application of 'infrared waves' for determining the moisture content can be used for both laboratory and in situ applications.
Therefore, evaluation of soil moisture sensors was conducted by Leib *et al.*, (2003), Jones *et al.*, (2005), and Blonquist *et al.*, (2005). Capacitive technique is a simple, small volume, easy fabrication, rapid and low cost method to determine the quality of bio-products.
Due to these advantages this technique is widely used in agriculture (Tong *et al*., 2013; Soltani and Alimardani, 2013). But, because these sensors often operate at the low end of or below the frequency range of TDR, they are often criticized for being more susceptible to soil environmental effects (Kizito *et al*., 2008; Chen and Or, 2006).
In Considerable work has been done to determine optimal measurement frequencies, but some has been contradictory. Kizito *et al.,* (2008) determined that a measurement frequency of 70 MHz was required to result in stable real soil dielectric permittivity values. However, Kelleners *et al.*, (2005) concluded that measurement frequencies must be above 500 MHz for stable dielectric permittivity values, whereas Chen and Or (2006) concluded that measurement frequency should be equal or greater than 100 MHz to minimize Maxwell–Wagner polarization.
Also, studies continue to determine the effects of soil environment variables like temperature, electrical conductivity, and soil type that effect the accuracy and reliability of the capacity measurement (Kizito *et al*., 2008; Zhang *et al*., 2004; Jones and Or, 2004; Chandler *et al*., 2004). A comprehensive review on soil moisture measurement have provided by Susha *et al.*, (2014) and Dobriyal *et al.*, (2012). This paper, the capacitance technique has been evaluated as a method for dynamically measuring soil moisture content.

MATERIALS AND METHODS

The clay loam soil representing major agricultural soils in Arak, Iran was selected. The soil samples (24.5±3.1% sand, 36.7±4.4% silt, and 38.8±3.5% clay) were collected horizontally from the top layer (5 to 15 cm) of soil profile located at the Arak Branch, Islamic Azad University agricultural farm, Arak, Iran. Soil particle size distribution was determined using the hydrometer method. Soil had an initial moisture content of 20.8 ± 0.5% wet basis, which was determined by using a standard oven method at 105 ºC for 24 h (Ekwue *et al*., 2011). The moist soil samples was dried in a hot air oven at 70°C to get the desired difference moisture content levels between 30 (±0.54) and 5% (±0.26) wet basis. Each dried soil sample was kept in a plastic box which was sealed by plastic film to prevent moisture loss. Then it was refrigerated at 5°C for at least 24 h to allow moisture in the samples to equilibrate before analysis. Finally, moisture content of the sample was checked again before use to ensure it was at the correct level.

An instrument based on capacitive technique was designed and developed to measure the dielectric constant of soil at various moisture contents. The instrument consists of a parallel plate capacitor (surface area: 80 ×50 mm; plate thickness: 3 mm, gap between plate: 25 mm) as a standard hardware sensor, signal conditioning circuit, a 10-bit Microcontroller interfaced with a 16×2 LCD display and sinusoidal function generator. The electrodes material was selected from aluminum. To avoid any occurrence of conduction, two wood plates were used in construction of sensor. Function generator produces an AC current with variable magnitude and frequency. The produced sine signal was fed to capacitive sensor and output signal from the sensor was sent to signal conditioning circuit. The final output voltage was measured by ADC unit of microcontroller and the capacitance and dielectric constant of sample was computed by microcontroller and results displayed on LCD. The electrodes material was selected from aluminum. To avoid any occurrence of conduction, two wood plates were used in construction of sensor. The dielectric constant of soil samples was calculated as follow:

$$C = \frac{\varepsilon_s \varepsilon_0 A}{d} \qquad (1)$$

where A is the overlapping surface area of the plates (m^2); ε_s is the dielectric constant of material, ε_0 is the permittivity of air (8.85×10^{-12} F/m), d is the distance between the plates (m), C is the capacitance (pF). The experiments are carried out at ten replications and the mean values of data are reported with standard deviation. All measurements were performed in a laboratory with an average room temperature of 15 ºC. Microsoft Excel 2007 was used to analyze data and determine the regression models between the studied attributes.

RESULTS AND DISCUSSION

Plot of moisture content against dielectric constant of soil is shown in Figure 1. The dielectric constant values of varied between 3 and 16.8, and increased ($P\leq0.05$) as the moisture content of soil increased. When the moisture content of soil increases, the ratio of water to dry material increases and as a result the capacitance increases as well (Soltani *et al*., 2014; Berbert *et al*., 2002). Singh *et al.*, (2006) reported that at higher moisture levels, more water dipoles contribute to the polarization, due to high water mobility, showing that the water dipoles easily follow the applied field vibrations. At low moisture content, because of strong bound water state (monolayer), the distance between the water molecule and cell wall is very small and attraction force is very large. Therefore, the dielectric properties of material are small.

The values of dielectric constant of soil samples are comparable with the reported values of 2.2-23.1 mentioned for Yuma sand at 1.1–1.5 GHz and 0-25% wet basis (Lundien, 1971); 4–20 for sand soil at 0.13-3GHz and 3.5-22.5%wet basis (Leschanskii *et al*., 1971); 2–9 for rich field silt loam soil at 300 MHz and 9-37% wet basis (Lundien, 1966), 3-20 for sandy loam soil and 0–31 for clay loam soil at 10.6 GHz and 0–40% wet basis (Wiebe, 1971); 4.5-18.5 for clay soil at 10 GHz and 0-37% wet basis (Matzler, 1970); 2–22 for silt clay soil at 0.5 GHz and 0-40% wet basis (Hoekstra and Delaney, 1974), and 2.5-17 for clay loam soil at 1.0 GHz and 0-35% wet basis (Hipp, 1974). A second order polynomial relationship was found to correlate the dielectric constant with corresponding moisture content of samples and is given by equation (2)

$$\varepsilon = 0.0099\mathrm{M.C}^2 + 0.2193\mathrm{M.C} + 2.2749 \qquad R^2 = 0.9782 \qquad (2)$$

Thus:

$$\mathrm{M.C} = -0.0629\varepsilon^2 + 3.0814\varepsilon - 4.7363 \qquad (3)$$

where is the dielectric constant of soil, and M.C is the moisture content (%, wet basis).

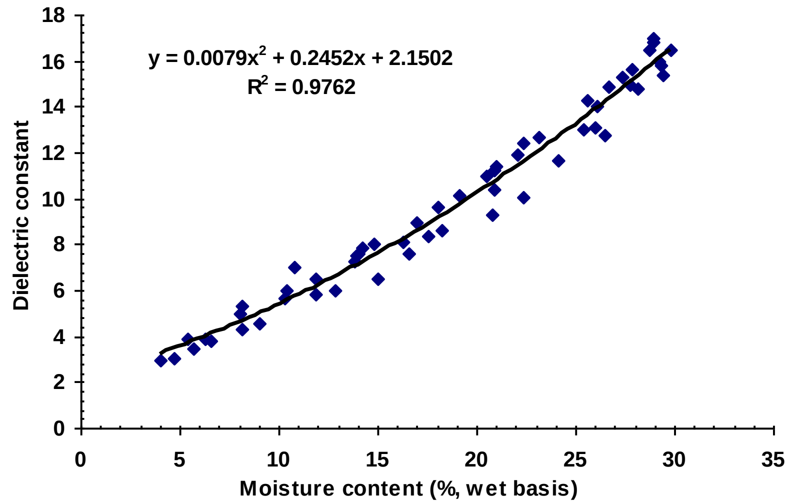

Figure 1: Change in moisture content versus dielectric constant of clay loam soil

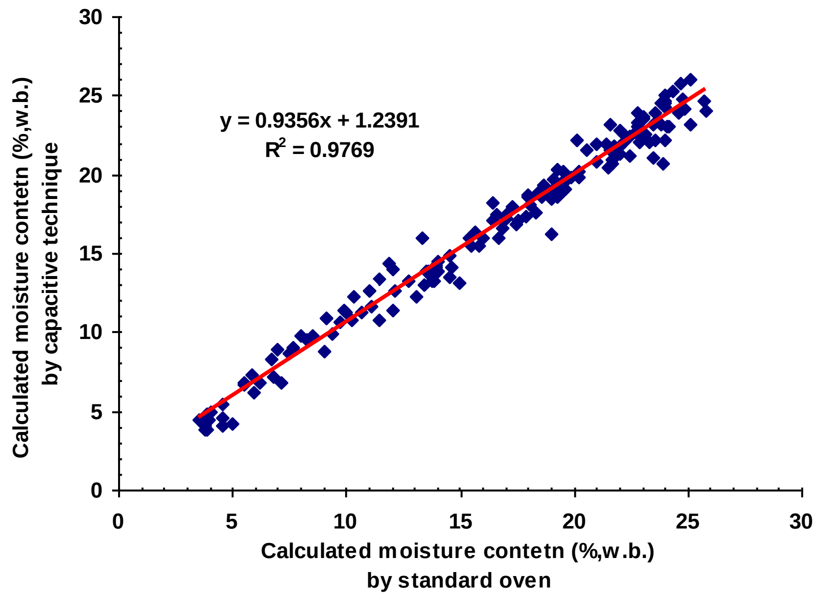

Figure 2: The comparison of the measured moisture content with the data calculated by capacitive technique

Sacilik and Colak (2010) proposed second and third-order polynomial equations to describe the existing relationship between the dielectric properties and the moisture content of corn seed. Berbert *et al.*, (2002) reported a polynomial relation between moisture content and the dielectric constant of bean. The same results were obtained by Das *et al.*, (2010); Guo *et al.*, (2008); Soltani and Alimardani (2013). The result of comparison between predicted and actual values of moisture content for soil and also the correction equation and coefficient for it is presented in Figure 2. As can be seen, the dots in Figure 2 are closely banding around at a 45° straight line (R^2 = 0.976) – a very good agreement between calculated and experimental data, which indicates that the capacitive technique could adequately measure the moisture content of soil. Similar trends were also observed by Soltani *et al.*, (2011); Singh *et al.*, (2006); Guo *et al.*, (2008).

Conclusion

Dielectric measurement is a powerful tool for determining the moisture content and more practical than time-consuming oven method. In this study, the dielectric constant of clay loam soil was investigated as a function of moisture content. Polynomial regression was used to analyze the relationship between dielectric constant and moisture content. The dielectric constant increased with increasing of moisture content.

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