IMPROVING THE ACCURACY OF SOIL MOISTURE MEASUREMENT USING TDR METHOD AND CONSIDERING THE EFFECT OF BULK DENSITY

AMELIORATION DE LA PRECISION DE L'EVALUATION DE LA TENEUR EN EAU DU SOL UTILISANT LA METHODE TDR ET EFFET DE LA MASSE VOLUMIQUE

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ABSTRACT

Accurate measurement of soil moisture helps in better planning for the amount and duration of water applied to the farms, improving irrigation efficiency and preventing degradation of soil and water quality. The time domain reflectometery (TDR) is a relatively new and easy method of estimating volumetric moisture content in soil based on electromagnetic waves movement through the soil. By inclusion of soil compositions in the TDR calibration curves the accuracy of soil moisture estimation increases. Because of the significant impact organic matter on bulk density and surface area of soil particles, calibration curves in organic and non-organic soils are different. In this study, disturbed samples of three soil types with light, medium and heavy textures and with high organic matter were tested in pots of 25.5 cm height and 25 cm diameter. Tested soils range included clay-sand to loam-clay-sand with bulk densities between 0.87 and 1. Comparison of the volumetric moisture content, obtained from TDR calibration curve and weight method, shows high correlation between them. Besides, analysis of the observed data analysis by curve fitting showed that a cubic form described the relationship between the TDR dielectric constant and soil moisture content.

Key words: *Soil moisture, bulk density, dielectric constant, soil moisture content, organic material.*

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RESUME

La mesure précise de la tenuer en eau du sol aide dans la meilleure planification de la quantité et la durée d'eau appliquée aux fermes, l'amélioration de l'efficience d'irrigation et la prévention de la dégradation du sol et de la qualité de l'eau. Le « Time domain reflectometery (TDR) » est une nouvelle méthode facile à évaluer la teneur en eau du sol volumétrique compte tenu du mouvement des vagues électromagnétique sous le sol. L'inclusion des compositions du sol dans les courbes de calibrage TDR donne d'évaluation exate de la teneur en eau du sol. En raison de l'impact signatif de matière organique sur la masse volumique et la superficie du particule du sol, les courbes de calibrage des sols organiques et non organiques sont différentes.

Dans cette étude, les échantillons dérangés de trois types de sol ayant les textures légère, moyenne et lourde et la haute matière organique ont été évaluées dans les pots de hauteur de 25.5 cm et de diamètre de 25 cm. Le type de sol varie de argileux-sableux à limon-argileux-sableux ayant la masse volumique de 0,87 et 1. La valeur de la teneur en eau du sol volumétrique obtenue de la courbe de calibrage TDR et de la méthode de poids, motnre une haute corrélation entre ces facteurs. En outre, l'analyse des données obtenues de la courbe motre qu'une forme cubique évoque la relation entre le « TDR dielectric constant » et le teneur en eau du sol.

Mots clés : *Teneur en eau du sol, masse volumique, dielectric constant, matière organique.*

1. INTRODUCTION

Soil water content and its availability to the plants are important considerations in agriculture and particularly in irrigation. Food security, health and economics are affected by water shortages severely. The agricultural sector is the major and in fact, the maximum in water consumer in comparison to all other competitive sectors. Hence, increase of water use efficiency in agriculture will lead to saving of this precious resource at the basin level. Table 1 gives the productivity of some important crops in Iran as compared with developed countries.

Table 1. Performance comparison of some major crops (t/ha)

Crop	In developed countries	In Iran
Wheat	11-17	3.2
Beet	50-100	28
Sorghum	8-14	4-7

As Table 1 shows, agricultural production efficiency in Iran is very low in comparison to the developed countries. Moreover, production of these crops consumes more water in comparison with developed countries. Application of a scientific program, like; irrigation at the right time and by necessary amount, is an important to increase irrigation efficiency. Accurate estimation of the soil moisture and plant water requirement will reduce the unnecessary application of water to farms and save more water for downstream regions. This water saving increases the water use efficiency over the waterbasin, which in turn increases the value and reliability of water.

Most of the soil properties such as stability, plasticity, strength, compaction and permeability depend on the water content. The most commonly used and accurate method for soil water content measurement is weight method. In recent years, other methods and devices have been developed. Among them the TDR is quite popular (Oleszczuk et al, 2004). Several studies indicate that TDR method, in spite of its many advantages, does not measure the moisture content accurately in certain situations. These situations include; clayey soil, soils containing organic matter and saline soils. Due to differences in bulk density and specific surface area of organic and non-organic soils the relationship between dielectric constant and volumetric moisture content differ in them (Pumpanen et al, 2005).

Determination of soil water content by TDR method requires the knowledge of relationship between the apparent dielectric constant (Ka) and the volumetric moisture content of the soil (θ). The first general TDR calibration results were published by Topp et al (1980) and they reported a polynomial (cubic) relationship between (Ka) and (θ) for mineral soils and when the soil water content does not exceed 55%. They also established a calibration equation (Ka - (θ)) for organic soils. Stein and Kane (1983), after a preliminary verification of the equation, indicated an overestimation of the water content in organic soils with bulk density around 0.55 g/cm^3. A number of empirical relationships between the dielectric constant and soil water content for mineral soils were published later (Ledieu et al., 1986; Nadler etal., 1991; Dasberg and Hopmans, 1992; Roth et al., 1992; Jacobsen and Schjonning, 1993). However, only a few relationships for organic and peat soils were developed. The calibration equations for organic soils published in the literature together with a 'universal' equation, was proposed by Topp et al. (1980). The majority of the equations presented are in the form of a cubic polynomial:

$$\theta_V = \left(A + BK_a + CK_a^2 + DK_a \right) 10^{-4} \qquad (1)$$

some other quadratic form formulas are also proposed as shown below:

$$\theta_V = A + B\sqrt{K_a} \qquad (2)$$

Where θv is soil moisture content (cm^3 cm^{-3}), Ka is dielectric constant and A, B, C, D are constants of the models.

The above equations show the relationships between dielectric constant and moisture content. They do not include other properties of the soil matrix, such as bulk density or porosity. The respective Ka - (θ) relationships for organic soils are significantly different from the "universal" function developed for non-organic soils. The measured values of the dielectric constants of organic soils at each selected moisture content level are lower than for similar moisture levels in non-organic soils. According to Roth et al. (1992), bulk density is a physical parameter influencing the moisture content in organic soils. Jacobsen and Schjonning (1995) suggested that a few layers of water molecules around the soil particles are thought to have a restricted rotational freedom. In fact, due to particularly large surface area of these particles, more water molecules are involved as boundary water. Soil organic matter is a major factor in deciding the amount of boundary water. The aim of this study is to determine the contribution of bulk density to the accuracy of relationship between the dielectric constant to moisture content for soils with different organic matter contents.

2. MATERIALS AND METHODS

Three samples with light, medium and heavy texture and various contents of organic matter were tested. Disturbed soil samples were put in 25.5 cm height and 25 cm diameter pots. In order to make soils with different percentages of organic matter, after determination of organic matter percent by the wet oxidation method, litter manure was added to the soil mass with specific treatment of organic material. In each texture, there were five mixtures containing 0.5, 2, 3.5, 5 and 6.5 per cent organic matters in three replicates. After about 24 hours of saturation, moisture content measurement was performed by using weight and TDR method. TDR device in water research laboratory is model 6050X1, made by SOIL MOISTURE Company (Trase system 1). The Measurement continued until no change was observed in the samples weight. Sample bulk density was calculated in saturated and dry conditions at the end of the experiments. Bulk density values for each sample are presented in Table (2).

Table 2. Bulk density (g/cm^3) at different percentages of organic material

Soil texture	Soil organic matter percent				
	0.5	2	3.5	5	6.5
Light (Loam Sand)	1.18	1.07	1.02	0.94	0.87
Medium (Loam)	1.05	0.94	0.93	0.91	0.83
Heavy (Loam Clay Sand)	0.95	0.93	0.92	0.90	0.80

3. RESULTS AND DISCUSSION

The relationship between dielectric constant and volumetric moisture content for all three textures with different percentages of organic matter are shown in Figs. 1 to 3.

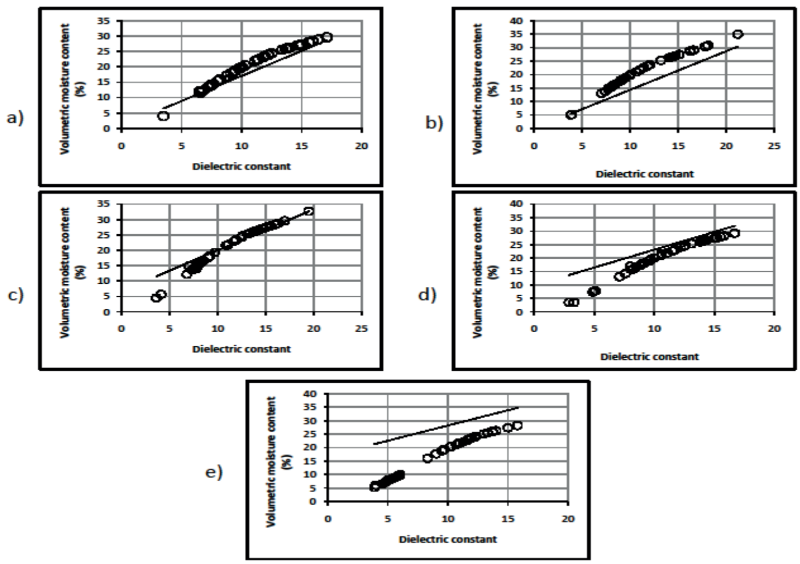

Fig. 1. Relation between soil moisture and dielectric constant in light texture soil with organic matter contents: a) 0.5%, b) 2%, c) 3.5%, d) 5%, e) 6.5%.

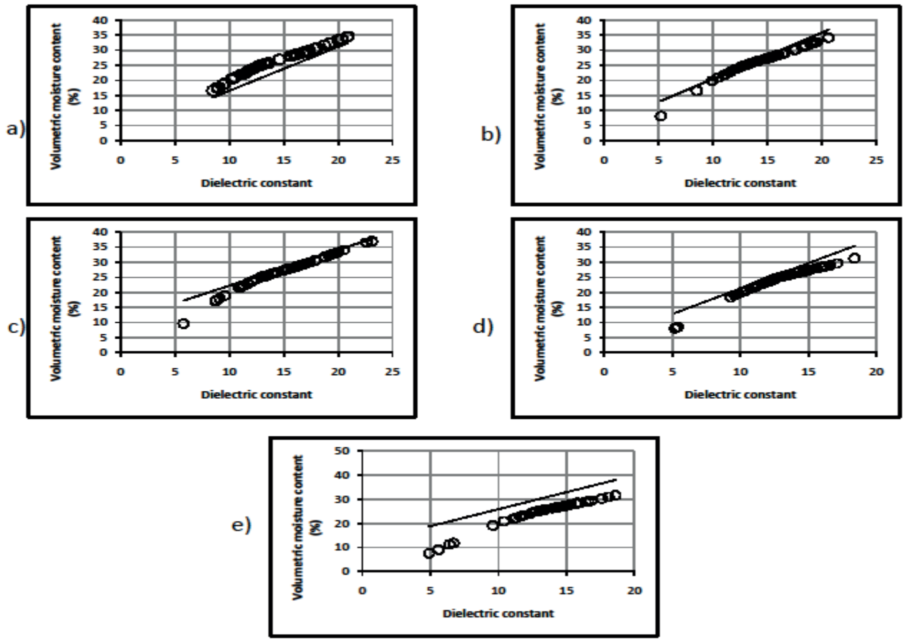

Fig 2. Relation between soil moisture and dielectric constant in medium texture soil with organic matter contents: a) 0.5%, b) 2%, c) 3.5%, d) 5%, e) 6.5%.

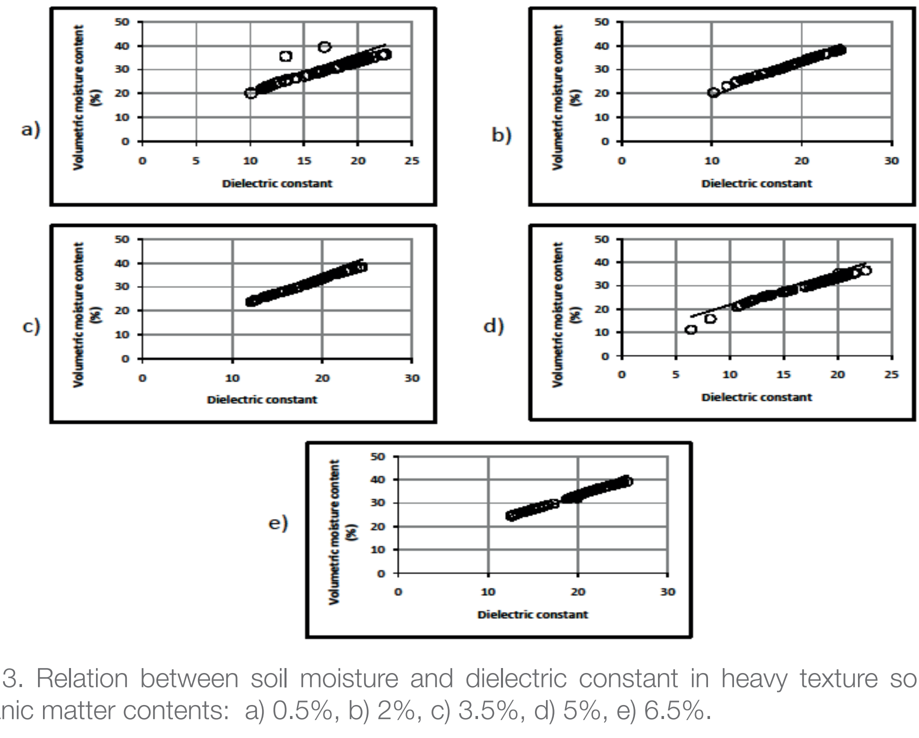

Fig. 3. Relation between soil moisture and dielectric constant in heavy texture soil with organic matter contents: a) 0.5%, b) 2%, c) 3.5%, d) 5%, e) 6.5%.

These figures show that the relationship between volumetric moisture content and the dielectric constant depends on the percentage of organic matter, which can be characterized by different bulk density values.

3.1 Calibration equation

The following relationship was fitted to the measured data for any of the 24 soil samples considered:

$$\sqrt{Ka} = a + b\theta_V \quad (3)$$

Where; √Ka is refractive index, a is intercept, b is slope and θv is moisture content ($cm^3 . cm^{-3}$).

This type of relationship was considered because in non-magnetic media square root of the dielectric constant is a measure of the absolute value of refraction coefficient of magnetic wave (Malicki, 1993). Results of data analysis show that ‘a’ and ‘b’ coefficients have 0.70 to 0.73 correlation values respectively for three textures with the data obtained by weighing method. According to the Malicki et al (1996), this equation gives accurate moisture contents ranging from 98.6 to 99.9 of the values determined by weight method. They proposed a cubic polynomial to express the effect of bulk density. Comparison of relationship between bulk density and coefficients ‘a’ and ‘b’, according to the result of Table (3) in second and third equation, shows that a cubic form function has the highest fitness in regression. Therefore the cubic form was used in other calculations. Regression coefficients (a: slope and b: intercept) are associated with the apparent density in accordance with equation (3). Coefficient of the linear Eq. (3), which was estimated by measured data for each soil sample, show relatively high values of R2 ranging from 87.6 to 99.9%.

Table 3. Relationship between coefficients a and b and the soil bulk density

Texture	a	R2	b	R2
Light (Loam Sand)	$Y = -11\rho^3+33\rho^2-32\rho+10$	0.88	$Y = -6\rho^3-19\rho^2-17\rho-5$	0.89
Medium (Loam)	$Y = -11\rho^3+33\rho^2-32\rho+10$	0.89	$Y = -5\rho^3-14\rho^2-+15\rho-5$	0.89
Heavy (Loam Clay Sand)	$Y = -16\rho^3+50\rho^2-51\rho+17$	0.87	$Y = -6\rho^3+10\rho^2+17\rho+6$	0.86

In Table 3, ρb is soil bulk density (g cm^{-3}).

The values of intercepts (a) and slopes (b), plotted versus the corresponding bulk density values ρb, are shown in Fig. (4) to (6). It can be seen that in all the textures, the relationship between ‘a’ and ρ’b’ shows increasing values of ‘a’ as ρb increases, and the relationship between ‘b’ and ‘ρb’ shows decreasing values of (b) with increasing ρb.

The relationship between ‘b’ and ’ ρb’ influence each other inversely in comparison to the corresponding relationship presented by Malicki et al (1996). It can be attributed to the differences in the ranges of ρb values which, for the different contents of soil organic matter, vary from 0.87 to 1.0 g cm^{-3}, while the data presented by Malicki et al. (1996) covered soils with bulk density from 0.2 to 1.8 g cm^{-3}.

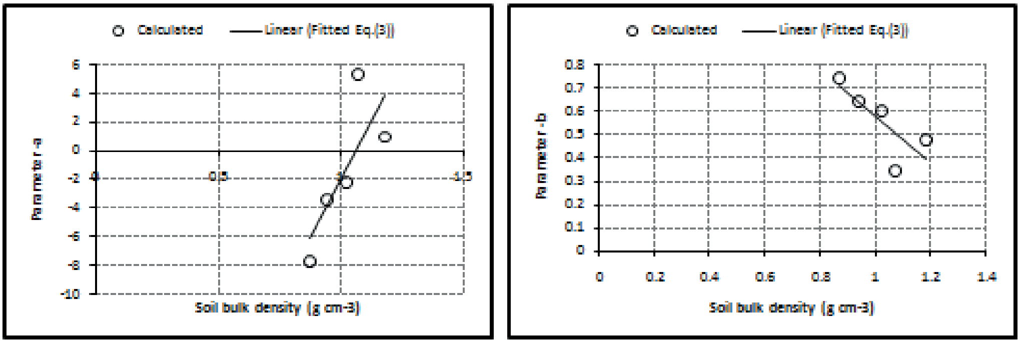

Fig 4. Relations between parameters in Eq. (3) and bulk density in light soil.

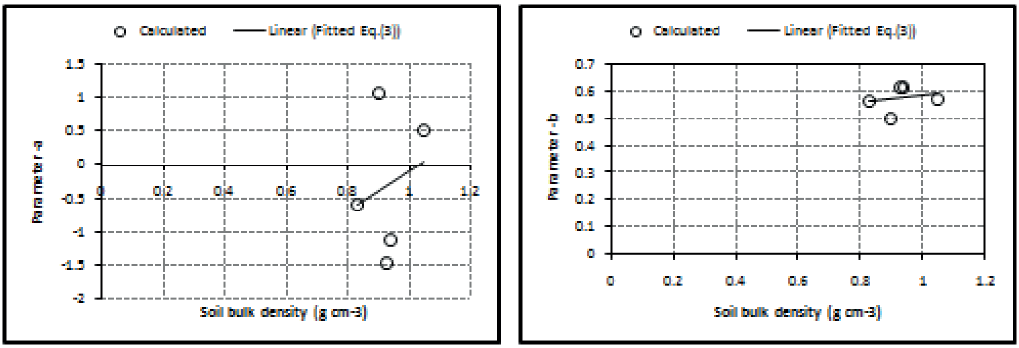

Fig 5. Relations between parameters in Eq. (3) and bulk density in medium soil

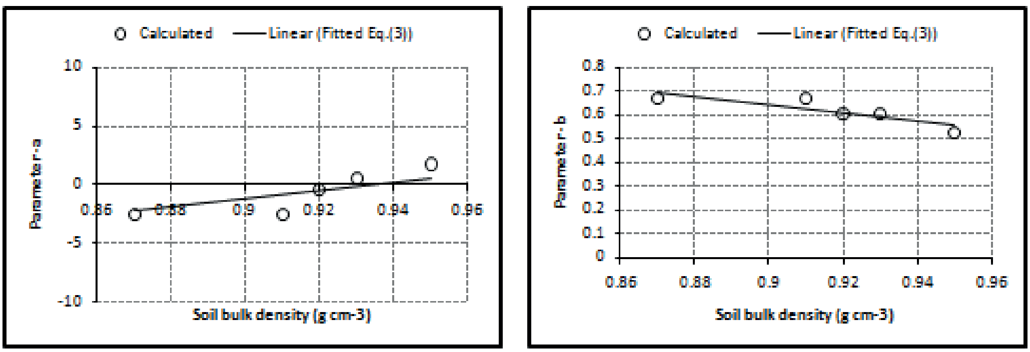

Fig. 6. Relations between parameters in Eq. (3) and bulk density in heavy soil

Comparisons between proposed relationship for each texture with true water content, shows accuracy increase in estimation of ware content with proposed equation. According to Table (4) regression coefficients are estimated.

Table 4. Regression coefficients in proposed relations with weight method

Texture	Device relation	Proposed relation
Light (Loam Sand)	0.71	0.90
Medium (Loam)	0.69	0.88
Heavy (Loam Clay Sand)	0.69	0.87

Comparisons between measured and calculated (from Eq. (3)) values of volumetric moisture content, coefficient of determination (R2) values are 0.90, 0.88 and 0.87, respectively, in light, medium and heavy texture soils. The data presented show that bulk density significantly influences the dielectric constant at volumetric soil moisture content lower than 40%. Increasing soil bulk density leads to higher dielectric constant for a given moisture content.

4. CONCLUSIONS

The results obtained from the presented research led to the following conclusions:

1. The measurements performed on disturbed samples showed that bulk density of soils substantially affects the relation between the dielectric constant and the moisture content.

2. The relationship between the dielectric constant and moisture content in peat deposits can be represented by a square-root relation as Eq. (3) and it was proven that the values of intercept (a) and slope (b) in this equation were strongly dependent on bulk density.

3. The proposed calibration, relating the moisture content with the dielectric constant and bulk density for TDR moisture measurements, is statistically significant and can be applied for soils with bulk density ranging from 0.87 to 1.0 g cm^{-3}. The peat bulk density significantly influences the dielectric constant for the volumetric soil moisture content lower than 40%. Increasing values of soil bulk density lead to higher values of the dielectric constant for a given moisture content.

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