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Calibration equations for two capacitance water content probes

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A b s t r a c t. This paper presents the calibration equations of two capacitance probes for monitoring the soil water content in a lysimeter field. Capacitance probes provide readings at desired depths and time intervals. The calibration equations are derived by regression analysis between measurements of scaled frequency and volumetric soil water content. The calibration equations are compared with the manufacturer default equations to estimate the irrigation water depth. The accuracy of capacitance probes in monitoring soil water content increased by using the site-specific calibration equations rather than the manufacturer default equation.

K e y w o r d s: capacitance probes, calibration equations, soil water content, Diviner 2000, EnviroScan

INTRODUCTION

Continuous monitoring of soil water content (θ_v) within and below the rooting zone can facilitate optimal irrigation scheduling aimed at minimizing both the effects of water stress on the plants and also the leaching of water below the root zone (Fares and Alva, 2000). Also, irrigation scheduling requires accurate measurements of soil water content. These measurements can be accomplished with direct or indirect methods. The most common direct method to measure soil water content is the gravimetric method. Soil water content using indirect methods is determined from the physical properties of soil *eg* dielectric constant. These properties are measured with installed probes or through the movement of floating probes inside special tubes, which are permanently placed in the soil. The indirect methods are used for monitoring soil water content simultaneously and continuously on the same point with no soil disturbance. Amongst the most widespread indirect methods are the methods of dielectric constant, neutron probe, electrical resistivity tomography and thermal conductivity probe. The method of dielectric constant includes the capacitance method, the Time Domain Reflectometry (TDR) and the Frequency-Domain Reflectometry (FDR) (Gardner *et al*., 1991; Topp *et al*., 1980). The theory behind the technique of dielectric constant and reviews of capacitance methods have been presented by Dean *et al*. (1987) and Paltineanu and Starr (1997).

In this paper the FDR technology is used to determine the soil water content in a lysimeter field in which two capacitance probes (EnviroScan and Diviner 2000) by Sentek Pty Ltd. (Sentek, 2006; 2007) are installed.

The use of these soil water content probes requires site-specific calibration. Each probe comes with general calibration equations, which are sampled from a variety of soil textures. Specifically for the EnviroScan and the Diviner 2000, the manufacturer default equations derive from an average of three soil materials (sands, loams and clay loams) and provide relevant measurements of soil water content. The measurements resulting from these equations are inaccurate and often overestimate the soil water content (Leib *et al*., 2003; Starr and Paltineanu, 1998) or, in the case of light soil, underestimate it (Morgan *et al*., 1999).

The proposed manufacturer calibration procedure for the EnviroScan and the Diviner 2000 (Sentek, 2001) is painstaking and damages the soil structure. This led the scientists to use either laboratory or field methods to obtain calibration equations with less destructive effect to the soil. Many times they also use literature calibration equations.

Among the first papers concerning the Sentek soil water content probes, is the one conducted by the U.S.D.A. (Mead *et al*., 1995). This paper involved the calibration and sensitivity analysis of the EnviroScan probe, to salinity and bulk density changes. It also presented a laboratory method for

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the calibration of three soil types: a light (coarse sand), two medium (sandy loam with two bulk densities) and a heavy soil (clay). The calibration showed significant differences even within the two medium soil textures, which only differ in bulk density.

Morgan *et al*. (1999) calibrated the EnviroScan probe to three sandy soils in Florida, USA with very satisfactory coefficients of determination (R^2=0.83). They also compared their equation with the manufacturer default equation and concluded that the latter underestimates the soil water content in these soil types.

Evett *et al*. (2002), calibrated in Austria the Diviner 2000 for two soils (silty clay loam and silt loam) and presented a wide range of data and calibration equations with relatively low coefficients of determination (R^2=0.533 and R^2=0.416, respectively). Geesing *et al*. (2004) calibrated the Diviner 2000 probe for two soil types (silt-loamy Cambisol and loamy Cambisol) and presented an equation with a relatively high coefficient of determination (R^2=0.78) compared with the large number of samples (*n*=282). In the same paper, they compared their equation to the equations of Morgan *et al*. (1999) and Paltineanu and Starr (1997) the manufacturer default equation.

Groves and Rose (2004) proposed a laboratory calibration method of the Diviner 2000 probe. They derived new calibration equations with high coefficients of determination (R^2>0.93) for five topsoils and one subsoil, including soils with a high organic matter content.

Pasturel (2004) and Reinhard (2005) compared the measurements of the Diviner 2000 and a neutron probe, in loamy soils. They calibrated the probes and compared their equations to those of Evett *et al*. (2002), Groves and Rose (2004) and the manufacturer default equation. Finally, they mention that the problems are caused in loamy soils from cracks created by the swelling and shrinking of clay minerals, thus changing the measurement of the air from the probe.

Jabro *et al*. (2005) calibrated the EnviroScan probe through the measurements by a calibrated neutron probe rather than gravimetric soil water content samples in a silt loam and alfalfa cultivation. At the same time they compared the soil water content levels with the factory equation, for the next two seasons of cultivation, confirming the differences between these values. The calibration of the probe was achieved with 31 measurements by the neutron probe with very good coefficient of determination (R^2=0.96).

Burgess *et al*. (2006) calibrated and compared the measurements for the Diviner 2000 and neutron probes in loamy soils. To calibrate the Diviner 2000 probe they followed the method suggested by the manufacturer. The comparison of the results after the calibration showed that the two probes have similar accuracy.

Evett *et al*. (2006) evaluated several types of soil moisture sensors. In laboratory columns of three soils (silt loam, loam and clay) they calibrated and compared the EnviroScan and the Diviner 2000 probes with other soil moisture sensors. The calibration of the EnviroScan probe was achieved with 268 soil samples and the calibration of Diviner 2000 was achieved with 528 measurements. Both calibrations had very good coefficient of determination (R^2>0.99).

Starr and Rowland (2007) compared the volumetric soil water content levels and scaled frequencies of EnviroScan and Diviner 2000 probes. The comparison was made in 48 PVC tubes in three different soils and resulted in two linear relationships with very satisfactory coefficients of determination (R^2>0.98).

Guber *et al*. (2010) developed a correction of the original calibration equations of EnviroScan probe in order to remove the systematic errors. The depth-specific linear transformation of the factory calibration improved the estimation of plot-average at all observations depths.

Gabriel *et al.* (2010) calibrated the EnviroScan probe using a laboratory and a field method for loamy soils. The two methods gave calibration equations with very satisfactory coefficients of determination (R^2=0.96 and 0.92, respectively) and the equations derived gave very similar results. The results of both equations diverged significantly from the manufacturer default equation.

A summary of the literature calibration equations described in this paragraph is shown in Table 1. The probe which was calibrated (EnviroScan, E/Diviner 2000, D), the soil texture, the organic matter and the bulk density of samples are shown in this Table. Furthermore, the table also shows the type of calibration (Laboratory, Lab/Field, Fld), the number of samples used (*n*), and the coefficients of determination R^2 for two forms of the calibration equations:

$$SF = a\theta_v^b + c \text{ and } \theta_v = A\ SF^B + C,$$

where: θ_v – volumetric soil water content, *SF* – scaled frequency and *a, b, c, A, B* and *C* calibration coefficients.

The objectives of this paper are:

– calibration of the EnviroScan and the Diviner 2000 capacitance probes for two soil textures in a lysimeter field and
– comparison of the calibration equations with the manufacturer default equations and with literature calibration equation in monitoring soil water content.

MATERIALS AND METHODS

The capacitance probes used in this study are the Diviner 2000 and the EnviroScan (Sentek, 2006; 2007) which use a similar measurement technique. These probes use Frequency-Domain Reflectometry (FDR) technology and have an operating frequency of 100 MHz.

For the measurement of soil water content the installation of PVC tubes into the soil is needed. Both probes take measurements every 10 cm depth with a radius of influence of 5 cm.

Diviner 2000 (Sentek, 2007) is a portable probe for measuring soil water content. The measurement is accomplished by inserting the probe in the PVC tube. The probe slides into the tube with the aid of the user. The probe takes two measurements of soil water content per 10 cm, one during descending and one during ascending. The average of these measurements is stored in the probe data logger.

T a b l e 1. Soil texture, organic matter, bulk density (ρ_b) of samples, number of samples (*n*), calibration equations and coefficients of determination (R^2) for the two capacitance probes (EnviroScan and Diviner 2000) for different calibration procedures from literature

Source	Sand	Silt	Clay	Organic matter	Soil texture	ρ_b (g cm^{-3})	R^2	$SF = a\theta_v^b + c$ or $\theta_v = A\ SF^B + C$		
	(%)							α or A	b or B	c or C
Manufacturer (Sentek 2001) (E, D, Fld)	-	-	-	-	Sands, loams, clay loams	-	0.974	0.1957	0.404	0.02852
	-	-	-	-	Sands, sandy loams, clay	-	0.998	0.2746	0.3314	0
	-	-	-	-	Uniformly textured cracking clay (0-100 cm)	-	0.500	0.0254	1	-0.125 (10) -0.020 (20) -0.074 (30) -0.030 (40) -0.004 (50) 0.031 (60) 0.011 (70) 0.029 (80) 0.041(100)
Mead *et al*. (1995) (E, Lab), *n*=40	100	0	0	-	Sand	1.3	0.987	0.17	1	0.268
	59	22	19	-	Sandy loam	1.3	0.965	0.013	1	0.326
	59	22	19	-	Sandy loam	1.5	0.987	0.013	1	0.372
	16	35	49	-	Clay	1.01	0.979	0.012	1	0.146
Platineanu and Starr (1997) (E, Lab) *n*=15	35	56	9	0.08 g kg^{-1}	Silt loam	1.24-1.58	0.992	0.5512	0.2582	-0.5272
Morgan *et al*. (1999) (E, Fld)	>95	-	-	-	Sand	-	0.831	1.455	0.471	0
Evett *et al*. (2002) (D, Fld)	-	-	-	-	Silt loam (0-60, 100-120 cm) Silty clay loam (60-100, 120-135 cm)	-	0.533	0.567	5.276	0.039
	-	-	-	-	Silt loam (0-80, 100-140 cm) Silt (80-100 cm)	-	0.416	1.94	0.326	-1.56

Table 1. Continuation

Source	Sand	Silt	Clay	Organic matter (%)	Soil texture	ρ_b (g cm^{-3})	R^2	$SF = a\theta_v^b + c$ or $\theta_v = A\ SF^B + C$		
	(%)							α or A	b or B	c or C
Geesing *et al*. (2004) (D, Fld) *n*=140, 142	32.9±8.1	46.8±6.3	20.4±2.6	-	Silt-loamy, Cambisol (0-30, 30-60, 60-90 cm, respectively)	1.51-1.56	0.93	1.360	0.468	0
	32.7±10.5	46.3±7.9	20.9±3.4	-						
	20.8±7.6	53.0±4.4	26.2±5.9	-						
	46.5±9.4	37.2±5.3	16.3±4.8	-	Loamy, Cambisol (0-30, 30-60, 60-90 cm, respectively)	1.64-1.68	0.88	1.770	0.516	0
	47.6±18.8	33.2±13.4	19.2±7.5	-						
	43.6±23.9	34.6±15.2	21.8±11.0	-						
Groves and Rose (2004) (D, Lab) *n*=15	91	4	5	0.34	Sand	1.58±0.10	0.97	0.2162	0.4149	0
	78	10	12	0.96	Sandy loam	1.44±0.1	0.97	0.2532	0.3628	0
	47	22	31	2.13	Silty clay loam	1.39±0.08	0.96	0.3531	0.2621	0
	37	19	44	3.59	Clay	1.09±0.07	0.93	0.3107	0.2966	0
	60	16	24	12.9	Organic sandy clay loam	1.02±0.08	0.97	0.1765	0.4434	0
	29	29	42	19.3	Organic-mineral soil	0.83±0.14	0.97	0.2161	0.3785	0
Jabro *et al*. (2005) (E, Lab) *n*=31	44	53	3	-	Silt loams	1.45-1.65	0.96	$\theta_v = K\ e^{LSF}$		
								K=0.0034		L=26.592
Reinhard (2005) (D, Fld) *n*=16	19	25	54	-	Clay	1.3	0.81	0.4754	0.4185	0
Burgess *et al.* (2006) (D, Fld) *n*=15	19	26	55	-	Clay	1.3	0.81	0.4750	0.4180	0
Evett *et al*. (2006) (E, D, Lab)	17	53	30	-	Silty clay loam (*n*=178)	1.42	0.99	0.605	3.812	0.024
	13	39	48	-	Clay (*n*=178)	1.45				
	25	40	35	-	Clay loam (*n*=90)	1.41	0.99	0.781	4.981	0.041
	17	53	30	-	Silty clay loam (n=336)	1.42	0.99	0.457	5.421	0.034
	13	39	48	-	Clay (*n*=336)	1.45				
	25	40	35	-	Clay loam (*n*=192)	1.41	0.99	0.563	6.182	0.028
Gabriel *et al*. (2010) (E, Lab, Fld)	25±1	49±3	26±3	1.27-1.85	Loam (*n*=4)	1.23-1.44	0.96	0.478 or 0.482	3.303 or 3.097	0.010 or 0
					Loam (*n*=16)	1.24-1.69	0.92	0.444 or 0.443	3.049 or 2.536	0.027 or 0

EnviroScan (Sentek, 2006) is a multisensor capacitance probe. It consists of ten capacitance sensors that are placed one above the other. The EnviroScan probe remains in the PVC tube for the measurement period. The extra feature of this probe, comparing to the Diviner 2000, is that it can measure soil water content at regular time intervals defined by the user. Along with the probe installation, a data logger and a solar panel are installed. The solar panel helps maintaining the data in the data logger and also powers the probe.

The probes measure the frequency in soil (F_s) that depends selectively on the soil dielectric constant and later this frequency is used to determine the scaled frequency (*SF*):

$$SF = (F_a - F_s) / (F_a - F_w), \tag{1}$$

where: F_w is the frequency readings from each probe inside the tube exposed in a 200 l tank filled with water at 22°C, F_a is the frequency readings from each probe inside the tube exposed to air.

The transformation of scaled frequency (*SF*) to volumetric soil water content (θ_v) is done by the equation:

$$SF = a\theta_v^b + c \Leftrightarrow \theta_v = \sqrt[b]{(SF - c)/a}, \tag{2}$$

where: a, b, c are calibration coefficients.

The two lysimeters in which the two soil water content probes were installed, are located in Sindos, Thessaloniki, Greece, and specifically in the Land Reclamation Institute of the National Agricultural Research Foundation of Greece (22°48'16.93"N, 40°41'20.77"E). Each of the two free drainage lysimeters (disturbed soil profiles) have a depth of 90 cm, and a surface area of 4 m^2. The two lysimeters were installed in an irrigated field cultivated with cotton. In the center of each lysimeter, one PVC access tube was installed. In the first lysimeter the soil water content was measured with the Diviner 2000 probe and in the second lysimeter the soil water content was measured with the EnviroScan probe. The soil texture and the bulk density of the lysimeter soil at different depth are shown in Table 2.

The manufacturer proposed probe calibration procedure would be impossible to implement in the lysimeters, because it would lead to destruction of their soils. For this reason, an alternative field calibration method was chosen, similar to those followed in the literature (Geesing *et al*., 2004; Reinhard, 2005), and with the least possible disturbance of the soil profile. According to this method samples were taken every 10 cm around each access tube and the soil water content was measured gravimetrically in three conditions *ie* dry, average and wet. The samples were taken within a radius of 20-30 cm around each access tube, which is beyond the sphere of influence of the probe, but capable of being regarded as a representative measurement of the soil water content in each lysimeter. These samples were placed in a drying oven (105°C) for 24 h. Along with the gravimetric sampling, the soil water content was also measured by the probes.

RESULTS AND DISCUSSION

The coefficients a, b and c of Eq. (2) were determined by nonlinear regression. The value of the coefficient c was very low and was omitted for easy conversion of $SF = a\theta_v^b$ into the equation $\theta_v = A\ SF^B$ where $A=(1/a)^{1/b}$ and B=1/b. Figures 1 and 2 present the calibration equation for each soil layer. For each lysimeter a calibration equation for the whole profile was also estimated.

The calibration results are presented in Tables 3 and 4. Along with the coefficients a, b for the Diviner 2000 and the EnviroScan probes, the coefficients of determination (R^2) are presented for each layer and also for the whole soil profile. Coefficients of determination for the calibration equations for each soil layer of Diviner 2000 ranged from 0.812 to 0.961 indicating that the calibration accuracy was very good resulting in accurate determination of soil water content. Coefficients of determination for the calibration equations for each soil layer of the EnviroScan ranged from 0.868 to 0.992 indicating that the calibration accuracy was also very good. Specifically for the EnviroScan probe (due to the similar soil texture of all three layers) the calibration equation of the soil profile is considered very good (R^2=0.890). In contrast, for the calibration of the Diviner 2000, the coefficient of determination of the calibration

T a b l e 2. Soil texture and bulk density (ρ_b) of the lysimeter soil at different depth

Site (Probe)	Soil depth (cm)	Sand	Silt	Clay	Soil texture	ρ_b (g cm^{-3})
			(%)			
Lysimeter 1 (Diviner 2000)	0-30	31.2	40.8	28.0	Clay loam	1.043
	30-60	35.6	38.4	26.0	Loam	1.220
	60-90	43.2	32.4	24.4	Loam	1.228
Lysimeter 2 (EnviroScan)	0-30	39.2	36.0	24.8	Loam	1.083
	30-65	41.2	32.0	26.8	Loam	1.296
	65-90	45.2	36.0	18.8	Loam	1.112

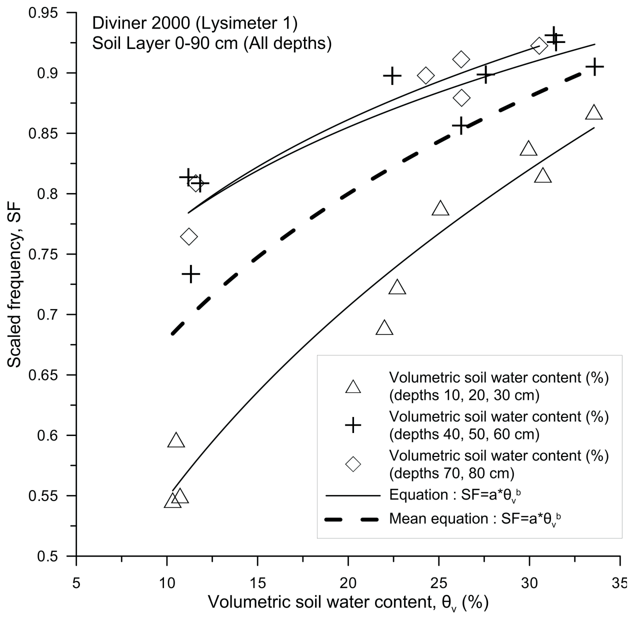

Fig. 1. Calibration equations for different soil layers and for the whole soil profile for the Diviner 2000 probe in lysimeter 1.

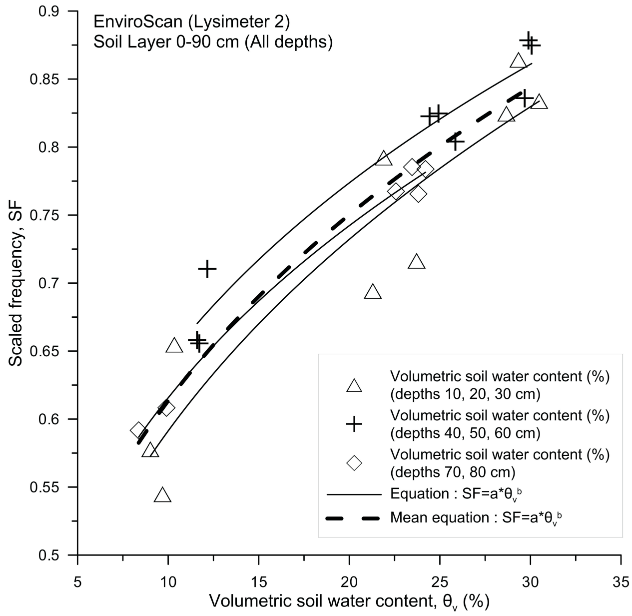

Fig. 2. Calibration equations for different soil layers and for the whole soil profile for the EnviroScan probe in lysimeter 2.

T a b l e 3. Calibration equations and coefficients of determination for different soil layers and soil profile and manufacturer default equation for Diviner 2000 probe in lysimeter 1

Coefficient	Calibration equation for soil layer (cm)			Calibration equation for the soil profile 0-90 cm	Manufacturer default equation
	0-30	30-60	60-90		
a	0.2352	0.5474	0.5313	0.3942	0.2746
b	0.3672	0.1489	0.1613	0.2363	0.3314
c	0	0	0	0	0
R^2	0.9610	0.8120	0.9280	0.5300	

T a b l e 4. Calibration equations and coefficients of determination for different soil layers and soil profile and manufacturer default equation for EnviroScan probe in lysimeter 2

Coefficient	Calibration equation for soil layer (cm)			Calibration equation for the soil profile 0-90 cm	Manufacturer default equation
	0-30	30-65	65-90		
a	0.2908	0.3514	0.3308	0.3143	0.1957
b	0.3082	0.2634	0.2698	0.2904	0.4040
c	0	0	0	0	0.02852
R^2	0.8680	0.9490	0.9920	0.8900	

equation for the whole soil profile was very low (R^2=0.530), due to the alteration of the surface layer (Clay loam) compared to the other layers which are of loam soil texture.

The calibration equations for each soil texture are presented in Table 5. The number of the samples (n) and the coefficient of determination (R^2) are also shown in the table. It is noticed that the Diviner 2000 probe was calibrated for two soil textures *ie* clay loam and loam. They correspond to the first soil layer (0-30 cm) and the two subsequent soil layers (30-60 and 60-90 cm) of the lysimeter 1 (Table 2). The coefficient of determination for the loam soil texture using 15 soil samples is R^2=0.850. The value of the coefficient of determination for the clay loam soil texture is higher (R^2=0.961), but this could be attributed to the smaller number of samples (*n*=9). The EnviroScan probe was calibrated using all the samples (*n*=24) obtained from the lysimeter 2 which were of a loam soil texture. In this case the coefficient of determination was very good (R^2=0.890).

The calibration equations for the clay loam and loam soil textures of the lysimeter 1 (Diviner 2000 probe) and of the loam soil texture of the lysimeter 2 (EnviroScan probe) are shown graphically in Fig. 3 along with the manufacture default equation. The site-specific calibration equation of the EnviroScan probe is also compared with the equation of Gabriel *et al.* (2010) which was also obtained with the same probe in a loam soil texture. As shown, the equation of Gabriel *et al.* (2010) is almost identical for low values of soil water content, to the equation obtained in this paper and varies slightly for high values of soil water content.

The calibration equations obtained in this paper were used to compute the water depths of a number of irrigations events applied in the two lysimeters. Table 6 shows the irrigations of 63.5, 69.3 and 69.3 mm applied to the lysimeter 1 at 25/6/2007, 25/7/2007 and 23/8/2007, respectively. The water content of the whole soil profile was estimated before and after each irrigation event with the site-specific equation obtained in this paper for the Diviner 2000 probe and with the manufacturer default equation. It is shown that the absolute errors obtained with the calibration equation vary from 0.4 to 4% while the errors obtained with the default equations vary between 7.4 and 10.4%.

Table 7 shows the irrigations of 63.5 and 69.3 mm applied to the lysimeter 2 at 19/7/2007 and 23/8/2007, respectively. As in Table 6 the water content of the whole soil profile before and after each irrigation event was estimated with the site-specific equation obtained in this paper for the Enviro Scan probe and with the manufacturer default equation. For the same reason, the equation of Gabriel *et al.* (2010) is also applied. It is shown that the absolute errors obtained with the calibration equation vary between 2.9 and 4.8% while the errors obtained with the default equation vary between 4.5 and 10.2% and with the equation of Gabriel *et al.* (2010) vary between 12.3 to 15.4%.

T a b l e 5. Soil texture, bulk density (ρ_b), number of samples (*n*), calibration equations and coefficients of determination (R^2) for the two capacitance probes (Diviner 2000 and EnviroScan)

Probe	Soil texture	Sand	Silt	Clay	ρ_b	n	R^2	$SF = a\theta_v^b + c$		
			(%)					a	b	c
Diviner 2000	Clay loam	31.2	40.8	28.0	1.043	9	0.961	0.2352	0.3672	0
	Loam	39.4±3.8	35.4±3	25.2±0.8	1.224±0.004	15	0.850	0.5427	0.1527	0
EnviroScan	Loam	42.2±3	34±2	22.8±4	1.19±0.107	24	0.890	0.3143	0.2904	0

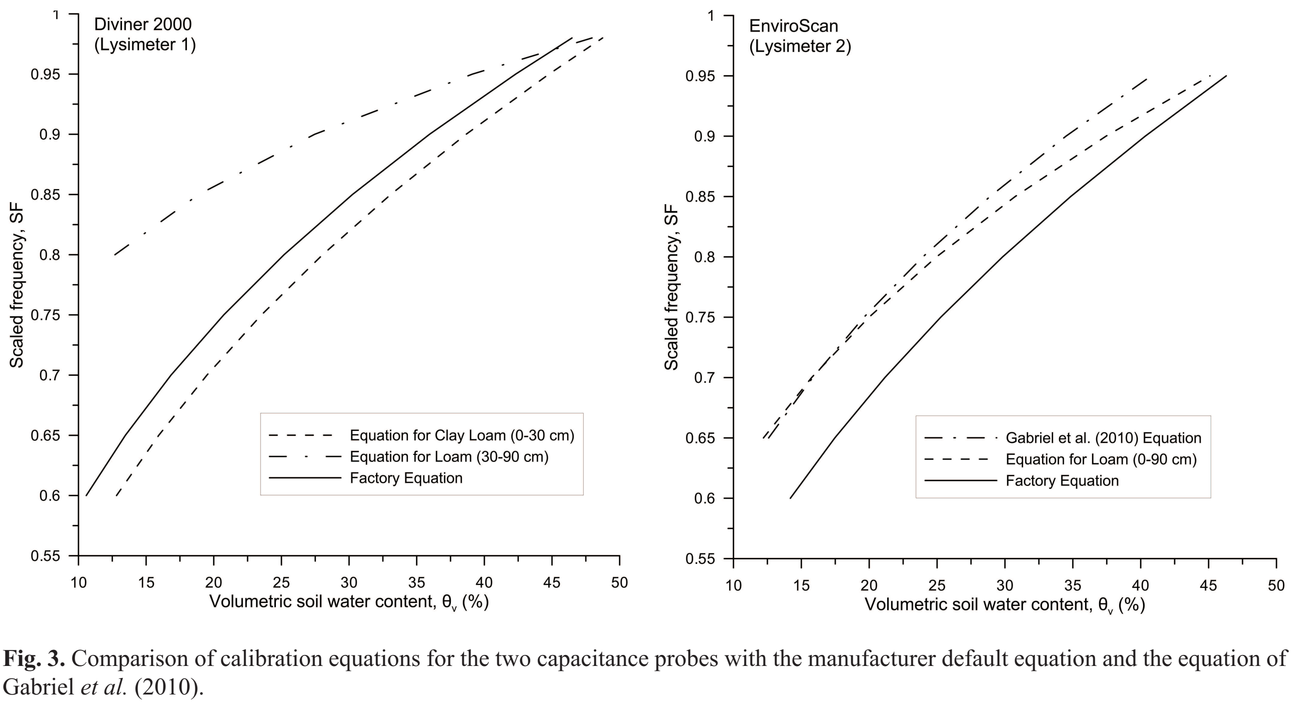

Fig. 3. Comparison of calibration equations for the two capacitance probes with the manufacturer default equation and the equation of Gabriel *et al.* (2010).

T a b l e 6. Estimated irrigation water depth from site-specific and manufacturer default equations in lysimeter 1 (Diviner 2000) for three irrigation events

Irrigation (mm) [Date]	Site-specific equation				Manufacturer equation			
	y_{tot}[a] (mm)		Difference		y_{tot}[a] (mm)		Difference	
	Before	After	(mm)	(%)	Before	After	(mm)	(%)
	Irrigation				Irrigation			
63.5 [25/6/07]	160.5	223.8	63.3	-0.4	213.5	272.3	58.8	-7.4
69.3 [25/7/07]	128.6	195.2	66.5	-4	187.3	249.4	62.1	-10.4
69.3 [23/8/07]	129.3	197.2	67.9	-2	188.1	251.7	63.6	-8.2

[a]Total soil water content in soil profile.

T a b l e 7. Estimated irrigation water depth from site-specific, manufacturer and Gabriel *et al*. (2010) equations in lysimeter 2 (EnviroScan) for two irrigation events

Irrigation (mm) [Date]	Site-specific equation				Manufacturer equation				Gabriel *et al*. (2010) equations			
	y_{tot}[a] (mm)		Difference		y_{tot}[a] (mm)		Difference		y_{tot}[a] (mm)		Difference	
	Before	After	(mm)	(%)	Before	After	(mm)	(%)	Before	After	(mm)	(%)
	Irrigation				Irrigation				Irrigation			
63.5 [19/7/07]	117.4	179.1	61.7	-2.9	164.0	224.7	60.7	-4.5	120.9	176.6	55.7	-12.3
69.3 [23/8/07]	117.2	183.2	66.0	-4.8	163.8	226.1	62.2	-10.2	120.7	179.4	58.7	-15.4

[a]Explanations as in Table 6.

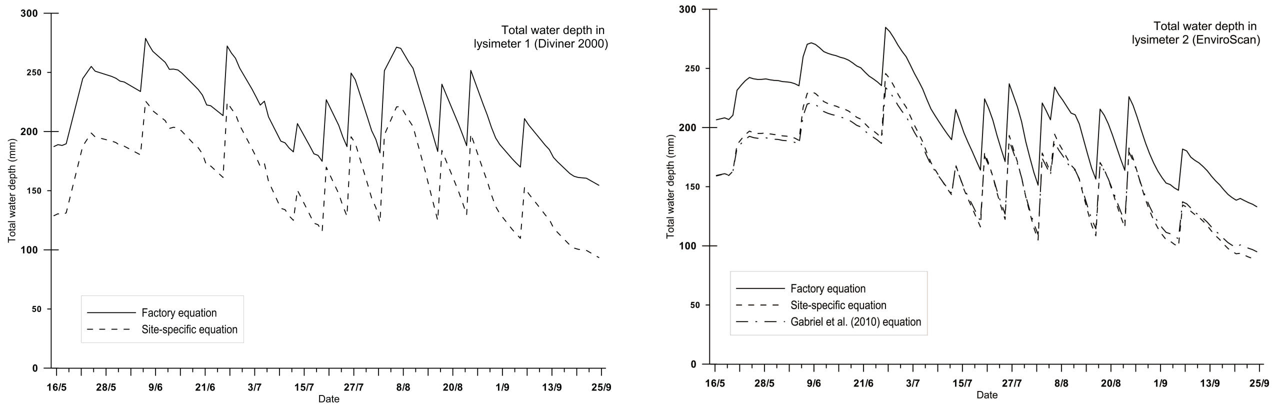

Fig. 4. Total water depth from site-specific, manufacturer and Gabriel *et al*. (2010) equations in lysimeter 1 and 2 for the whole cultivation period.

It is pointed out that similar results with those presented in Tables 6 and 7 were obtained for the remaining irrigation/rain events of the cultivation period.

A common characteristic of both Tables 6 and 7 is that the manufacturer default equation yields values of the water content that are much higher than the values obtained with the site specific equation. These higher values are consistent before and after irrigation, therefore the error in the estimated irrigation depth is not large. These errors are also smaller than the errors obtained with the Gabriel *et al*. (2010) equation which gives absolute values very close to those obtained with the site specific equations.

This characteristic of the manufacturer default equation is shown in Fig. 4 where the water content for the whole soil profile is shown graphically for the total cultivation period for both lysimeters. The water content obtained with the default equation is always higher than the water content obtained with the site specific equation. However, both curves follow the same trend. It can be concluded that when differential water content values are required then the default equation can be used with relatively small errors. When absolute values of the water content are required then the site specific equation must always be used. It can be noticed also in Fig. 3 that the Gabriel *et al*. (2010) equation overestimates the small values of the water content and underestimates the higher values. This is consistent with Fig. 3 where Gabriel equation deviates from the site specific equation at the higher values of the water content.

CONCLUSIONS

1. The soil water content measurement with the Diviner 2000 and EnviroScan probes appears to be very accurate.

2. The ability to provide soil water content measurements per 10 cm of soil depth in conjunction with the ability to provide user-defined time step in measurements can be very helpful in studying the soil water dynamics.

3. The calibration of the capacitance probes, no matter how painstaking a process can be, is necessary to compute accurately the soil water content for optimal irrigation scheduling. The equations exported from the local calibration outweigh the ones in literature and from the manufacturer default equation.

4. The default equation can be used only for differential (relative) and not precise and quantitative measurements of soil water content.

5. On the contrary, the calibration equation of the literature (Gabriel *et al*., 2010) for a similar soil texture with a soil texture used in this paper gives much better quantitative measurement of soil water content comparing to the manufacturer default equation.

6. The peripheral sampling (and not adjacent) to the probes, although different than the proposed by the manufacturer, can yield very satisfactory calibration results.

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