Australian Journal of Basic and Applied Sciences, 6(6): 77-85, 2012
ISSN 1991-8178

The Evaluation And Determination Of Soil Moisture By Weight And Time Domain Reflectometery (TDR) Methods

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Abstract: There are several methods for estimating soil moisture. The Time-Domain Reflectometery (TDR) is a new method that in which the volumetric soil moisture is estimated base on electromagnetic waves speed in the soil. As for the influence of soil composition on the calibration curve, the device must be calibrated. The purposes of this study are studying of TDR method accuracy, the effect of soil texture on accuracy of TDR measurements, and comparison of weight and TDR method to determine of soil moisture. Field tests to determine the volumetric soil moisture content by weight and TDR methods were performed in three soil types including clay, sand, and moderate texture, in two depth 0-30 and 30-60 cm, and by 5 treatments. After determining the physical and chemical properties of soils and the volumetric soil moisture content by such methods completely randomized design - Factorial Experiments was considered. Then Duncan's multiple range and ANOVA analysis were performed to data by MSTAT-C software. Results showed that there were meaningful differences at 5 % significant level between soil moisture measured by two methods for all three soil types. In sand and clay soils the average of volumetric moisture that measured by TDR was lower than those measured by weight method. But in soils with medium texture, Results was reversed. TDR device show the lower amount of moisture for high moistures. This difference increases by increasing clay content and organic matter. Variance analysis showed the meaningful differences at 5 % significant level for reciprocal effects of soil moisture and measurement method. The regression equations were extracted and fitting line were drew for moisture data based on TDR and weight methods for clay, sand, and moderate soils. Results showed the maximum and minimum correlation relate to sand and clay soils and equal 0.95 and 0.74 respectively. To determine measurements accuracy the coefficient of variation was calculated and was equal 16.17 %.

Key words: weight method, Time-Domain Reflectometery (TDR), volumetric moisture, measurements accuracy

INTRODUCTION

Plants absorb the required water from the soil through the roots, so availability and usability of water in the soil are considered as main factors for the growth of the plant. In addition to these, some characteristics such as stability, muddiness resistance compressibility, penetrability and quartering in the soil are dependent on the amount of water. The moisture of the soil also affect on the amount of air in the soil and the quartering of gases. The activity of fine species and chemical activities of the soil are also functions of its moisture.

The standard way to determine moisture is the weight procedure (direct way) which is usually utilized for calibration of other procedures. Recently the dielectric property of the substances has been wed to determine the moisture and based on this some instruments have been designed so as to determine the moisture using dielectric property of the soil. The most known of these procedures, is time domain reflectometery which is called TDR. Using TDR has been recently known as a modern, non destructive and fast way for determination of the mass moisture of the soil. Using this procedure is based on the abnormal property of water which is its dielectric constant. Generally dielectric means in conductivity and dielectric constant of each substance which is also called proportional conductivity is defined as the ration between the capacities of the same capacitor in a case that dielectric is air or vacuum. The mentioned equation is Shown as D, ε or K_a.

Topp *et al* (1994) stated that the time of transmission and its and its echo of the electromagnetic wave to the end of carrier were proportional to the mass moisture of the surrounding. The benefit of TDR set is that its calibration curve is the same for all kinds of soils; its precision is about 2% and the variations of the measured amount in a soil and for different repetitions is equal to 1%**.** Therefore this set can be well used for measuring

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soil moisture for irrigation aims and soil and water studies. Regarding the effect of soil structure upon the calibration of TDR very finite number of studies has been represented in our country.

These studies can be enumerated as Soltani Mohammadi (2005) on the effect of soil texture upon the calibration of TDR set, in Khozestan, Salari researches upon the effect of salinity for calibration of TDR set on various soil suctions(2008).We can also enumerate the use of this set for measuring moisture in several investigations for example, the determination of unsaturated hydraulic properties of sand soils through controlling the hydrostatical level using TDR by Kashkoli and Zohrabi(2005) and evaluating the operation of burial sensors made for TDR hydrometer by Kamalie and Mehdian(2005).

Regarding the effect of soil properties upon the calibration of diverse models of TDR we can enumerate these studies. Topp *et al* (1994), Topp *et al* (1980), Dobson *et al* (1985), Dirksen and Dasberg (1993) and Persson and Berndtsson (1998). Also, regarding the effect of organic soil ingredients upon the calibration of TDR set we can enumerate.

These research : Deloor(1964), stain and Kane(1983), Ledieu *et al*(1980), Roth *et al*(1993), Herkelrath *et al*(1991), Jacobsen and Schjonninng(1993), Malickiet *et al*(1994), Borner *et al*(1996), Wetize *et al*(1997), Schaap *et al*(1996), Regalado *et al*(2003), Oleszczuk *et al*(2004), Pumpanen and Lvesniemi(2005) and Shibcharn *et al*(2005).

In this article we are about to reach some goals such as: calibrating the TDR set, scrutinizing the precision of TDR method to determine the soil moisture, investigating the effect of soil structure upon measuring accuracy of reflectometery method , weight method comparison and that of TDR.

MATERIALS AND METHODS

Researching area consists of the lands belonging to IAUS and its surrounding which is 10 Km away from Sanandaj on the road to Kermanshah. The latitude of the area is: $36^o,10',38''$ and the longitude is $44^o,03',47''$.

Determining soil moisture using weight procedure:

Using a drilling machine for different depths for example 20, 40 and 60cm some soil samples is provided. Then the samples will be put in closed-lid cans so as to prevent from their evaporation. The samples will be taken to the laboratory, they are reweighed and their weights are written.

After that the lids are opened**.** If the samples are too moist, it is possible that after weighing then, they are first kept in laboratory atmosphere so as to get dried and for the find drying phase they are kept in the oven for 24 hours with the temperature of $105C^o$. This action is solely performed so as not to harm the oven, unless we can put them in the oven immediately. After 24 hours the samples will be put out of the oven and after reweighing then percentage of their weight moisture will be calculated based on the equation1. One of the benefits of the weight procedure is that it can be used as a reference for controlling the measured moisture using all other procedures.

Also, this procedure does not require many or expensive instruments. One of the deficiencies of this procedure is that it harms the soil of the farm and also the fact that it can not be effective for the amounts of moisture which are more than its tolerance capacity.

$$\theta_m = \frac{m_w}{m_S} \times 100 \qquad (1)$$

In this equation θ_m signifies the percentage of weight moisture m_w signifies the weight of water (the total weight of the moist soil and the container minus the total weight of dried soil and the container) and m_s signifies the weight of the dried soil (the total weight of the dried soil and the container minus the weight of the container).

Determining soil moisture using time domain reflectometery method:

One of the some what new procedures which are used for determining moisture is the TDR procedure. This procedure is based on abnormal properties of water regarding its fixed amount of di electricity in a way that di electricity means in conductivity. That is to say if a material is put between two charged plates (a capacitor), it prevents from the formation of electrical charge current. In TDR method two or three metal bars which are made of steel or copper will be chosen, than they are plugged into a signal receiver, next the bars are embedded into the soil. The bars whose diameter is about 5mm, at as conductors and the soil between and around the bars at as the dielectric atmosphere. Now if the TDR set generates electrical voltage impulses or some signals and propagates them along the parallel bars, the velocity of the high frequency signals will be reduced by some substances like moist soil whose dielectric constant is high, then the signals whose speed is low will be echoed from the end of the bars to the set, the set measure the time between the transmission of the signal and its reception according to the fixed length of the bar. There is a reverse relation between transmission-echo time period and the velocity of signals propagation (v) in the soil. On the other hand there is also a reverse relation between propagation velocity and the amount of dielectric constant of the soil which is a function of moisture, so the more the moisture is the more the dielectric constant will be. There fore signal propagation velocity will be reduced and due to this transmission-echo time period will increase.

The first relations between dielectric constant and the percentage of mass moisture were represented by Topp *et al* (1980).

$$\theta_V = -5.3\times10^{-2} + 2.9\times10^{-2}(\varepsilon) - 5.5\times10^{-4}(\varepsilon)^2 + 4.3\times10^{-6}(\varepsilon)^3 \quad (2)$$

$$\varepsilon = (\frac{C\Delta t}{2L})^2 \quad (3)$$

In above cited equations: $\theta_V =$ the percentage of mass moisture, $\varepsilon =$ dielectric constant, $L =$ the length of the bars, $\Delta t =$ transmission-echo time period, $C =$ propagation velocity of the electromagnetic waves in free space (light velocity) which is equal to $3\times10^8 \frac{m}{s}$,velocity can be calculated according to the length of the bars(L) which is equal to(2 L) here.

Sampling procedure:

According to the appearance information of the soils and performing several tests, three zones whit the structures of clay, medium-sized and sand were identified in the mentioned area. Using TDR set, sampling of the soil and the measuring moisture were performed in each of the mentioned zones. In continuation of the text, the number and the procedure of samplings have been explained. In each zone, two samples were taken so as to determine physical and chemical parameters of the soil structure. Using cylinder bars one of the samples was taken in an untouched way.

The process was in a way that the cylinder was embedded into the soil by a hammer. Then the surrounding soil was removed and using a palette knife the surrounding area of the untouched sample became even and the soil was transferred into an aluminum can. Using a dibble the other sample was put in side a plastic bag and was taken to the laboratory. To check the soil moisture of the sample during five repetitions, in each the above mentioned triple zones and in the depths of 0-30cm and 30-60cm, the samples were picked up by a drilling machine and were put in the aluminum cans that had been weighed before in the laboratory.

Through a simultaneous action during 5 repetitions in the both depths of 0-30cm and 30-60cm, the mass moisture of the soil was measured with TDR set in the mentioned zones. All of the picked up samples for moisture determination and also 30 cases were performed with TDR set**.** Through the process of moisture measurement (TDR) two bars which are usually mode of copper or steel are chosen and plugged into a signed receiver. Then the two bars which are about 2 to 4mm long are embedded into the soil, the bars will act as conductors and the soil between the bars plays the role of the dielectric atmosphere (the distance between the bars is 5cm). Now the TDR set generates an electrical field in a mass of soil and propagates the generated electrical voltage impulses through the parallel bars. The velocity of these signals which have been propagated in a high frequency will be reduced by some substances like moist soil whose dielectric constant is high. The signals whose velocity is low will be reflected from the end of the bar and bounce back to the set.

The set measures the time between the transmission and the reception of the echoed signals. If the length of the bar is a fixed amount, the transmission-echo time period will be in a reverse relation with the velocity of propagation in the soil. On the other hand the velocity of propagation will be in a reverse relation with the dielectric constant of the soil which is a function of moisture.

There fore the more the moisture of the soil is, the more the amount of the dielectric constant will be. As a result, the velocity of propagation will decrease and due to this, transmission-echo time period will increase. A microwave moves along the bars and acts like a band of light beams. Any kind of discontinuity in transmission lines and their atmosphere will make an amount of small wave's energy be echoed backward. When these impulses reach to the end of transmission line, all the remained energy of the impulses will be echoed backward. These properties will enable us to measure the moving time of the pulse along the transmission bar.

Transmission time is defined as the time required by a pulse to move in a direction from the beginning of a carrier up to the end of it.

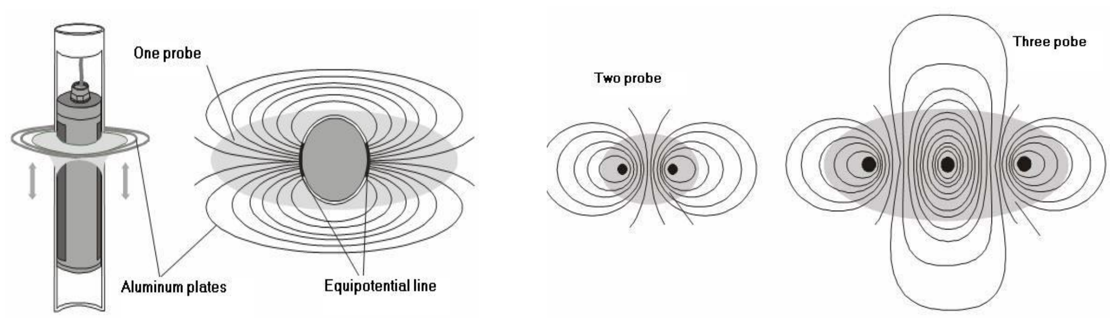


Fig. 1: The electrical field around the probes in the states of one, two and three probes

In this research we used the TRIE-FM model of TDR set which had been model by the company of IMKO in Germany, (Figure2). This system has been designed for the quick measurement of moisture in soil and other atmospheres. From 1994 the set has been used in the realms of earth sciences and environmental researches that require a lot of care. General features of the set are: moisture measurement limit: 0-100%, measuring precision: ± 0.1%. Using standard carriers, repetition precision: ± 3%, operating temperature: 15 to 45 C^o, the source of energy: DC curren7 to 15 volts, electrode battery with the capacity of 600 $\frac{ma}{h}$, Data logger: regular continuous registrations of the data's in an automatic way with the analogue out put of 0-1 voltage DC Connectivity: Via RS232, Calibration: Using mine soils and the software of the set.

Fig. 2: The measurement of soil moisture using TDR set

Having collected the data's, they were analyzed using Microsoft Excel and MSTA-C soft wares. To compare the weight procedure with the TDR procedure and to determine the meaningfulness of the difference between two procedures in each of the contexts and to determine the measuring fullness of the difference between treatments, in a complete random form the analysis of variance was performed using ANOVA testing and MSTAC-C soft ware. The Duncan multiple range test was also performed to determine the homogeneity of the difference between treatments.

RESULTS AND DISCUSSION

In table1 the results of variance analysis have been represented for both TDR and weight procedures. It relates to the implementation of both procedures in3 types of soil: clay, medium sized and sand. It is also related to the two depths and their effect upon determining the average percentage of the mass moisture. Also in order to determine the precision of the test, the coefficient of variance was applied it signifies error based on the average percentage of the tests. The amount of the coefficient of variance was equal to 16.17%.

Table 1: The results of variance analysis

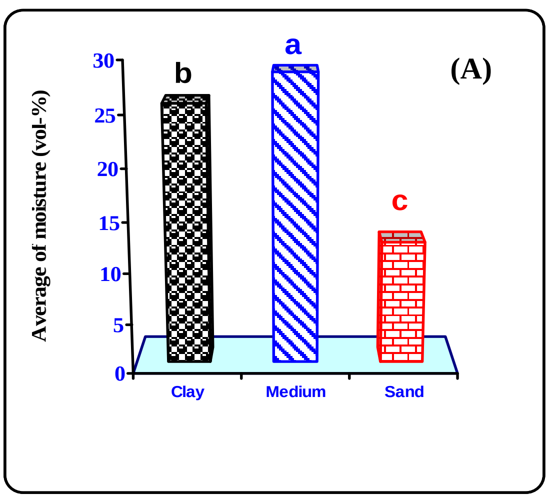
Row	Sources of variations	Freedom degree	The sum of squares
1	Soil type	2	1529.134**
2	Measurement procedure	1	60.060*

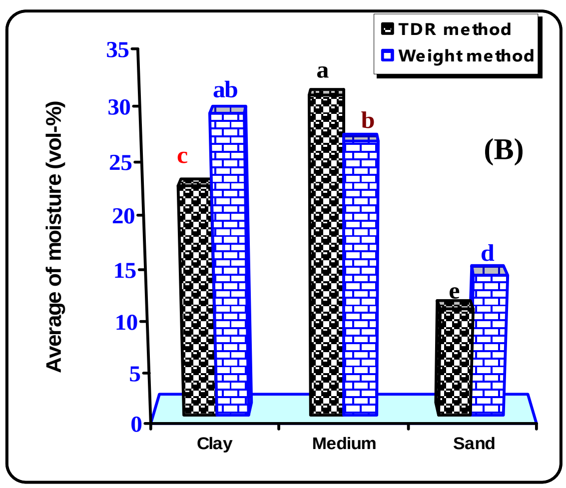
3	Soil type × Measurement procedure	2	155.03**
4	Measurement depth	1	14.123ns
5	Soil type × Measurement depth	2	56.259*
6	Measurement procedure × Measurement depth	1	0.004ns
7	Soil type × Measurement procedure × Measurement depth	2	7.731ns
8	error	48	12.756
9	total	59	
10	The coefficient of variance(CV)		16.17%
**significant at the level of 1% ,* significant at the level of 5% ns: no significant			

The comparisons between the percentages of mass moisture have been represented in Figure3. They are based on both TDR and weight procedure for different soil types in the depths of 0-30 and 30-60 cm. Variance analysis of the data's signified that the average amount of mass moisture for different soil types was significant at the 1% level and for measurement procedure was significant at 5% level. But the measurement depth was of on significant effect upon the average amount of mass moisture. Also the TDR and weight procedure were significantly different at the level of 5% regarding the determination of the average percentage of mass moisture in the three mentioned soil types.

The average amounts of mass moisture in clay and sand type which had been measured by TDR were less then those by weight procedure while it was vice versa regarding the medium sized soil type. In all there are significant differences between the amounts of measured percentage of mass moisture in both 0-30 and 30-60cm depths, the highest amount was related to the medium sized type of the soil which was equal to 30.36% and the least amount was related to the sand type of the soil which was equal to 10.74% in the depth of 0-30cm. The highest amount of moisture difference in both depths of 0-30 and 30-60cm was related to the medium sized type of the soil which was equal to 3.69% and the least amount was related to the clay type of the soil which was equal to 2.01%.

Also there was a significant difference between the two procedures in the case of the measured amount of mass moisture in a way that the highest amount was related to the weight procedure and was equal to 23.08% and the least amount was related to TDR procedure and was equal to 21.08% and the difference of moisture amount was equal to 2%. The highest amount of difference was related to medium sized type of the soil which had been measured by TDR procedure and was equal to 30.58% and the least amount was related to TDR procedure but for the sand type of the soil which was equal to 22.23%.





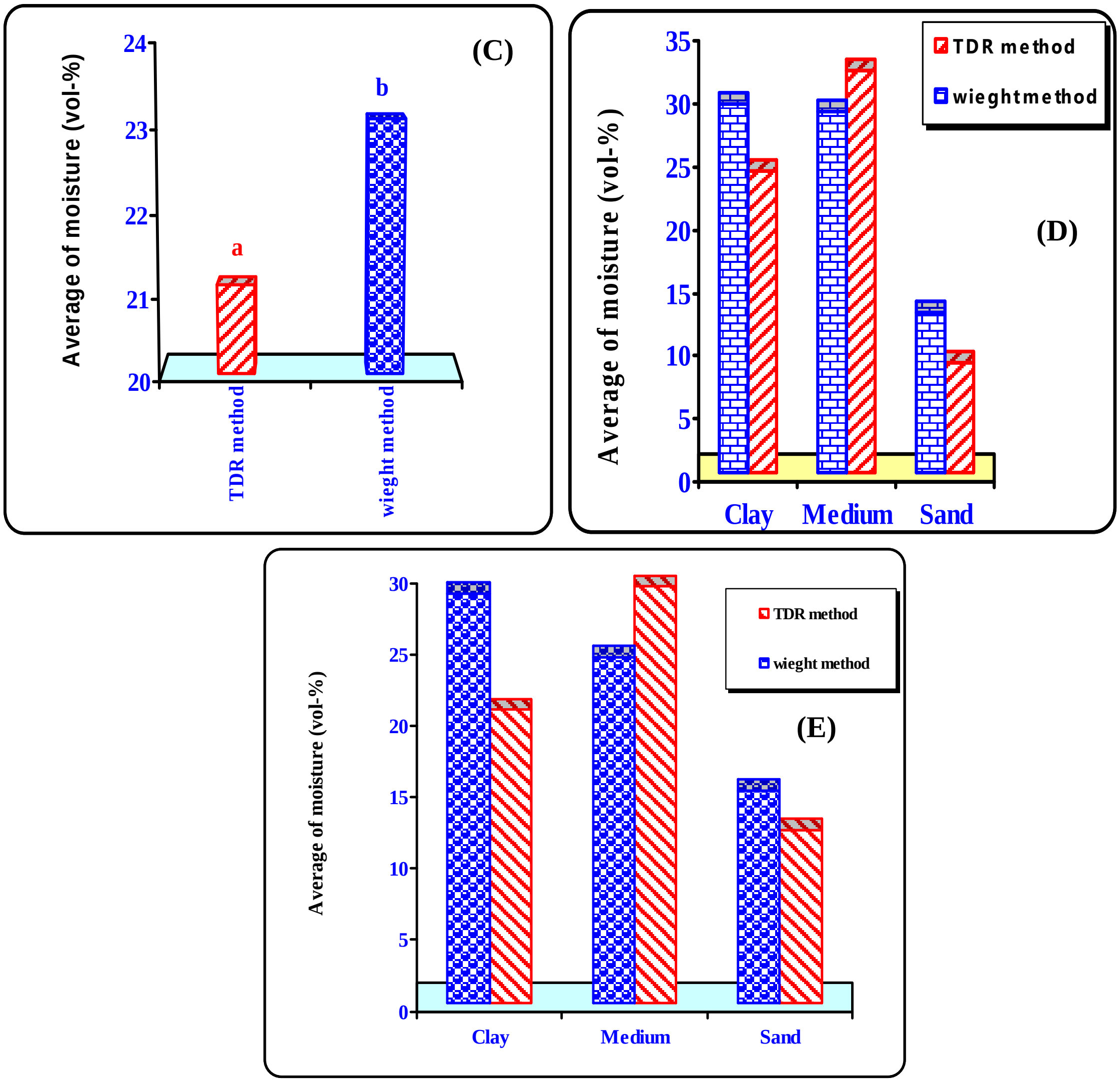


Fig. 3: Comparing the moisture using weight and TDR procedures in different soil types:

A: Comparison of the interaction effect of soil type and measurement depth on the amounts of mass moisture.
B: Comparison of the mutual effect of soil type on the amounts of mass moisture.
C: The comparison the effects of both procedure upon the amounts of mass moisture.
D: The comparison between the effects of both procedures upon the amounts of mass moisture In different soil types in depth of 0-30cm .
E: The comparison between the effects of both procedures upon the amounts of mass moisture In different soil types in depth of 30-60cm.

The results of outdoor tests (both procedures) showed that there was a significant difference between the average amounts of the mass moisture percentages which were measured in the depths of 0-30 and 30-60 cm, but it showed that there was not a significant difference between the average percentages of moisture measured by TDR and weight procedures which were performed in different depths of measurement. The different average amounts of mass moisture in both above cited procedures were 2.01% for the depth of 0-30cm and 1.98% for the depth of 30-60cm. Also there was a significant difference between average percentages of measured mass moisture in clay, medium sized and sand type of the soil in both depths(0-30 and 30-60cm),but there was not a significant difference between the average percentages of each measuring procedure in a variety of soil types . The highest and the least amounts of difference in the case of moisture were related to the depth of 0-30cm which were 5.35% for the clay type and 3.28% for the medium sized type.

The highest and the least amounts of moisture differences for the depth of 0-60cmwere related to the clay and sand types of the soil that were equal to 8.77% and 2.76% in order. Using their own international equation, Topp *et al* (1980) mentioned that there was a significant difference between these results of TDR and those of weight procedure and described the surface of the clay and its mineral as the reason. The researches performed by Marufpoor *et al*(2009) on the effects of soil structure upon the calibration of TDR set indicated that the more the amount of clay, the less the TDR mass moisture estimation precision. In other words the heavier the structure of the soil, the less the TDR estimation precision.

In a similar research, Vesna *et al* (2005) discovered that TDR procedure was suitable for clay and silt soil types while it measured a higher amount of mass moisture for the sand type. For all soil types (clay, medium sized and sand type) there were significant difference among the measured average percentage of mass moisture in the depth of 0-30cm and the one for the depth of 30-60cm.

In a research Mazidi (2009) with deduced that in the measured moisture range (0.1 to 0.35) and the presence of variable amounts of organic materials, the TDR procedure estimated higher amount of moisture in comparison with the weigh procedure. The difference between the measured amounts was then 2%, in a way that TDR set showed a higher amount of moisture which was about 2% more than the result of weight procedure. Comparing the mutual effects of these parameters upon each other, it became clear that there was a significant difference at the level of 5%. Also to determine the precision of the tests, the coefficient of variations was applied. This factor signifies the error based on the average percentage of the tests.

The measured amount of CV was equal to 16.17%. To check more the results of:

1-Fitting the regression lines

2-The fitted line equation

3-Their coefficient of correlation for the percentages of mass moisture in the three soil types were evaluated by both TDR and weight procedures. The results showed that in the depths of 0-30 and 30-60cm, the amounts of moisture differed significantly while there were no significant difference between the measured average percentages of mass moisture which were acquired by both TDR and weight separate tests in mentioned depths. The average amounts of difference for both procedures were 2.01% for the depth of 0-30cm and 1.98% for the depth of 30-60cm.

In his research, Soltani Mohammadi(2005) showed that in all testing treatment, consisting of sand type, sandy loamy, loamy sandy, silt loamy, clay loamy and silt clay that were made from3,8,16,16.30 and 40 percents of clay, there were not a significant differences between the amounts of the moisture measured by both TDR and weight procedures. Disregarding the type of the soil, depth of measurement, the range and the relations of mass moisture amounts for both procedures, the level of correlation between the two procedures is as below:

Table 1: The fitted line equation and the coefficient of correlation in different soil type

Soil texture	Line equation	R
sandy	$\theta_V(TDR) = 1.2814\theta_V - 7.298$	0.95
medium	$\theta_V(TDR) = 0.5228\theta_V + 16.749$	0.85
clay	$\theta_V(TDR) = 0.7126\theta_V + 1.5764$	0.74
Total	$\theta_V(TDR) = 0.963\theta_V - 1.164$	0.82

In Figure4, the relation between mass moisture amounts has been shown for both procedures. Through checking by both TDR and weight a procedure it was found that the highest amount for the coefficient of correlation be longed to the sand type and was equal to 0.95 while the least amount belonged to the clay type and was equal to 0.74. In medium sized type of the soil the amount for the coefficient of correlation was equal to 0.85.

Dasberg and Hopmans (1992) reported that the correlation between the average percentage of mass moisture in both TDR and weight procedures were 0.91 for sandy loamy soils and 0.99 for silt loamy soils. Also, Kamali and Mehdian (2005) deduced that due to the homogenous distribution of the particles, the sand type soils have got a higher amount as their coefficient of correlation. The average amounts of mass moisture in TDR procedure made a difference about ± 2 % in all cases with the related amounts using weight procedure. This fact can be closely matched with the mentioned digits in the TDR catalogue.

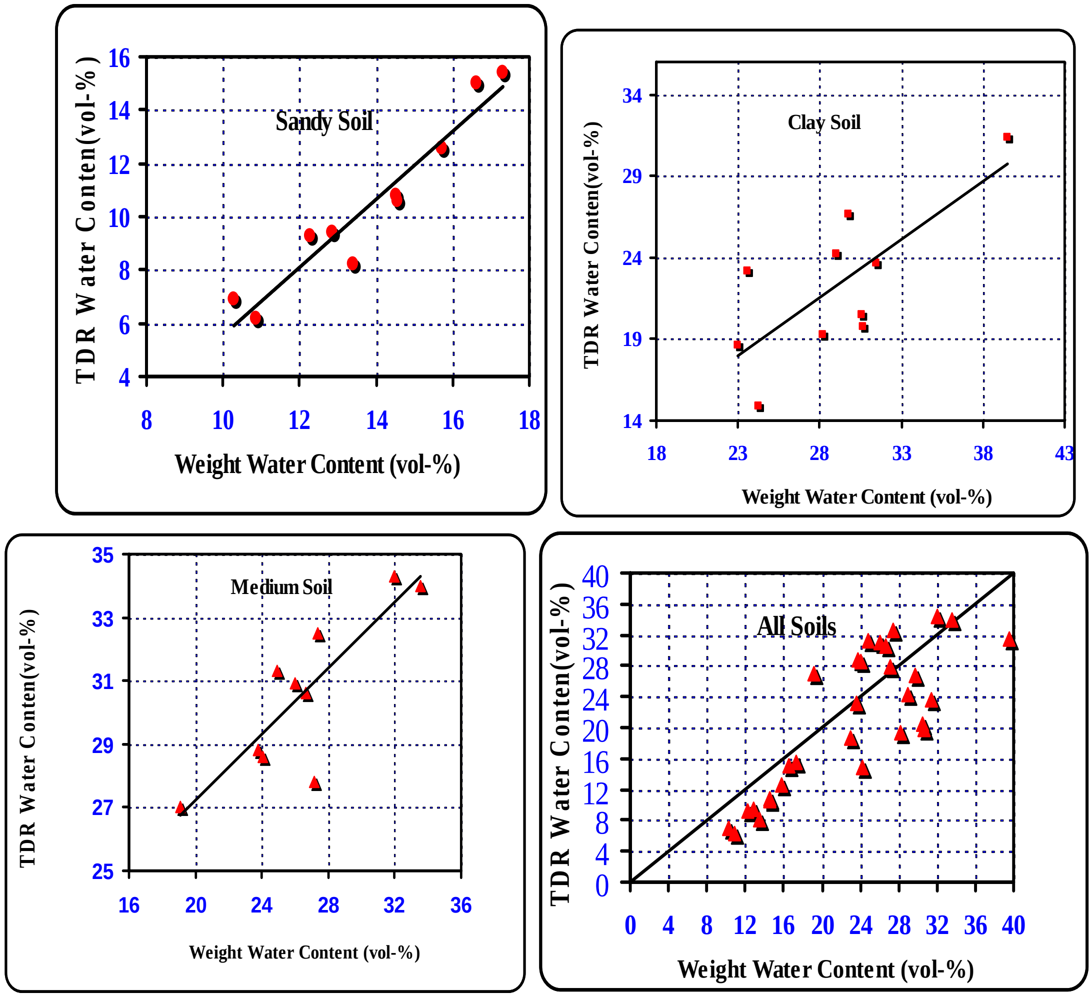


Fig. 4: The relation between the average percentages of mass moisture in both weight and TDR procedures

ACKNOWLEDGEMENTS

This article was the product of a research which was supported financially by IAUS (Islamic Azad University of Sanandaj). There fore it is highly appreciated.

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