Effect of Soil Texture on Moisture Measurement Accuracy with Theta Probe ML2 in Sistan Region

Nooshin Sarani, Peyman Afrasiab

***Abstract*--**Among the various methods of estimating soil moisture, the Theta probe method is a relatively new method. Theta probe measures the volumetric soil moisture content in soil based on the speed of electromagnetic waves. The purpose of this study is determination of moisture measurement accuracy by Theta probe in various soil textures in Sistan. For this purpose, four types of volumetric soil moisture, clay, loam, sandy loam, and sand was measured in triplicate using Theta probe. Then the device calibrates with both linear and nonlinear methods and compared measurements values with gravimetric method. The result showed that in the sandy soil has the highest precision and accuracy is reduced with increasing amount of clay. Consistencies of the graphs were plotted Theta probe and gravimetric method. The results of this study showed that the highest correlation in the sandy soil (R^2 = 0.95) and there is less correlation between these two methods in clay soil (R^2=0.90)

***Keywords*--**Moisture, Sistan, Soil texture, Theta probe.

I. Introduction

MANY soil properties such as stability, dough strength, compression capability, soil permeability and the ability to pass is a function of water in it. The amount of water available per unit mass or volume of soil, soil moisture is known that both direct and indirect measurement can be measured. Some methods of measuring moisture content are used directly in the field, but in some way, the soil must be sampled and the moisture content was determined in the laboratory. In the direct method, the values of mass or volumetric moisture content typically are measured, but indirect methods, a factor that affects the moisture content, can be measured. In recent years, the dielectric properties of materials are used for determining moisture content; And accordingly, the device has been designed using the dielectric properties of soil, moisture can be determined; The most famous of which is the Time Domain Reflectometry, the TDR has been called. With further development of the dielectric, such as Theta probe devices are created. Theta probe performance as the TDR system is based on the variation of the dielectric. And these changes into voltage and moisture in the soil with salt and volume are 100 (ds/m) has a high accuracy; and it can be calibrated to meter to 2000 (ds/m) salinity [8].

Nooshin Sarani and Peyman Afrasiab are with University of Zabol, College of Watwr and Soil, P.O. Box: 98615-538 R. IRAN, Tel: 0098 (0542) 2240711,Fax: (0542) 2230540, Email: saranisistani@gmail.com

Using of methods of measuring soil moisture, based on the unusual properties of the dielectric constant of water, from when Topp *et al* [15] and the possibility of its practical implementation, is highly developed. Topp et al [15] and, Topp and Davis [14] the high dependency of the dielectric constant of soil volumetric water content of the soil for a number of soil texture expressed. They concluded that in the high-frequency fixed dielectric, much less of factors such as soil type, soil density, soil temperature and pore water electrical conductivity coefficient, will be affected. During period of evolution of this method, a lot of criticism about the validity of this method was applied; that the researchers (Dasberg and Hopman, [3]; Jacobsen and Schjonning, [7]; Dirksen and Dasberg, [4]; Whalley, [16]; Ponizovsky *et al*., [11], Robinson *et al*., [12], [13]) to effects of moisture, soil texture, specific surface area of particles, dry density, the amount of organic matter, clay, salts, ice and water trapped, by frequency, cable length, temperature and so on. The dielectric constant led. Theta probe method, has many advantages, which can be automated and data storage capability, reliability, measurement speed, high precision, safe use of these methods, compared with Neutronmeter method, simultaneous measurements in the different depths, direct measurement of volumetric moisture content, using laboratory and field conditions mentioned, However, considering that in most parts of the world's research has been done with this device, It has been known that physical and chemical properties of soil, the calibration device is effective and should be evaluated on the impact of these factors. Analyzing the results of research conducted, it is clear that the physical and chemical characteristics of soil type, texture, clay content and soil salinity in the three main factors affecting the calibration device are Theta probe. Therefore, using these devices, for precise measurements of soil volumetric water content in each zone, soil conditions for the calibration of precision measuring instruments and enhance it in various soil texture is essential; and if necessary the calibration equation and a correction factor for each tissue obtained according to the Sistan and Baluchestan Regional Water Company, according to the fact that the most of Soil tissue of Sistan is medium to heavy,effect of soil texture and clay content in it and also check on the calibration Theta probe advantage of this method in Sistan soil conditions seems necessary. It has not been comprehensively investigated using Theta probe, and a few number of studies are in the field of electromagnetic devices, such as Theta probe. For example Lukanu and Savage, [9]; Cosh *et al*, [2] Yoshikawa *et al*, [17]; Robinson *et al*, [12] and so on.

Yoshikawa *et al* [17], seven sensors, including TDR and Theta probe were calibrated to determine the soil moisture content. They test for all sensors, a calibration equation with the polynomial coefficients of determination (R^2 = 0.99) have presented. Cosh *et al* [2], expressed that Theta probe in most soils (except in sandy soils), shows moisture content higher than the actual estimates. Also expressed that to achieve results more accurate calibration is essential for reducing error. Lukanu and Savage, [9] said that the volumetric water content measured by gravimetric method and moisture content was estimated using the method of Theta probe there is a strong relationship. Kargas and Kerkides, [6] stated that the calibration curves Theta probe provide device manufacturers have been predicted for most of the diverted water and soil is essential for any special calibration. In most cases this will result in improved results. Alizadeh *et al* [1], with study of compaction and soil moisture effects on measurement accuracy by Theta probe expressed that sandy soils have the highest accuracy and with increasing clay the accuracy is reduced. The effect of compaction on measurement accuracy in sandy soils is poor, but with increasing clay, the compaction effects are increased. Finally, charting correlation of Theta probe and gravimetric method, results showed that the highest correlation in the sandy soil as well as there is less correlation between these two methods in clay soil. The purpose of this study accurately measure the volumetric moisture Theta probe in estimates of soil texture is Sistan. For this purpose, four types of volumetric soil moisture, clay, loam, sandy loam, and sand was measured in triplicate using Theta probe.

III. Materials and Methods

Geographical Area

Region of Sistan is located in the north of Sistan and Baluchistan province with an area of 15,197 km, equivalent to between 29 to 32 degrees north latitude and between 60 and 64 degrees east along the prime meridian; Sistan region of Afghanistan to the north and east, west and northwest of the southern city of Zahedan and the Lut Desert and the city is limited Nehbandan. The climate of Sistan, due to the desert near Lut desert is hot in summer, and kind of warm and dry. The average annual temperature of 21.7 ° C and relative humidity varies between 2 to 52. Annual rainfall is about 99 mm.

Volumetric moisture content measured by the ML2 Theta probe

Theta probe device used in this study is the model ML2; Aforementioned device is made from the four same bars 60 mm in length and 3 mm diameter, And a waterproof box, called the probe body, and the signal input and output cable to connect the representative data, it is made. In the following figure Theta probe device used in this study are shown. This means that the Soil moisture is measured by volume, based on the dielectric constant is change. These changes are converted to voltage and volumetric moisture content. Signals generated by device, which sent 100 MHz frequencies are transmitted by a transmission line through the four-cylindrical and rod are transferred to soil. Because the signals are sent, with a frequency of 100 MHz, the minimum ionic conductivity, so the only resistance of the signals is soil moisture (content of the dielectric). Since the dielectric constant of water = 81, soil = 4 and air = 1 is; so the amount of dielectric constant of soil extremely is dependent on the amount of moisture. If be created the resistance between the bars with a probe internal resistance of transmission lines is the difference of the signals produced by the connecting rods of the probe body into the machine returns. Return signals and emitted at a constant potential difference causes the transmission line. And voltage changes on the screen of the data is recorded; Measuring the resistance and voltage changes can be found through the following relationship between dielectric constant and the volumetric moisture content was determined. The following relations are used in the ML2 model Theta probe:

$$\theta = \frac{\left(\sqrt{\varepsilon} - \alpha_0\right)}{\alpha_1} \tag{1}$$

$$\sqrt{\varepsilon} = 1.07 + 6.4V - 6.4V^2 + 4.7V^3 \tag{2}$$

Or with a linear relationship:

$$\sqrt{\varepsilon} = 1.1 + 4.44V \tag{3}$$

Voltage changes can be measured by Theta probe through relations (1), (2) and (3) dielectric constant and volumetric moisture content to be determined [5] [10].

In these equations: α_0, α_1 : Constants are dependent on soil type.

Parameters α_0 and $\alpha 1$ Theta probe device by the manufacturer for non-organic soil, respectively, 1.6 and 8.4 and for organic soils, respectively, 1.3 and 7.7 is presented. With these values are used, the mineral soil moisture by using equation (4) and for organic soils using equation (5) gain:

$$\theta = 0.119\sqrt{\varepsilon} - 0.190 \tag{4}$$

$$\theta = 0.13\sqrt{\varepsilon} - 0.168 \tag{5}$$

It should also Theta probe device, be calibrated for each of the soil texture tested. Calibration device with the above equations needs to determine the two parameters in equation (1). Theta probe special calibration device:

Choose a sample of damp soil and using the installation Theta probe, reading the measured voltage (V_w), and using equations (2) and (3), $\sqrt{\alpha_W}$ is calculated. The soil samples placed in the oven at 105 degrees. Therefore, calculate the volumetric water content of the sample (θ_w) and $\sqrt{\alpha_0}$ is calculated using the equations (2) and (3). In the next step, replacing θ=0 in the

equation (1) , $\alpha_0 = \sqrt{\varepsilon_0}$ from the dried soil sample is obtained. Finally, with regard to placement $\sqrt{\alpha_W}$ and θ_w in the equation (1), α_1 is calculated:

$$\alpha_1 = \frac{\left(\sqrt{\varepsilon_W} - \sqrt{\varepsilon_0}\right)}{\theta_V} \quad (6)$$

Finally define α_0 and α_1 , after integrating equations (1) , (2) and (3), calibrated moisture can obtain for each point moisture:

$$\theta = \left[\left(1.07 + 6.4V - 6.4V^2 + 4.7V^3\right) - \alpha_0\right] / \alpha_1 \quad (7)$$

$$\theta = \left[\left(1.1 + 4.44V\right) - \alpha_0\right] / \alpha_1 \quad (8)$$

Equation (7), is for a non-linear, and equation (8), is for linear mode. The following table ties used to evaluate the accuracy of The Calibration Theta probe Device is presented.

TABLE1. CALIBRATION FUNCTIONS PROVIDED TO SOILS.

Calibration functions provided to soils	Type of soil	Source
$\theta = 0.119\sqrt{\varepsilon} - 0.190$	Mineral	The device manufacturer (1999)
$\theta = 0.13\sqrt{\varepsilon} - 0.168$	Organic	The device manufacturer (1999)
$\theta = 0.128\sqrt{\varepsilon} - 0.23$	Sand	Soil-specific calibration
$\theta = 0.114\sqrt{\varepsilon} - 0.18$		
$\theta = 0.172\sqrt{\varepsilon} - 0.55$	Clay	Soil-specific calibration
$\theta = 0.188\sqrt{\varepsilon} - 0.62$		
$\theta = 0.137\sqrt{\varepsilon} - 0.26$	Loam	Soil-specific calibration
$\theta = 0.115\sqrt{\varepsilon} - 0.62$		
$\theta = 0.295\sqrt{\varepsilon} - 0.3$	Sandy loam	Soil-specific calibration
$\theta = 0.15\sqrt{\varepsilon} - 0.24$		

Information collection requirements

Preparation of tissue: For this purpose soil Sistan region studied four types of soil and clay, loam, sandy and sandy loam were selected for testing. The hydrometer method for obtaining laboratory soil and sand, silt and clay was used.

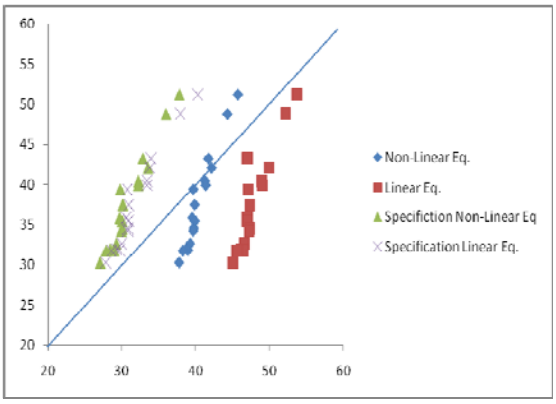
Determination of dry bulk density: In laboratory conditions, the dry bulk density was calculated by standard method and special cylinders.

This study was performed in the Zabol University Laboratory of Hydraulics, Faculty of Land and Water, The perpetrated soil texture are laid inside the pipes made of polyethylene having a height of 40 cm and 30 cm diameter, Beginning and end of each tube is open, but at the end of each tube has a fine mesh. Also for each soil texture was considered three replications. After preparing the soil containers with used soil texture, all containers were saturated and after that about 24 hours' moisture measurements were made to the following methods:

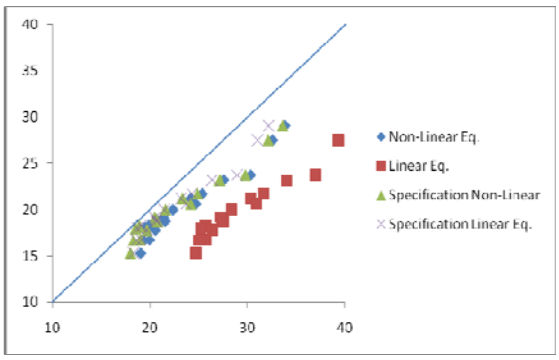
Gravimetric method: soil moisture by using the gravimetric method calculated every day. Using different calibration functions Theta probe.

IV. DISCUSSION AND CONCLUSIONS

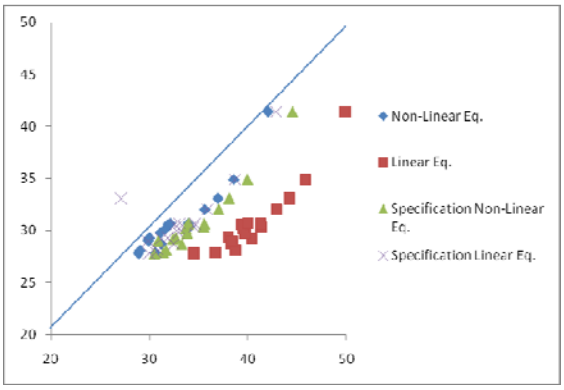
The following figures show estimated amounts of moisture to the values measured by direct methods (gravimetric method) in applied soil texture:



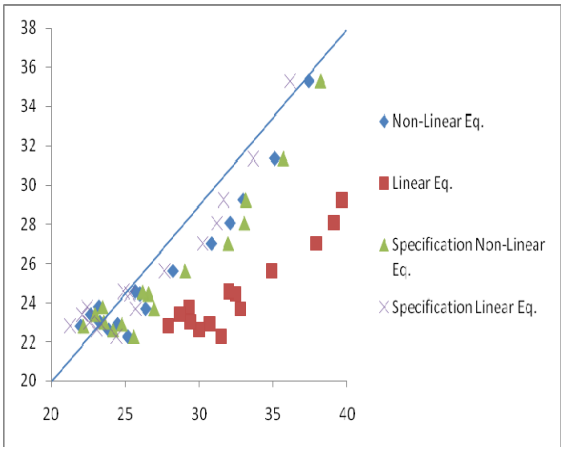
a) Clay



b) Sandy



c) Loamy



d) Sandy loam

Figure1. Estimated amounts of moisture to the values measured by gravimetric method.

The results of the various models are being applied.

In this study to determine the correlation between the Theta probe and gravimetric method, moisture measurements were plotted against the estimated values; and then the correlation coefficient (R^2) for displaying variations of humidity variance estimated by the moisture of gravimetric method was measured and used. The root mean square error (RMSE) was used for parity. Equations R2 and RMSE is given below:

$$R = \frac{\sum(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum(X_i - \bar{X})^2 (Y_i - \bar{Y})^2}} \quad (9)$$

$$RMSE = \sqrt{\frac{\sum[\hat{z}(X_i) - z(X_i)]^2}{n}} \quad (10)$$

In the above formula, X_i and Y_i are i th real data and by gravimetric method. $\bar{X}$, $\bar{Y}$ are the average Xi and Y_i data and $z(X_i)$ is measured value in the i th point, $\hat{z}(X_i)$ the estimated amount of the i th point by theta probe and n is the number of X_i and Y_i are examples.

Table2 shows R^2 and RMSE values for the best model in each soil texture.

TABLE2. R^2 AND RMSE VALUES

Soil type	R^2	RMSE
Sand	0.95	0.03
Clay	0.90	0.108
Loam	0.91	0.038
Sandy loam	0.93	0.029

The results obtain that in most soil texture; soil- specification calibration model has the best correlation with values has been measured. As the figures suggest, there are the least deviation from the correlation line in the sandy and sandy loam soil texture; and texture of clay soil has the maximum deviation from the correlation line, the estimated values. In most cases, calibration curves are provided by device manufacturers Theta probe have been diverted from the prediction of moisture, the obtained results comport with the results of Karagas and Kerkides (2008). Generally, in most soil texture, measured moisture by theta probe is more than the real value that this result with the results of Robinson et al (1999) and Cosh et al (2005) is similar. These over estimates can change, so that the estimation of moisture in sandy soils is relatively good, but with a heavier texture become more than the actual amount of soil. The results are matched with the results presented by Alizadeh et al (1387).

V. CONCLUSION

With increasing amounts of clay, soil dielectric constant decreases and using estimation formulas Theta probe estimates moisture less than actual values measured (Alizadeh and colleagues, 1387).

The following results were obtained in this study:

a) Calibration provided by device manufacturers in most cases will be diverted from the specified range.

b) Theta probe device in the light soil texture is best matched with gravimetric method

c) Because in most cases, soil-specification calibration has most correlation with the actual values, thus for reducing errors, soil-specification calibration is necessary

d) With increasing the amount of clay, the difference between the measured values using gravimetric method and the estimated values using Theta probe is increased.

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