

*Full Length Research Paper*

# Calibration of time domain reflectometry (TDR) on the basis of torf sand and its optimisation for irrigation automations

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Accepted 28 November, 2020

In this study, requirement calibrations performed for irrigation automation at the agricultural irrigation, particularly by means of taking as a base the torf sand, from the greenhouse, garden and flowerpot soil, were carried out. In order to make the TDR (time domain reflectometry) device suitable for watering automation, the water pump was automatically used to perform drip irrigation according to the humidity values provided via integrated adjusted resistances and the relay system to the device. Compatibility was determined between the values obtained from automation. As a result, TDR humidity sensors, used for soil water content measurement, are both easier and cheaper than other systems. It has been seen that this examined system can be applied for different types of soils too.

**Key words:** Time domain reflectometry (TDR), soil water content, torf, irrigation, automation.

## INTRODUCTION

Positive results which have been obtained as a result of developing agricultural irrigation systems, have a big importance for all creatures in the world, because the most important issue of the future will be the usage of the limited sources in a most productive way. Therefore, in irrigated farming, determination of irrigation water and planning of irrigation systems is necessary.

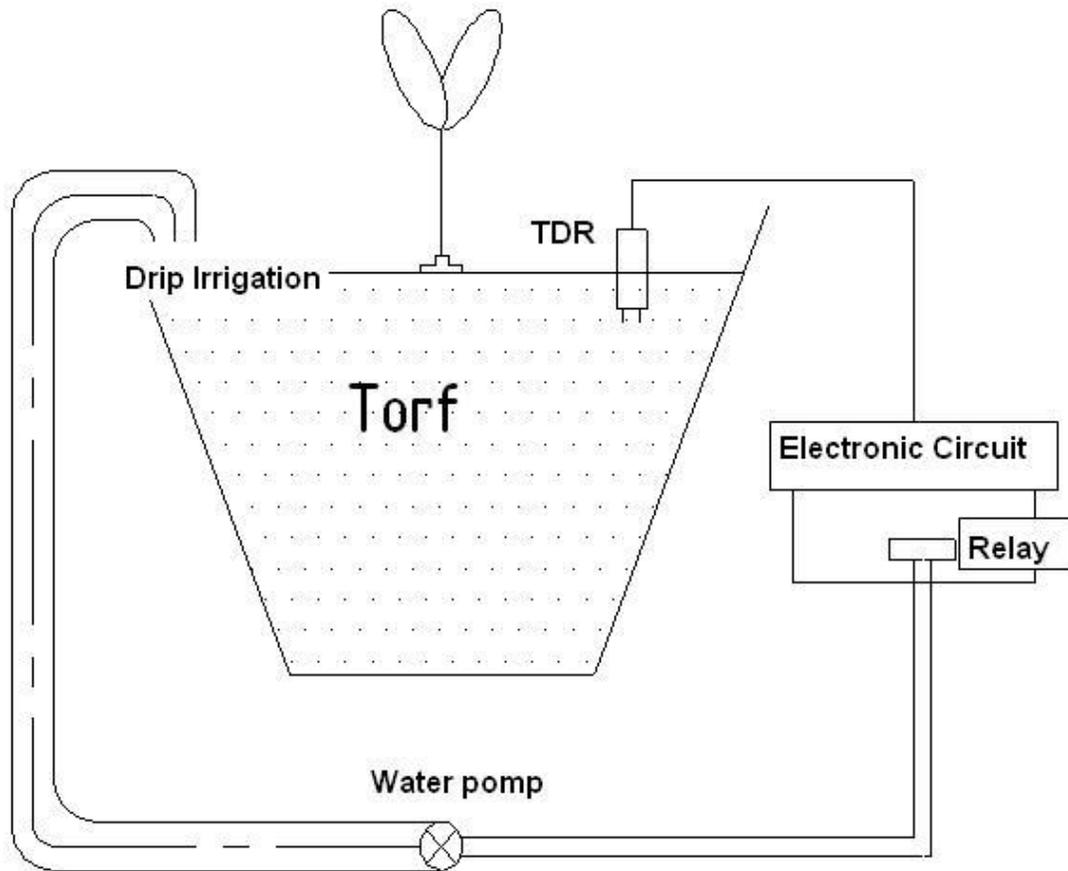
The basic purpose of watering is to ensure optimum plant growth, to store a sufficient amount of plant root zone water which could not be met by natural means in soils and to decrease the plant stress. Accordingly, with the selection of suitable irrigation system, the preparation of irrigation schedules, which detects irrigation time and determines the amount of irrigation water amount, gains importance. A trial was made with plant water stress to quantitatively determine the usage of different techniques via spot measurements performed from plant corona and various parts of the plant or soil. For example, the techniques of pressure chamber, leaf water pressure (Oosterhuis et al., 1987; Laker et al., 1987; Rana et al.,

1998), diffusion resistance in the stroma with porometric measurement (Idso et al., 1981), transpiration rate with measurement instrument of plant juice flow (sap flowmeter) (Smith and Allen, 1996; Cohen and Li, 1996) and soil water potential with tensiometer (Abdel-Rahman et al., 1994; Sinclair et al., 1998) were used.

It was determined by Kacira (2000) that plant water index, which indicated water stress level in plants by infrared temperature measurement technique (infrared thermometer), based on the principle that transpiration occurred on plant leaves, was also established as contact-free to plant. By developing the technology, very different techniques in irrigation automation have been brought into usage. In this study, the TDR (time domain reflectometry), which measures the volumetric water content of soil by electromagnetic reflexion method, was used. Tanriverdi (2005) calibrated the TDR instrument for different soil types in order to use it in agricultural irrigation. The research data were collected, in cultivation terms, from a cornfield in Wiggins Colorado in 2002. As a result, the researcher concludes that the usage of TDR instrument is an acceptable method for measuring soil water content because it is reliable and gives correct results.

Biteli et al. (2007) indicated that the main problem of

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**Figure 1.** Schematic demonstration of system running that will be developed using TDR technique.

TDR usage was the negligible loss of humidity in soil content. TDR can demonstrate, with an utmost accuracy rate, the soil water content via set-connection by itself between volumetric water content and electrical conductivity. However, they used the dry oven gravimetric water content to evaluate, as an independent method, the soil water content. Schaap et al. (1996) benefited from the TDR tool, in that they used it to observe the soil water content in different forest grounds. Inoue et al. (2000) have designated TDR sticks for estimation of the humidity amount close to the soil surface. Noboria (2001) has obtained, paralelly, soil water content and electric conductivity at the same time, by means of one single probe usage to recently developments in the TDR.

In this study, we developed the use of TDR technique, detected water amount consumed by plants at the specified time range and then made an automatization of irrigation according to the amount of water necessary. It is thought that the developed system is used alternatively to conventional irrigation systems in the greenhouses. TDR humidity sensors are components of electronic circuit, which can give output in various units according to humidity rates in soil. Although its various types are present, it has been seen that the type with capacity

property is more suitable for this application.

In this study, soil humidity level was detected by "TDR humidity sensor" and transferred to multimeter. Also, control of irrigation motor can be done by the help of relay according to multimeter voltage value or can be performed by running/stopping. Thus, full automatic irrigation is performed. The full automatic irrigation states that the manual control of the current irrigation systems is removed, and the running or stopping of the irrigation motor control is provided according to soil humidity variation.

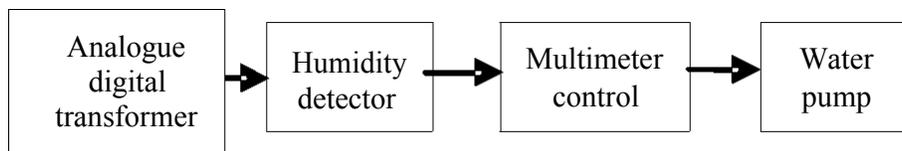
## MATERIALS AND METHODS

Studies for creating irrigation schedule were classified at three different manners based on plant, climate and soil (Doğan et al., 2005). In this study, the aim was to determine soil moisture based on soil. These can be lined up as direct method (lysimeter), TDR, tensiometer and other methods.

Processing of the irrigation system, which will be used in this study and developed by using TDR technique, was schematically demonstrated in Figure 1. Due to the fact that the alteration in the soil humidity level is related to plant temperature and water stress, an irrigation automation system, which run at the limit levels of different soil humidity values entered into the system, will be developed. This system would monitor continuously, the humidity



**Figure 2.** Graphic of TDR instrument and irrigation pump.



**Figure 3.** System block schema.

alteration in the soil by TDR device and irrigation based on the limit levels that are specified by the user and its requisite. An electronic circuit which will be connected to the TDR device was developed, in order to possibly monitor the TDR's measurement and data that can enter different soil humidity limit levels and make active the irrigation pump by comparing these humidity limit levels and their measurements in soil.

### The humidity sensor

The sensor, which is used in application of the TDR sensor as seen in Figure 2, is a humidity sensor, working capacitively and it accepts the soil as a dielectric substance. While the humidity density on it is changing, its capacity value and thus resistance level changes as well. Applying positive (+) voltage to its input, results to voltage alteration on it. Also, the current alteration can be monitored by a suitable circuit.

### OPAMP (operational amplifier)

Amplifiers, which consist of transistors, are called operational amplifier (Op-Amp). They are an important component used in the electronic systems, such as amplifier, comparator, oscillator, filter, etc. Opamps have two input, as one negative and one positive, and one output. When difference in voltage between the two inputs occurs, it changes output voltage based on this difference. In this study, opamp was used as a comparator. If we define the negative and positive two voltage lead-in of opamps as V1 and V2, and the output voltage as V0, V0 changes according to the status of V1 and V2. If V1 is >V2, V0 + V gives the input value; however, if V2 is

>V1, V0 gives zero (0).

### Torf sand

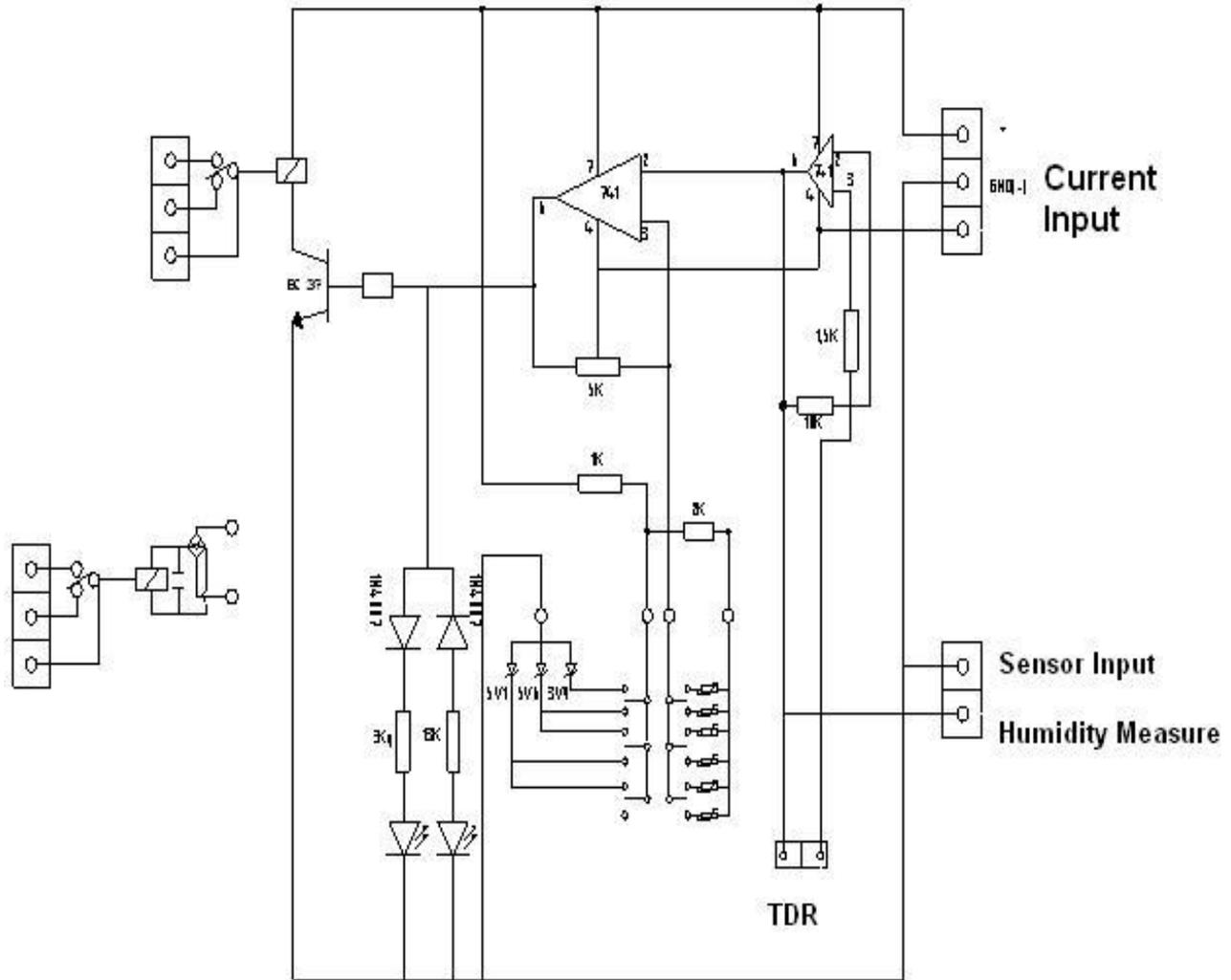
Torf sand are formations of moss and other marsh plants, which are submerged, decayed and which grow big layers. It is insufficient in terms of nutrition substance, in that it has an acidic characteristic (pH 3.5 - 4.5), very permeable and looses structure. Its waterholding capacity is very high. Torf sand is used at the cultivation of house plants and decoration plants. In this kind of environment, cuttings or plants provide, very well, rooting and growth.

TDR device, which was designed as an automatic irrigation system in this study, has been placed on torf sand.

### Method

By taking 500 g of torf sand and keeping them for a determinate period of time in the oven at 105°C, the amount of water level in it can be taken out. Then simultaneous mV values were determined by the integrated TDR device, which was designated by adding water at the determinate period and amounts, and calibration was carried out. To determine the applicability of the system, it was immobilized by adjusted resistances at the determinate mV levels. Comparing the obtained results with the calibration values, reliableness of the system was established.

Block schema of the system, which was designed in this study was given in Figure 3. Humidity sensor, seen in the block schema, gives an analogue output based on humidity rate in one part of the air. Analogue digital transformer converts the received information



**Figure 4.** Technique circuit schema of TDR (time domain reflectometry) device.

into digitale and conducts the microcontroller. Microcontroller manages the speed control level according to the received information. In Figure 4, analogue digital transformer and multimeter parts take place. The sensor's resistance on it has been changing according to humidity alteration in soil. As shown in Figure 4, humidity density (RH%) and resistance value are inversely correlated. Therefore, V0 has taken voltage variation on the other resistance of 10 K. Thus, V0 information was sent to multimeter from here.

Multimeter is a block, which increases or decreases levels according to voltage information (V0) from humidity detector. Its open circuit schema is demonstrated in Figure 4. It is carried out by a comparison of the voltage values on the five calibration resistances (Trim pots) and the Opamp of 1 K analogue information in V0. However, the values of calibration resistances determine the sensitivity of the system. The selected values make sure that the system runs in humidity density at the 0 and 100% RH ranges. These ranges meet the humidity density amount that is necessarily applied in the field for water pumps, if the required measuring adjustment can be changed.

Operational amplifiers that were used here were opamp LM741. For all LM741, while V0 information was connected to the positive (+) input, the level information from calibration resistances was

connected to the negative (-) input. After the values were taken from suitable outputs, as a result of comparison, relay stepped in and provided running of irrigation pump.

#### Calibration of TDR device

The linear relationship between the output signal of TDR device and the soil dielectric conductivity is presented in Equation 1:

$$\sqrt{\mathcal{E}} = 1.1 + 4.44V \quad (R^2 = 0.99) \quad (1)$$

where  $\mathcal{E}$  is the dielectric conductivity constant of the soil (-), and V is the voltage input into probe (V).

Soil sample was primarily measured as a signal output (Volt) by means of the device that submerged this soil sample, which will be brought to field capacity and which was waterlogged. Using

Equation 1,  $\sqrt{\mathcal{E}_w}$  value was determined. Damp soil was weighted and its wet weight (Ww) was determined. After the soil was kept in the drying oven at 105°C for one day, a signal output value was

read by means of the device that submerged the dried soil sample.

Again, by using Equation 1,  $\sqrt{\epsilon_0}$  value was established (this value is a0 value). Then, the dried soil sample was weighted and  $W_0$  value was detected. The volume (L), which was covered by soil within the pot, was determined. Using the aforementioned obtained values, soil volumetric water content ( $\theta_w$ ) and a1 value can be established with the help of Equations 2 and 3:

$$\theta_w = \frac{(W_w - W_0)}{L} \quad (2)$$

$$A_1 = \frac{\sqrt{\epsilon_w} - \sqrt{\epsilon_0}}{\theta_w} \quad (3)$$

where:  $W_0$  = weight of dry soil (kg);  $\epsilon_w$  = saturated soil dielectric conductivity (-);  $\epsilon_0$  = dry soil dielectric conductivity (-); L = volume covered by soil ( $m^3$ );  $W_w$  = weight of wet soil (kg) and  $\theta_w$  = volumetric water content ( $m^3 m^{-3}$ ).

With the aid of the obtained a0 and a1 values, calibration curve will be generated by means of using Equation 4:

$$\theta = \frac{[1.1 + 4.44V]}{A_1} - A_0 \quad (4)$$

Here,  $\theta$  = Volumetric soil humidity value ( $m^3 m^{-3}$ );  $a_0$  = standard soil dielectric conductivity (-); and  $a_1$  = Dielectric conductivity obtained according to water (-).

Calibration equation of the TDR device, which will be used in the study, was obtained by calculating the determined data. Thus, the electronic circuit, which made the irrigation to be automatic, was developed in order keep the humidity level in soil between these limits.

#### Preparation of torf sand

Torf sand of 500 g was taken into a suitable vessel and kept in the drying oven at 105°C for one day and was then dried. This soil was put in a suitable vessel, in which a very small circular was drilled in the base part for exit of extra water. As such, water was irrigated in a dripping way at the determinate interval and amount until the soil was drained of water. Consequently mV and  $m^3 m^{-3}$  values of dry soil, wet soil and of both soils were obtained.

#### Performance of drip irrigation using water pump

Water pump runs together with TDR integrated circuit. The electrical circuit is provided from the input that is above the device by water pump. This input is integrated with a relay that is adapted by the adjusted resistance. According to the adjusted resistance value, running and stopping of the pump was provided. In other words, when the soil water content is brought to the desired level, the pump stops itself from running with the help of the relay. However, when the soil water content is brought below the desired level, the pump runs again.

#### Chi-square conformity test

Turanli and Güri (2000) used the conformity test to check if the distribution estimated according to the theoretical frequency belonged to the observed frequencies or not. If the real frequency

and theoretical frequency is close to one another,  $\chi^2$  statistic will be small. Therefore, it was concluded that the selected distribution, as a result of the test, was conformable with the theoretic distribution:

**H<sub>0</sub>**: Conformity exists (real frequency and theoretical frequency is close to one another)

**H<sub>1</sub>**: Conformity does not exist (real frequency and theoretical frequency differ from one another) in a way.

After the suitable error margin is determined,  $\chi^2$  statistic is calculated. Accordingly:

If  $\chi^2$  is  $< \chi^2_{\alpha}$ ,  $H_0$  is irreputable (conformity exists), while if  $\chi^2$  is  $> \chi^2_{\alpha}$ ,  $H_0$  is reputable (conformity does not exist). If the

estimated  $\chi^2_{0,05}$  value is high from the chi-square table value, it demonstrates the absent difference between two frequencies; otherwise, it shows the present difference between them. The estimated chi-square value is found as 0.0105 and it is said that the difference between the two frequencies is unimportant, because

this value is smaller than the chi-square table value ( $\chi^2_{0,052} = 7.81$ ).

## RESULTS AND DISCUSSION

### Calibration of the TDR device

Values, which were determined with sensitive readings at the TDR (time domain reflectometry) device, were given in Table 1, while graphic shown in Figure 5, was obtained according to the determined calibration values.

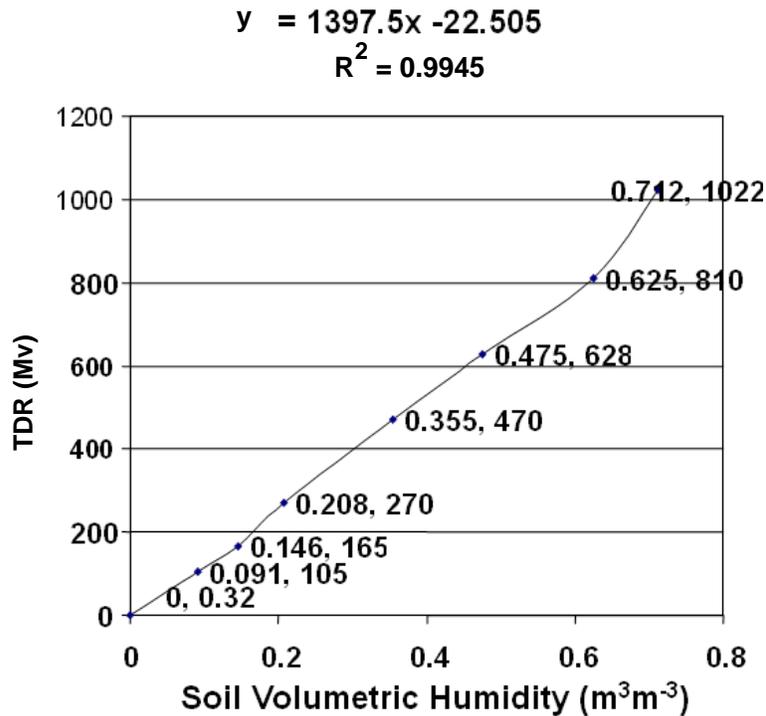
In Figure 5, values which were obtained from the TDR device, in the range of eight different volumetric humidities between dried and saturated soils were compared and calibration was performed. In conclusion, an equation was made according to the relation between soil volumetric humidity ( $m^3 m^{-3}$ ) and volumetric electrical conductivity (mV). Being close to the 1 of  $R^2$  value demonstrated a reasonable relation between two values.

### Values obtained from the standstill value

Here, closeness to the desirable result, by means of immobilizing the pump at different volumetric humidity values and comparing the values obtained from calibration, was determined. In Table 2, the system was adjusted in a way that water pump will stop at the 820 mV. By visually monitoring the determinate mV levels till they get to 820 mV level, additional three levels were obtained. Consequently, whether or not output results are coherent with each other, have been determined. By

**Table 1.** Values obtained from the calibration of TDR (time domain reflectometry) device.

| Soil volumetric humidity ( $\text{m}^3 \text{m}^{-3}$ ) | Volumetric electrical conductivity read from the TDR (time domain reflectometry) device (mV) |
|---|--|
| 0   | 0.32   |
| 0.091   | 105  |
| 0.146   | 165  |
| 0.208   | 270  |
| 0.355   | 470  |
| 0.475   | 628  |
| 0.625   | 810  |
| 0.712   | 1022   |



**Figure 5.** Calibration of TDR device.

**Table 2.** Results obtained from the irrigation value that was immobilized at 820 mV.

| TDR (mV) | Soil humidity ( $\text{m}^3 \text{m}^{-3}$ ) | Pump flow ( $\text{Lmin}^{-1}$ ) | Time (min) |
|----------|--|----------------------------------|------------|
| 219      | 0.16   | 0.008                            | 20.00      |
| 410      | 0.25   | 0.008                            | 31.25      |
| 612      | 0.43   | 0.008                            | 53.75      |
| 820      | 0.62   | 0.008                            | 77.50      |

means of converting these results into graphic form of values demonstrated in Table 2, the relation that existed among them was determined. Also, closeness to 1 of R2 value demonstrated the true correlation between these values (Figure 6).

#### Chi-square conformity test for standstill period values

By giving the values obtained from a standstill period in Table 3, the required chi-square conformity test

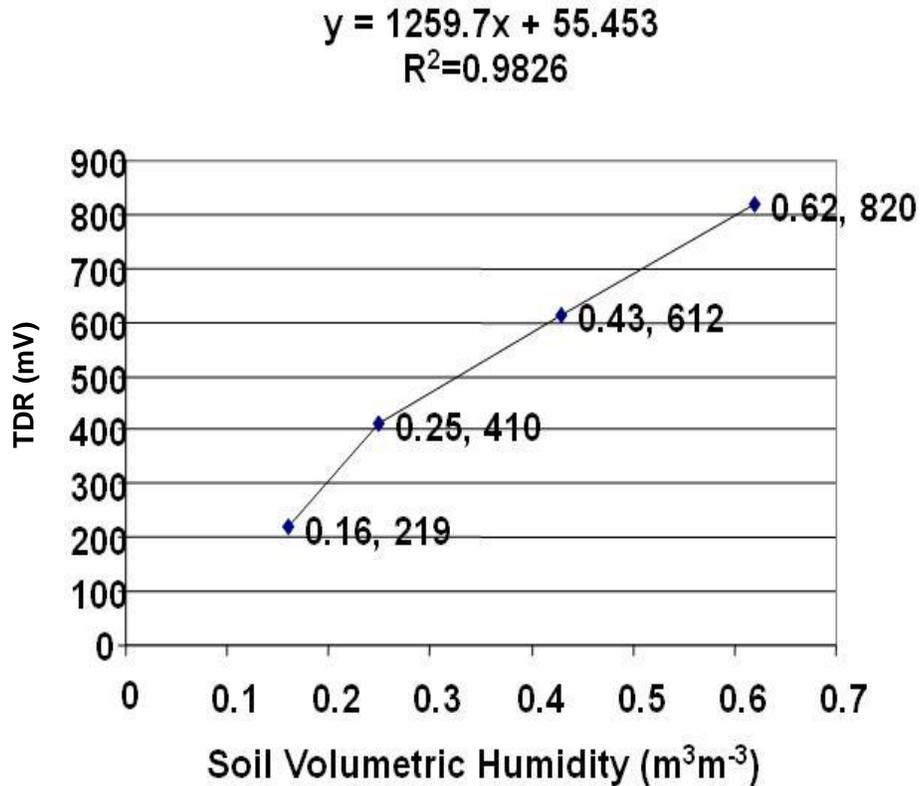


Figure 6. Graphic obtained from the irrigation value that was immobilized at 820 Mv.

Table 3. Performance of chi-square conformity test with results from the standstill period.

| TDR (mV) | $X_1 (m^3 m^{-3})$ | Value obtained from calibration ( $X_2 (m^3 m^{-3})$ ) | Calculated value $(X_2 - X_1) / X_1$ |
|----------|--------------------|--|--------------------------------------|
| 219      | 0.16               | 0.17   | 0.001                                |
| 410      | 0.25               | 0.30   | 0.008                                |
| 612      | 0.43               | 0.45   | 0.001                                |
| 820      | 0.62               | 0.60   | 0.001                                |
|          |                    |  | Total ( $\chi^2$ ) = 0.010           |

calculations were performed in order to determine the conformity of values from a calibration of these values. Using these results, a trial was made to prove the system's reliableness. Comparing values obtained from the standstill period with those obtained from calibration, a significant difference was not seen because the value (0.010) obtained in proving the system's reliableness was smaller than 7.81. Accordingly, the system runs reliably and correctly.

Dalton et al. (1986) did a research on the physical principles that form the basis of the time domain reflectometry method in simultaneously measuring the water content and bulk soil electrical conductivity. The volumetric soil water content was measured, using the TDR method (Topp et al., 1980). Fere et al. (2000) analysed that the weighting of the bulk electrical

conductivity, along TDR probes, showed the theoretical limitations to the measurement of solute concentrations with TDR. However, TDR probe was used for determining the water content of various soils by many researchers.

## Conclusion

In this study, a research was made on the necessity of carryiny out agricultural irrigation, especially in the automatic watering of garden, flowerpot and greenhouse by considering plant, soil and environmental factors. This was done by giving up traditional waterings and using TDR humidity sensor. Since there was a linear relation between volumetric electric conductivity of the soil and soil water content, information about soil water content

was also given. Test was made on the soil, which was called "torf sand" or a garden, flowerpot or greenhouse soil.

As a result, by means of taking torf sand as a base, the soil water content was measured with TDR humidity sensor and its status was worked up automatically with an applicable method. Furthermore, with adjustments done by specialists on the other soil types, it has been seen that TDR device can be adapted to these types. However, if the analysis is properly done, it can attain a better technological status by digital softwares.

## REFERENCES

- Abdel-Rahman GM, Fynn RP, McMahon RW, Short TH (1994). Effect of soil moisture tension on the growth of greenhouse tomato plants. Proceedings of 15 th Annual Conference of Hydroponics Society of America, April 13-17, Akron, OH, USA.
- Biteli M, Salvatorelli F, Pisa PR (2007). Correction of TDR based soil water content measurements in conductive soils. *Geoderma*, 143(2008): 133-142.
- Cohen Y, Li Y (1996). Validating sap flow measurement in field grown sunflower and corn. *J. Exp. Bot.*, 47(304): 1699-1707.
- Dalton FN, Van Genuchten MTh (1986). The time-domain reflectometry method for measuring soil water content and salinity. *Geoderma*, 38: 237--250.
- Dogan E, Kirnak H, Copur O, Aydemir S (2005). Creation of irrigation program for cotton plant via kanched irrigation model. GAPIV. Agricultural Congress, Sanliurfa, Turkey, pp. 1110-1115.
- Ferre PA, Rudolph DL, Kachanoski RG (2000). Identifying the conditions amenable to the determination of solute concentrations with time domain reflectometry. *Water Resour. Res.*, 36: 633-636
- Idso SB, Jackson RD, Pinter PJ, Reginato RJ, Hatfield JL (1981). Normalizing the stress degree day Pparameter for environmental variability. *Agric. Meteorol.*, 24: 45-55.
- Inoue Y, Watanabe T, Kitamura K (2000). Prototype Time-Domain Reflectometry probes for measurement of moisture content near the soil surface for applications to " On -the- Move" measurements. *Agric. Water Manage.*, 50: 41-52.
- Kacira M (2000). Non-Contact and early detection of plant water stress using Infrared thermometry and image processing. Ph.D. Dissertation, The Ohio State University, Columbus, OH, USA.
- Laker MC, Boedt LJJ, Hensley M (1987). Pre-Dawn leaf water potential as an indicator of plant water stress with special reference to problems encountered under conditions of high evaporative demand. Proceedings of International Conference on Measurements of Soil and Plant Water Status, July 6-10, held in Logan, Utah, USA.
- Noborio K (2001). Measurement of soil water content and electrical conductivity by Time Domain Reflectometry: A Review. *Comput. Electron. Agric.*, 31(2001): 213-237.
- Osterhuis DM, Le Maire F, Le Maire C (1987). Leaf water potential and crop color change in water-stressed peas. *HortScience*, 22: 429-432.
- Rana G, Katerji N, Mastrorilli M (1998). Canopy resistance modelling for crops in contrasting water conditions. *Phys. Chem. Earth*, 23(4): 433-438.
- Schaap MG, Lange L, Heimovaara TJ (1996). TDR calibration of organic forest floor media. *Soil Technol.*, 11: 205-217.
- Sinclair TR, Hammond LC, Harrison J (1998). Extractable soil water and transpiration rate of soybean on sandy Soils. *Agron. J.*, 90: 363-368.
- Smith DM, Allen SJ; (1996). Measurement of sap flow in plant stems. *J. Exp. Bot.*, 47(305): 1833-1844
- Tanrıverdi Ç (2005). Using TDR in the agricultural water management. *Sci. Eng. J. Kahramanmaraş Sutcu Imam Univ.*, 8(2): 108-115
- Topp GC, Davis JL, Annan AP (1980). Electromagnetic determination of soil water content: Measurements in coaxial transmission lines. *Water Resour. Res.*, 16: 574-582.
- Turanlı M, Güri S (2000). Main Statistic. Der Publications. İstanbul, 730s.