Evaluation of different water content measurement methods to analyze soil water dynamics

Ventrella D., Castellini M., Di Giacomo E., Giglio L., Campi P., Palumbo A.D., Mastrorilli M.

in

Santini A. (ed.), Lamaddalena N. (ed.), Severino G. (ed.), Palladino M. (ed.).
Irrigation in Mediterranean agriculture: challenges and innovation for the next decades

Bari : CIHEAM
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 84

2008
pages 151-159

To cite this article / Pour citer cet article

Ventrella D., Castellini M., Di Giacomo E., Giglio L., Campi P., Palumbo A.D., Mastrorilli M. **Evaluation of different water content measurement methods to analyze soil water dynamics.** In : Santini A. (ed.), Lamaddalena N. (ed.), Severino G. (ed.), Palladino M. (ed.). *Irrigation in Mediterranean agriculture: challenges and innovation for the next decades.* Bari : CIHEAM, 2008. p. 151-159 (Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 84)

Evaluation of different water content measurement methods to analyze soil water dynamics

D. Ventrella, M. Castellini, E. Di Giacomo, L. Giglio,
P. Campi, A. D. Palumbo, M. Mastrorilli

CRA-SCA - Agricultural Research Council - Research unit for cropping systems
in dry environments of Bari, Italy

Abstract. Many agronomic and hydrological investigations depend on accurate measurement of soil water content (SWC). Accuracy, precision, facility and speed, including the capability to carry out measurements at different depths, are essential characteristics for monitoring SWC in the agronomical experiments. At the present, common systems use sensors based on capacitance (FDR) or time domain reflectometry (TDR) principles. Both the methods introduce advantages and disadvantages.

In the framework of AQUATER Project (Decision support systems to manage water resources at irrigation district level in Southern Italy using remote sensing information), the main objective of this study has been to monitor the SWC dynamics in a tomato (Foggia) and watermelon (Castellaneta - TA) field cultivations, both located in Southern Italy, by using: (1) the Diviner 2000 (Sentek Pty. Ltd., South Australia), (2) the TDR-100 (Campbell Sci. Shepshed, UK), (3) ThetaProbe Soil Moisture Sensor-ML2x (Delta-T Devices Ltd) and (4) the typical gravimetric methods.

In the field experiment of Foggia the SWC was continuously monitored (from the flowering stage until harvest time) by means of TDR probes installed at three depth (15, 30 and 45 cm). The probe signals were controlled by a TDR-100 (Campbell Sci. Shepshed, UK) and stored every hour in a CR1000 data logger. Moreover, SWC was measured with Diviner 2000 into five PVC access tubes vertically installed, by means of a portable probe (scanning length of 1.6 m) collecting reading at 10 cm depth intervals in soil profiles of 1.3 m. In the field of Castellaneta, on watermelon cultivation, the SWC was monitored by using TDR method and ThetaProbe with four 5-cm steel rods. The TDR probes were installed horizontally and vertically below the plant row and between crop rows. SWC has been continuously monitored and stored every hour into a CR10X. Moreover, for both the experiments, the SWC was also measured at two different depth (0-20 and 20-40 cm) with the typical thermo-gravimetric method.

The soil water dynamic was accurately individuated with the TDR methodology, while the DIVINER allowed to characterize the plant water uptake along the soil profile. However, accurate measurements of surface SWC were obtained by using the Thetaprobe sensor.

Keywords. Volumetric water content – Soil moisture sensors – TDR – FDR.

Évaluation de différentes méthodes de mesure de la teneur en eau pour analyser la dynamique de l'eau du sol

Résumé. *Plusieurs investigations agronomiques et hydrologiques dépendent de la mesure précise de la teneur en eau du sol (TES). L'exactitude, la précision, la facilité et la vitesse, y compris la possibilité d'effectuer des mesures à différentes profondeurs, sont des caractéristiques essentielles pour la surveillance de TES au niveau des expériences agronomiques. Actuellement, les systèmes communs utilisent des sondes basées sur les principes de la réflectométrie dans le domaine fréquentiel (FDR) ou de réflectométrie dans le domaine temporel (TDR), deux méthodes que présentent des avantages et des inconvénients.*

Dans le cadre du projet AQUATER (systèmes d'aide à la décision pour contrôler les ressources en eau des zones irriguées en Italie méridionale, utilisant l'information de télédétection), une étude a été mené en plein champ, dans la zone de l'Italie méridionale, son objectif principal été de surveiller la dynamique de TES de la culture de tomate (cultivé à Foggia) et de pastèque (à Castellaneta - TA), en utilisant: (1) le Diviner 2000 (Sentek Pty. Ltd., South Australia), (2) le TDR-100 (Campbell Sci. Shepshed, UK), (3) la sonde Thétaprobe ML2x (Delta-T Devices Ltd) et (4) les méthodes gravimétriques typiques.

Dans le champ expérimental de Foggia la TES a été surveillée d'une manière contenue (à partir de la phase de floraison jusqu'à la récolte) au moyen des sondes TDR insérées à trois profondeurs (15, 30 et 45 cm). Les signaux de sonde ont été commandés par le TDR-100 (Campbell Sci. Shepshed, UK) et stockés, chaque heure, grâce à un système d'acquisition de données CR1000. D'ailleurs, la TES a été mesurée avec le dispositif Diviner 2000 dans cinq tubes d'accès en PVC installés verticalement, au moyen d'une sonde portative (longueur de balayage de 1,6 m) rassemblant la lecture à des intervalles de profondeur de 10 cm le long d'un profils du sol de 1,3 m.

Sur la culture de pastèque, cultivée dans le champ de Castellaneta, la TES a été surveillée en employant la technique TDR et celle de Thétaprobe avec quatre tiges d'acier de 5 cm. Les sondes de TDR ont été installées horizontalement et verticalement sur la ligne, entre les plantes, et dans l'interligne. La TES a été surveillée sans interruption et les données ont été stocké chaque heure dans un CR10X.

En outre, pour les deux expériences, la TES a été également mesurée à deux profondeurs différentes (0-20 et 20-40 cm) avec la méthode thermogravimétrique typique.

La dynamique de l'eau du sol a été mesurée exactement avec la méthodologie de TDR, alors que le Devinier a permis de caractériser la captation des ressources en eau par la plante le long du profil du sol. Cependant, des mesures précises de la surface de TES ont été obtenues en utilisant la sonde de Thétaprobe.

Mots-clés. *Contenu volumétrique en eau – Sondes d'humidité du sol – TDR – FDR.*

I – Introduction

Many plant-soil-water and hydrological investigations depend on accurate measurement of SWC. The field-measurements of soil water content (SWC) are of fundamental importance to study the soil water balance with particular reference to several components like the plant water uptake, the infiltration, the water re-distribution in the soil profile and the capillary rise.

In general, accurate measurements of the lower limit (also known as the permanent wilting point, PWP) and the drained upper limit (also known as the field capacity, FC) are required to estimate the totally or readily available soil water as critical inputs required by hydrological models base on simplified balance approaches.

However, some techniques, as irrigation deficit and drip irrigation, require great accuracy of soil water measurements in order to obtain high values of water use efficiency. SWC of shallow soil layers are very crucial also for hydrological study based on remote sensing information.

Figure 1. The six farms monitored in the study.

Accuracy, precision, facility and speed, including the capability to carry out measurements at different depths, are essential characteristics for monitoring the SWC in the agronomical experiments and applications.

Common systems actually use, mainly, sensors based on capacitance (frequency domain reflectrometry, FDR) or time domain reflectometry (TDR) principles. The FDR sensors use an oscillator to generate an AC field applied to the soil for detecting changes in soil dielectric properties linked to variations in SWC. Capacitance sensors consist essentially of a pair of electrodes which form a capacitor with the soil detecting changes in the operating frequency as influenced by variations in SWC. The theory has been discussed in Dean *et al.* 1987. In particular, the Diviner 2000, a capacitance probe, uses the same SWC sensing technology as the EnviroSCAN (Sentek Pty. Ltd., South Australia). It's a portable system designed to be moved from site to site and it's consists of one capacitance sensor at the end of a rod. As the rod is passed down the access tube the handheld display unit automatically records the SWC at each 10 cm depth increment.

Table 1. Experimental layouts

F arm	**TDR probes**		
	Geometric configuration	**Characteristics**	**Position**
F1	horizontal position at depths of 15, 30 and 45 cm	three-rod (25 cm long)	interrow
F2	vertical position at 0, 15, 30 and 60 cm from the row	three-rod (25 cm long)	row and interrow
F3	horizontal position at depths of 10-30-50-70 cm ; vertical position in the interrow	five-rod (15 cm long)	row

TDR determines the dielectric permittivity of a medium by measuring the time it takes for an electromagnetic wave to propagate along a transmission line that is surrounded by the medium. The transit time for an electromagnetic pulse to travel the length of a transmission line and return is related to the dielectric permittivity of the medium, κ, proportional to the square of the transit time. The time and speed of travel of reflected signal from the end of the probe varies with the dielectric of the soil, which is related to the water content of the soil. The theory and the relationship between κ and the volumetric SWC is described in detail in Topp *et al.* (1980).

In order to monitor the surface SWC, we also used the Moisture Meter Type HH2 with a ThetaProbe Soil Moisture Sensor-ML2x (Delta-T Devices Ltd), hereafter referred to as ThetaProbe. This probe provides a measure of the superficial volumetric SWC (about 60-70 mm in depth), by the well established method of responding to changes in the apparent dielectric constant. These changes are converted into a DC voltage, virtually proportional to soil moisture content over a wide working range. The pins act as a transmission line and detect changes in the soil's dielectric constant by monitoring changes in the way radio frequency energy is transmitted into and reflected by the soil. Handheld display is available and outputs either raw voltage readings or volumetric water content using the two generalised calibrations. For particular soils, a specific calibrations is recommended to achieve an high accuracy. The probe can be either inserted into the soil surface to make one-off readings or buried for continual in situ readings. In order to obtain distributed measurements of surface SWC, we have chosen the first approach.

The Diviner 2000 presents some potential limitations and the measurements are very sensitive to access tube installation. An accurate soil water measurement based into a previously installed PVC access tube and requires careful installation procedure, to prevent formation of air gaps along the sensor or alteration of soil properties within the sensor's zone of influence (approximately, 10 cm in length along the axis of the probe). Moreover, the effect of salinity is still unclear. To the opposite, it's an economical method for covering many sites and it allows a rapid and easy

SWC measurement; compared to TDR method, no specific knowledge of analysing wave-forms is required.

TDR method provides important advantages as accurate and continuous measurements, no need for calibration, relatively insensitive to salinity. However, present some limitations because of complex electronics and high cost.

In the framework of AQUATER Project (Decision support systems to manage water resources at irrigation district level in Southern Italy using remote sensing information), the main objective of this study has been to monitor the SWC dynamics in a tomato (Foggia) and watermelon (Castellaneta - TA) field cultivations located in Southern Italy, by using: (i) the Diviner 2000, (ii) time domain reflectometry (TDR), (iii) ThetaProbe and (iv) the typical gravimetric methods.

II – Materials and methods

The data used in this paper came from field monitoring of 2006 and 2007 carried out in order to link the soil/plant water status to satellite information. In general, the SWC has been continuously monitored by means of TDR, while the other methods were applied at every satellite over passing.

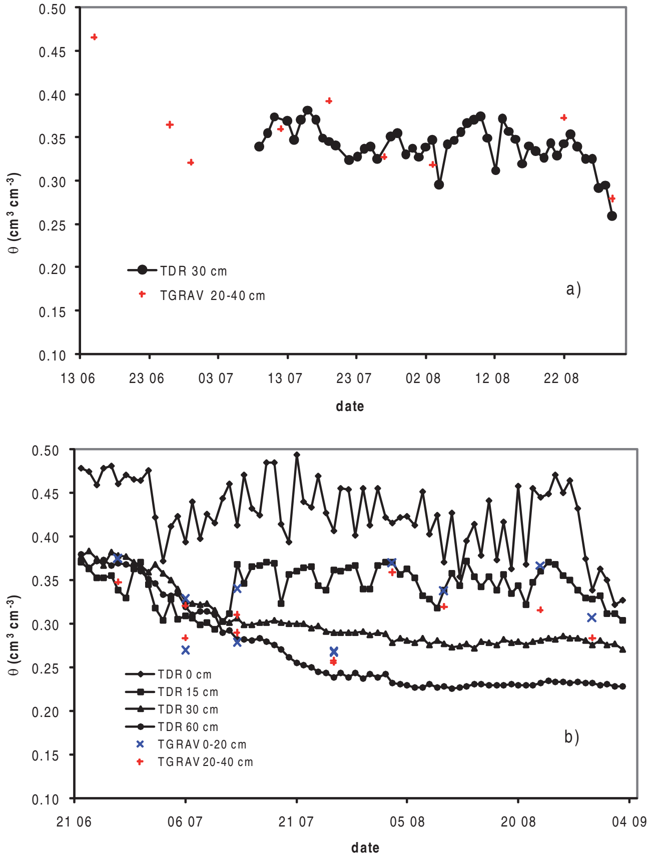

Figure 2. Variation of soil water content, θ, observed in F1 (top) and F2 (bottom) farms with both TDR and thermo-gravimetric method (TGRAV) during the tomato growing season.

A field experiment has been carried out in two farms located in Foggia (F1 and F2), in the Northern part of Puglia region (Southern Italy), and related to cultivation of tomato (Fig. 1). In these farms, the SWC was continuously monitored, from the flowering stage until harvest time, applying the TDR method described in Table 1 that reports the details of the experimental set-up, i.e. the probe geometric configuration, the characteristics and the position (row or interrow).

The probe signals were controlled by a TDR-100 (Campbell Sci. Shepshed, UK) and stored every hour in a CR1000 data logger.

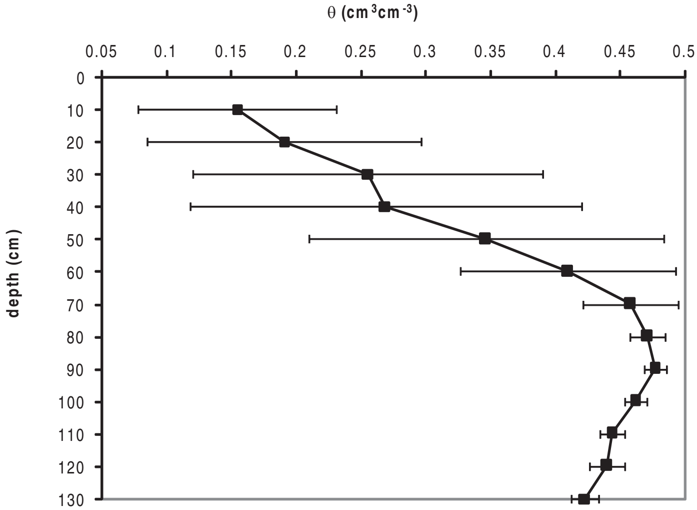

Figure 3. Variability of soil water content, q, during the tomato growing season, along the soil profile (0-130 cm), observed in F1 farm. Bars indicate standard deviation.

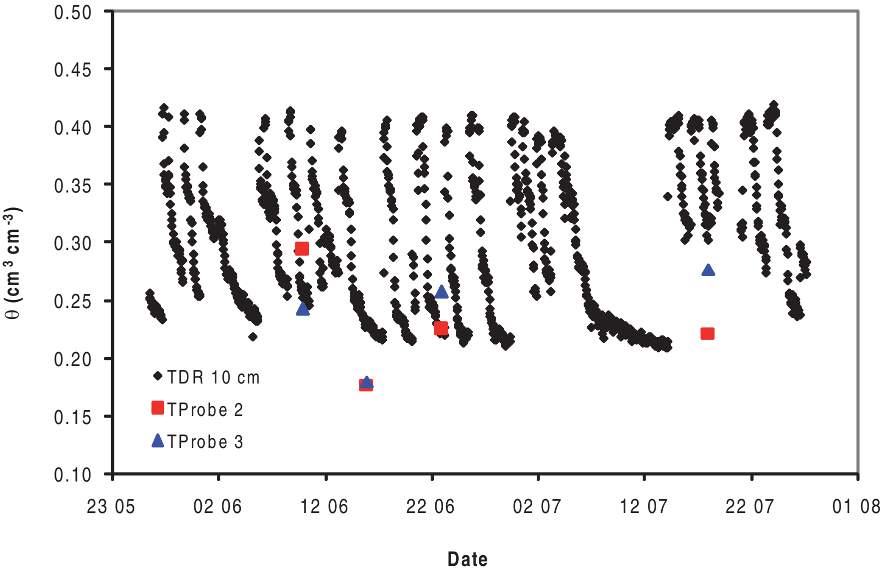

Figure 4. Variation of soil water content, θ, observed in F3 farm with both TDR and ThetaProbe (TProbe), under plastic mulch, during the watermelon growing season (2006).

Moreover, the SWC was also measured by means of Diviner 2000 with five PVC access tubes vertically installed in the soil, by using a portable probe (scanning length of 1.6 m) collecting reading at 10 cm depth intervals in soil profiles of 1.3 m. In the field, the access tubes were installed on crop rows.

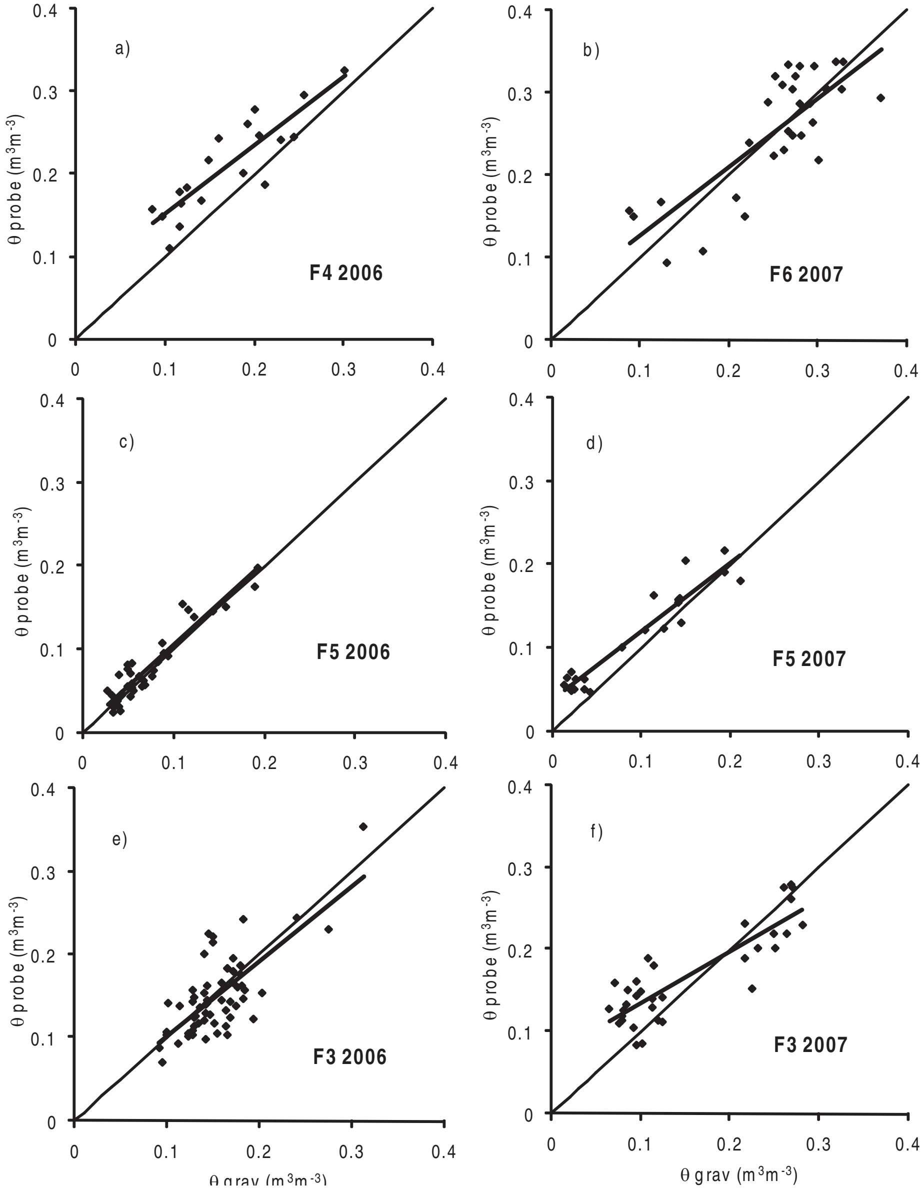

Figure 5. Comparison between the soil water content obtained with ThetaProbe (θ probe) and thermo-gravimetric (θ grav) method for each considered farm.

Another field experiment has been carried out in a farm (F3) located in Castellaneta (TA) close to the Jonical coastal area of Puglia region, on watermelon cultivation. SWC has been continuously monitored, along the soil profile, by using TDR method and stored every hour into a CR10X. The set-up of the TDR probes is described in Table 1.

Moreover the SWC of the shallowest layer of 5 cm was measured using ThetaProbe. For every measurement the probe was inserted into the soil surface on the plant row under the plastic mulch used by farmer in order to prevent the weed growth.

Finally, in order to estimate the volumetric SWC and bulk density by thermo-gravimetric method, undisturbed soil samples (steel cylinders with D=5 cm and H=5 cm) were collected from the surface layer of soil. The samples were weighed and dried in a ventilated oven at 105°C, until constant weight. For each undisturbed soil sample, four measurements were carried out by inserting, vertically in the soil, the ThetaProbe around the sampling points. This "calibration procedure" of ThetaProbe was also applied in other three farms localized in Jonical coastal plain ((F4, F5 and F6).

Moreover, for both of the field experiments, the SWC was also measured at two different depth (0-20 and 20-40 cm) with the typical thermo-gravimetric methods.

Water content estimates from ThetaProbe were compared with those obtained with the thermo-gravimetric method. For this purpose a systematic regression analysis, utilizing the SAS (1988) package, was performed by site and year testing three hypotheses concerning the coefficient of determination (R^2), the intercept (a=0) and slope (b=1).

III – Results and discussion

Figure 2 shows the dynamics of SWC as measured by TDR in two farms compared to measurements obtained in several days with the thermo-gravimetric method. Even if the comparison is not homogeneous, because of different soil sample volumes, it is possible observe a qualitatively good agreement among the two methods with one exception (i.e. in July 19, we observed a difference of 0.044 $m^3 m^{-3}$).

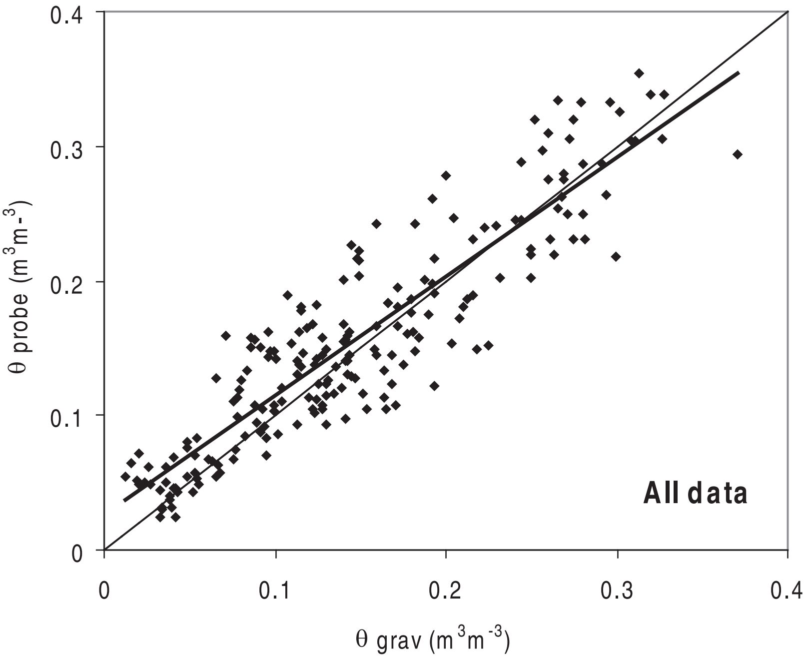

Figure 6. Comparison between the soil water content obtained with ThetaProbe (θ probe) and thermo-gravimetric (θ grav) method.

Below the dripper lines, the surface layer presented the largest temporal fluctuations due to irrigations, soil evaporation and plant water uptake. However in the interrow positions the SWC gradually decreased up to be constant beginning from the end of July around values of 0.25 and 0.30 at 30 and 60 cm from the plant-row, respectively.

Figure 3 reports the variability of SWC observed during the tomato crop season along the soil profile as observed by means of Diviner 2000. As expected, large differences in terms of standard deviation (corresponding to eight different measurements), were observed during the crop season in the topsoil (about 0-50 cm) and relatively constant water content below 90 cm.

In figure 4 we report the temporal variations of surface SWC measured at hourly scale by means of TDR during the watermelon growing season. In the same diagram we also show the ThetaProbe measurements carried out under plastic mulch. Several discrepancies (more than 0.05 m^3 m^{-3}) were detected on June 16 and July 18.

The results of the comparison between the Theaprobe instrument and thermo-gravimetric method are reported in Fig. 5 and 6 with the regression analysis statistics shown in Table 2. For any combination of year and site, the relationship among the two methods has been always highly significant with coefficients of determination, R^2, higher than 0.74 in four data-set on 6. Considering all the data in a pooled analysis, the R^2 was higher than 0.8 with a root mean square error of 0.03.

Table 2. Number of data points (N), intercept (a), slope (b) and coefficient of determination (R^2) of the linear regression analysis among the SWC measured with ThetaProbe and thermo-gravimetric methods

	N	**a**	**b**	**R^2**
Farm		**2006**		
F3	59	0.010 ns	0.907 ns	0.54***
F4	19	0.068**	0.833 ns	0.77***
F5	39	0.006 ns	0.990 ns	0.89***
		2007		
F3	33	0.072***	0.627***	0.74***
F5	22	0.038***	0.820 **	0.90***
F6	31	0.045 ns	0.831 ns	0.64***
All data	203	0.026***	0.885***	0.82***

Symbols: ns=not significant; *,**,***=significant at P<0.5, 0.01 and 0.001. a Significantly different from 0 (P=0.05). The tested hypothesis about intercept and slope are a=0 e b=1, respectively.

The intercept values, a, were close to 0 even if in three data-set the deviations from 0 were significant . However in four cases on six the coefficient b was significantly not different from the optimal value of 1.

IV – Conclusion

With the TDR it was possible to characterize with high precision the temporal evolution of the SWC at hourly and daily scale. Because of soil water fluxes of infiltration, redistribution in soil profile, evaporation and plant water uptake, in the shallow layer and below the dripper lines, we detected the largest fluctuation that were damped down on depth. In interrow position, the SWC stayed low and almost constant.

The DIVINER instrument proved to be an useful tool to estimate the soil water status along the profile giving important indication about the vertical root concentration. Thanks also to its low cost, the tool can usefully be employed for irrigation scheduling.

Finally, by means of ThetaProbe the shallow SWC was measured with precision and accuracy as demonstrated by the good results obtained with the regression analysis performed to compare the measurements of this instrument with the traditional thermo-gravimetric method. However, our data indicate that deviations from the line 1:1 can be significant and consequently preliminary calibration procedures have to be recommended if absolute values of SWC are required. In any case the TetaProbe is a very useful tool for studies and/or applications concerning the SWC estimation by remote sensing information.

Acknowledgements

This work was supported by the Italian Ministry of Agriculture, Food and Forestry Policies (AQUATER project, contract nr. 209/7303/05).

References

Dean, T. J., Bell, J.P., Baty, A.J.B., 1987. Soil moisture measurement by an improved capacitance technique, Part I. Sensor design and performance. *J Hydrol*, 93, 1-2. pp. 67-78.

SAS Institute, 1988. *SAS/STAT Users' Guide, Release 6.03 Edition*. Cary, NC: SAS Institute. 1028 p.

Topp, G.C., Davis, J.L., Annan, A.P., 1980. Electromagnetic determination of SWC: measurements in coaxial transmission lines. *Water Resour Res*, 16. pp. 574-582.