The Third International Symposium on
Soil Water Measurement Using Capacitance, Impedance and
TDT (2010, Murcia, Spain), State of the Art, Paper 1.5

Calibration of Diviner 2000[1] capacitance probe in two soils of Piaui State, Brazil

Aderson Soares de Andrade Júnior[2], Cláudio Ricardo da Silva[3], Claudinei Fonseca Souza[4]

[1] *References to any specific commercial products and manufacturer does not constitute or imply its endorsement, recommendation, or favoring by authors.*

[2] *Embrapa Meio Norte. Address: Av. Duque de Caxias, 5650, Buenos Aires, CEP 64006-220, Teresina/PI, aderson@cpamn.embrapa.br;*

[3] *Universidade Federal de Uberlândia, Instituto de Ciências Agrárias. Address: Bairro Umuarama, Av. Amazonas, s/n, CEP 38400-902, Uberlândia-MG, claudio@iciag.ufu.br;*

[4] *Universidade Federal de São Carlos, Departamento de Recursos Naturais e Proteção Ambiental, cfsouza@cca.ufscar.br.*

ABSTRACT

Soil water content (θv) is extremely variable both in time and space. Thus, knowledge of soil water content, under different conditions of soil and cultural practices is important for improving water use in agriculture. Among the indirect methods for determining soil moisture the capacitance method has grown in usage because readings of water content along the soil profile are fast and simple. The objectives of this study were (i) to determine the field calibration curve for Diviner 2000 for a distrofic Red-Yellow Argisol localized at Teresina (05° 05' S, 42° 48' W and 74.4 m of altitude) and a Yellow Latosol localized in Paranaiba (03°05'S; 41°47'W and 46 m of altitude), both cities of Piaui State, in Northeast of Brazil; and (ii) to compare local calibration curves with the manufacturer calibration. Six access tubes were installed in a 5 m by 2 m grid system. Three moisture levels (saturated, moist and dry) were used. Probe readings and soil sampling to determine θv were made at 0.1 m depth intervals to the total depth of 1.0 m. A power calibration equation was developed for each soil profile. Calibration equations, derived by regression analysis were significantly correlated with equipment measurements (r^2 >0.90) and with lower RMSE (0.01 m^3 m^{-3}). Despite localized calibrations increase the correlation and decrease the error, the manufacturer calibration presents for the Diviner 2000 is suitable for these soils.

INTRODUCTION

Irrigation scheduling based on soil water content is one of the most useful methods due to its practicability and low cost. However, as the soil water content is greatly influenced by rain, drainage, evaporations and by cultural practices, soil water content tends to be variable both in time and space. Therefore, to improve irrigation management, real time monitoring of soil water content is important. In this sense, there is a demand for equipments that access it very accurately, instantly and continuously.

With recent advances in microelectronics the capacitance probe has become popular for monitoring soil water content "*in situ*". The capacitance method includes a probe with a pair of electrodes or electrical plates that work as a capacitor. When activated, the soil-water-air matrix works as a dielectric of the capacitor and completes an oscillating circuit (Heng et al., 2005). Changes in the resonant frequency (F) of the circuit depend on the changes in the capacitance, which is given by general formula, $F = [2\pi\sqrt{(LC)}\,]^{-1}$, where L and C are circuit inductance and total capacitance respectively (Paltineanu & Starr, 1997). The probes have been used in a great variety of soils, as in Australia (Fares et al., 2004), the United States of America (Baumhardt et al.,2000; Fares & Alva, 2000) and Spain (Girona et al., 2002).

However, as an indirect method soil water content measurement, the equipment calibration needs to be done carefully in order to estimate the soil water content accurately. Studies have showed that calibration for individual soils improves the accuracy of soil water content estimated (Paltineanu & Starr, 1997; Baumhardt et al., 2000; Morgan et al., 1999; Leib et al., 2003; Fares et al., 2004 and Groves & Rose, 2004).

The objectives of this study were (i) to determine the field calibration for capacitance probe in a distrofic Red-Yellow Argisol localized at Teresina and for a Yellow Latosol localized in Paranaiba; and (ii) to compare the results with the manufacturer calibration.

METHODS AND MATERIALS

Experimental area

The calibration was conducted at Embrapa Meio Norte in two locations of Piaui State, Brazil. The first one was in a distrofic Red-Yellow Argisol localized in Teresina (05° 05'S, 42° 48'W and elevation 74.4 m). Teresina has a tropical climate with average annual air temperature and humidity of 27.9°C and 69.2%, respectively, and annual rainfall of 1299 mm (Bastos & Andrade Jr., 2000).

The second soil was a Yellow Latosol localized in Parnaiba (03°05'S; 41°47'W and 46 m of elevation). Parnaiba has a similar Teresina climate but annual rainfall is 965 mm, occurring from January to May (Bastos et al., 2000). Table 1 and 2 shows physical soil proprieties of experimental areas.

Table 1. Selected physical properties of distrofic Red-Yellow Argisol in Teresina, Brazil, 2005.

Depth (m)	**Level**	**Texture (g kg^{-1})**			**$\rho^\dagger$ kg m^{-3}**	**Textural Class**
		Sand	**Silt**	**Clay**		
0.00-0.15	A_p	785	78	136	1.63	Loamy sand
0.15-0.35	A_{12}	675	98	226	1.71	Sandy clay loam
0.35-0.65	Bt_{12}	606	97	296	1.54	Sandy clay loam
> 0.65	Bt_{21}	607	126	266	1.49	Sandy clay loam

Table 2. Selected physical properties of Yellow Latosol in Parnaiba, Brazil, 2005.

Depth (m)	**Level**	**Texture (g kg^{-1})**			**$\rho^\dagger$ kg m^{-3}**	**Textural Class**
		Sand	**Silt**	**Clay**		
0.00-0.25	A_p	852	62	86	1.3	Sand loam
0.25-0.40	AB	886	39	75		Sand loam
0.40-0.70	Bw_1	854	61	85		Sand loam
> 0.70	Bw_2	833	52	115		Loamy sand

† Soil bulk density

Access tube installation for both soils

Prior to calibration, in October of 2005, six PVC plastic access tubes with 1.5m of length were installed spaced at 5 m x 2 m in each soil (Figure 1a). The installation of tubes was done following the procedures suggested by manufacturer to ensure good contact between the soil and the access tube. Briefly, the access tubes were driven into the soil in ≈0.15 m increments using a rubber hammer with the soil within the tubes extracted by a 47 mm soil auger. This procedure reduces air gaps and variations in soil bulk density adjacent to the access tubes. After the installation, 4 cm of the access tubes was kept above the ground to prevent water to entering into the tube. A plastic top cap was firmly fitted at the upper end of each access tube. Approximately, 40 days after, three trenches were excavated about 0.4 m away from each tube line (Figure 1b).

As recommended by manufacturer (Sentek, 2001), three moisture levels (i.e. saturated, moist, dry) were used to cover much of the soil water content range in each soil. For saturated level, water was applied by using a cylinder infiltrometer (0.5 m diameter, Figure 1c) so that the wetted front reached >1.0 m of soil depth. For moist level, water applied was reduced by half. As the experiment was conducted in the end of dry period for dry level in both locations, addition of water was not required. Two replications were made per each moisture level.

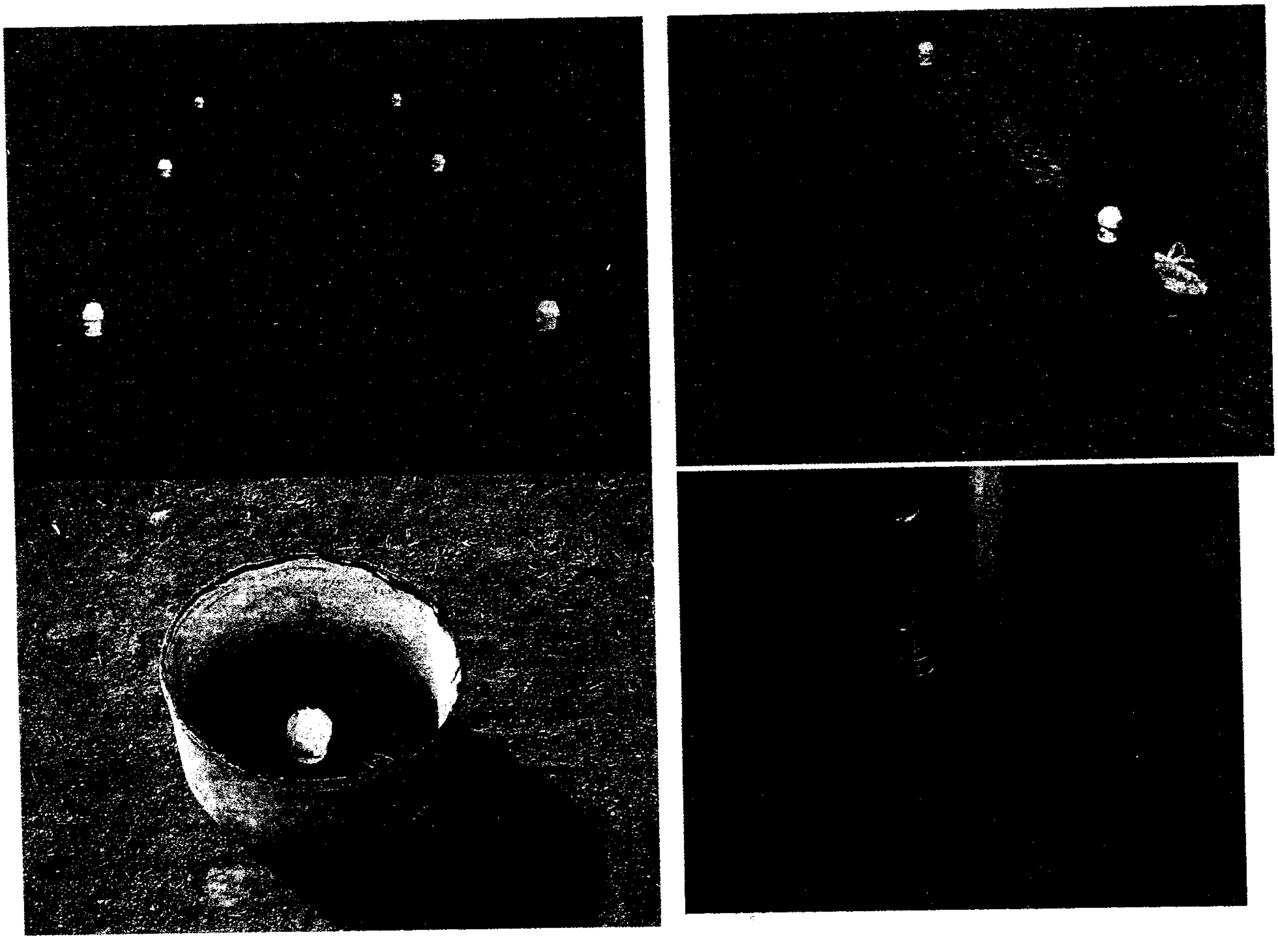

Figure 1. (a) The access tubes in a grid system (5 x 2 m). (b) Trenches excavated closed to tube line. (c) A cylinder infiltrometer used for applied water depth. (d). undisturbed soil cores being carefully collected.

Capacitance probe

The capacitance probe (model Diviner 2000, Sentek Pty Ltd., South Australia) is a hand-held, portable soil moisture-monitoring device consisting of a portable display/logger unit, connected by a cable to an automatic depth-sensing probe that moves up and down in the access tube.

Prior to calibration, the manufacturer recommends normalizing the probe using the scaled frequency (*SF*) values for air and water (≈25°C). The normalization is necessary for meaningful data continuity as is impossible to tune all sensors to count the exact frequency when measuring a particular standard, e.g. in a water bucket (Sentek, 2000).

Three readings of scaled frequency (*SF)* were recorded at each depth (0.1-1.0 m). Immediately after the readings, a soil platform at each 0.1 m of depth was made to determine the gravimetric water content and bulk density (Figure 1d). Soil core samples around the tube were collected and placed in a packed aluminum can (70 mm diameter by 60 mm tall) to determine the gravimetric soil water content. Also, to determine the bulk density, two undisturbed soil samples were carefully collected (Figure 1d) placed horizontally in such a way that the center of sampling ring was in the middle of each layer and at a distance of≈10 cm from the of tube . Immediately, soil samples were weighed and oven dried was done at 105°C for 48 hours. The volumetric soil water content, θ_v (m^3 m^{-3}) where determined by multiplying the gravimetric water content by the bulk density (kg m^{-3}) for each soil sample.

Regression analysis were conducted using average *SF* readings and their corresponding volumetric water content (θ_v) at sampling depths as well as the entire profile by using software Table Curve v.5.01 (SYSTAT, Software, Inc.). The root mean square error (RMSE) of regression models was used as a practical indicator of their accuracy as used by Fares et al. (2004).

To compare these results with manufacturer calibration a curve was plotted along with the field data and the fitted calibration curve for each entire soil profile.

RESULTS AND DISCUSSION

Table 3 presents the results of calibration of the Diviner 2000 for both soils derived from regression analysis of sensor measurements of *SF* against θ_v. A two-parameter power model was used for calibration sensor as used by other previous researchers (Morgan et al. 1999; Groves & Rose, 2004). The choice of this two-parameter was due to its simplicity despite other researchers (Polyakov et al., 2005; Fares et al.,2006) suggesting a three-parameter because of its robustness compared to the two-parameter.

In all cases, the regression equations were highly significant (P<0.001) and accounted for much of the variation in the data (>0.90 R^2 adjusted). Thus, indicating that the *SF* readings accounted at least 90 percent of the variations in the water content. An exception were at 1.0 m of depth in Teresina, probably, because of the small differences between saturated and dry soil as well as the high *SF* deviation observed in saturated level. The RMSE for these calibrations were about 0.01 for both soils, a value less than most in previous field calibration studies (Fares et al., 2004; Polyakov et al., 2005 and Fares et al. 2006). Paltineanu & Starr (1997) suggested that most accurate field calibration would probably be achieved by minimizing the uncertainty of wet bulk density and gravimetric soil water by using sub sampling technique. For this, we used two undisturbed cores in each depth for wet bulk density and another soil core sample for gravimetric water. All work was doing carefully and all samples being immediately weighted.

Table 3 - Calibration equations of the capacitance probe for different soil layers using a power model.

Location/Soil	**Horizon (m)**	***a***[†]	***b***	***R*²**	**RMSE**[*]	**N**	**Soil water content range (m^3m^{-3})**	
							Low	**High**
Teresina (distrofic Red-Yellow Argisol)	**0.1**[‡]	0.742	3.782	0.98	0.011	5	0.067	0.233
	0.2	0.503	3.144	0.98	0.009	6	0.098	0.247
	0.3	0.457	2.553	0.98	0.009	6	0.099	0.264
	0.4	0.484	2.596	0.99	0.007	6	0.101	0.252
	0.5	0.506	2.707	0.93	0.017	6	0.104	0.242
	0.6	0.542	2.923	0.97	0.011	6	0.104	0.238
	0.7	0.524	2.923	0.94	0.014	6	0.104	0.221
	0.8	0.476	2.640	0.92	0.013	6	0.116	0.216
	0.9	0.527	3.051	0.90	0.012	6	0.116	0.210
	1.0	0.503	2.813	0.56	0.021	6	0.121	0.198
	0-1.0	**0.492**	**2.757**	**0.93**	**0.014**	**59**	**0.067**	**0.264**
Parnaiba (Yellow Latosol)	**0.1**	0.440	2.725	0.97	0.012	6	0.007	0.158
	0.2	0.514	3.285	0.99	0.005	6	0.020	0.156
	0.3	0.566	3.278	0.99	0.003	5	0.034	0.180
	0.4	0.376	2.470	0.95	0.014	5	0.051	0.193
	0.5-1.0	0.371	2.333	0.97	0.008	32	0.049	0.206
	0.0-1.0	**0.397**	**2.533**	**0.97**	**0.010**	**54**	**0.007**	**0.206**

[†] The coefficients *a* and *b* are for the calibration $\theta_v = a\mathrm{SF}^b$, where *SF*, θ_v, and N are the scaled frequency readings, measure soil water content ($m^3\ m^{-3}$) and the number of samples used per analysis, respectively.
[‡] One outliner data point disregarded.
[*] RMSE = Root Mean Square Error

In this study, using individual calibrations per depth improved almost all correlation coefficients as well as minimized the Root Mean Square Error (RMSE) when compared to a unique calibration for the entire profile (0-1.0m). However, individual calibrations for each depth were not separate from that considering the entire calibration by F test.

Figure 2 shows the adjusted curve along the field data for each entire soil in Teresina and Parnaiba locations and manufacturer calibration curve. There were minimal differences between the calibration curves, especially for Parnaiba. Figure 3A and B shows the match between estimated and measured soil water content by using local and the manufacturer calibration in Teresina and Paranaiba soils. In Teresina, data were more scattered and the soil water content (θv) estimated using regression supplied by the manufacturer resulted in an underestimate of the soil water content by 9.1%. The better performance of the manufacturer calibration in Parnaiba was probably because the soil has less clay and is more similar to samples used in manufacturer calibration. Paltineanu & Starr

(1997) corroborated that differences in soil mineralogy, especially 2:1 clays, could affect *SF* readings. For Wraith & Or, (1999) large surface areas of 2:1 clays affect the bound water and corresponding bulk permittivity.

Despite the acceptable results obtained when using the manufacturer calibration, its resulted in a light over-irrigation in Teresina if absolute soil water content values were used to determine irrigation amounts or scheduling. Moreover, individual calibrations for each depth improve correlation coefficients. This study confirms that site-specific calibration improves the accuracy of soil water monitoring and is recommended especially for areas in the northeast of Brazil that has a limited water supply.

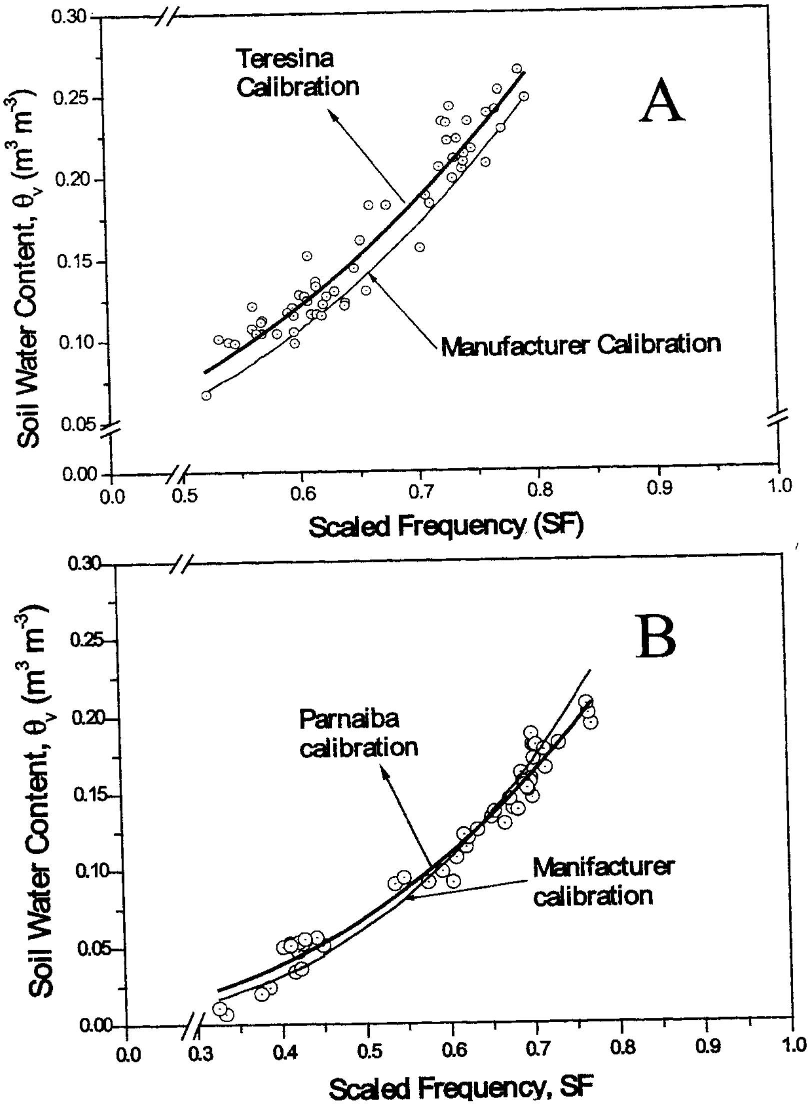

Figure 2. Comparison of the current field calibration of Diviner 2000 in Teresina (A) and Parnaiba (B) with calibration curve provided by manufacturer.

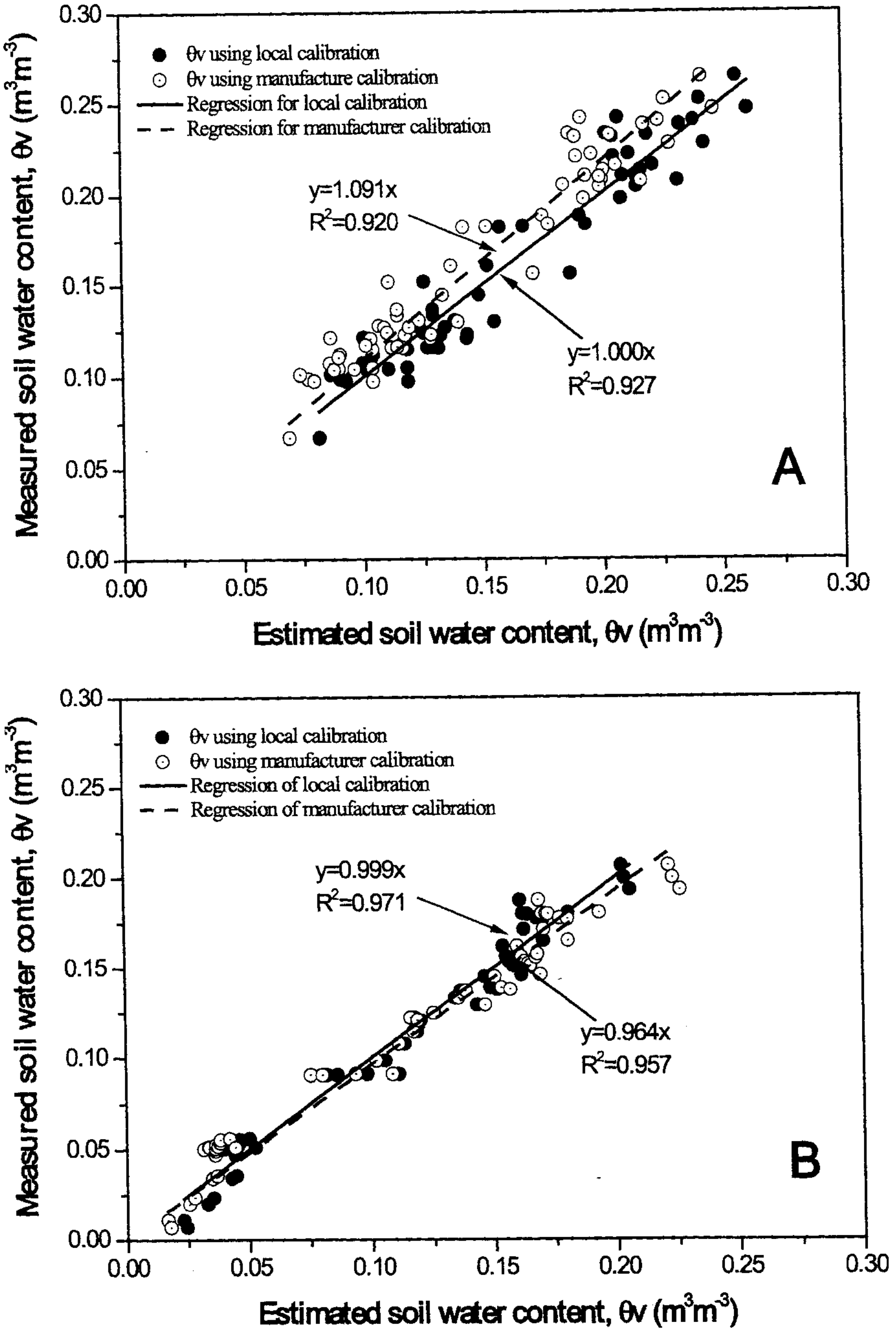

Figure 3. Measured versus estimated soil water content, θ_V for Teresina (A) and Parnaiba (B) soils using local and the manufacturer calibration.

CONCLUSIONS

The Diviner 2000 capacitance probe was found to be highly sensitive to detect variation in soil water content for both locations. A two-parameter field power curve was adjusted for each depth and for the entire profile with higher correlation ($R^2 > 0.90$) and lower RMSE ($0.01\ m^3\ m^{-3}$).

Use of the calibration supplied by the manufacturer was suitable for the soils, despite a slight underestimation in Teresina. However, calibrations for each soil depth and type of soil improve correlation coefficients.

REFERENCES

Bastos, E.A.; Andrade Júnior, A.S. Dados agrometeorológicos para o município de Teresina, PI (1980-1999). Teresina: Embrapa Meio-Norte, 2000. 25p. (Embrapa Meio-Norte. Documentos, 47).

Baumhardt, R.L.; Lascano, R.J.; Evett, S.R. Soil Material, Temperature, and salinity effects on calibration of multisensor capacitance probes. Soil Science Society of America Journal, v.64, p.1940-1946, 2000.

Embrapa.. Diagnóstico e prioridades de pesquisa em agricultura irrigada: região Nordeste. Brasília: DPL, p. 27-162, 1989. (Embrapa - DPL. Documentos, 9).

Fares, A.; Alva, K.A. Estimation of citrus evapotranspiration by soil water mass balance. Soil Science, v.164, n.5, p. 302-310, 1999.

Fares, A.; Buss, P.; Dalton, M.; El-kadi, A.I.; Parsons, L.R. Dual field calibration of capacitance and neutron soil water sensors in a shrinking-swelling clay soil. Valdose Zone Journal, v.4, p.1390-1399, 2004.

Fares, A.; Hamdhani, H.; Polyakov, V.; Dogan, A. Valenzuela, H. Real-time soil water monitoring for optimum water management. Journal of the American Water Resources Association, 2006, vol. 42, n.6, p. 1527-1535, 2006.

Gardner, C.M.K.; Bell, J.P.; Cooper, J.D; Dean, T.J.; Hodnett, M.G.; Gardner, N. Soil water content. In: SMITH, R.A.; Mullings, C.E. (Ed.) Soil Analysis: Physical methods. New York: Marcel Dekker, 1991, cap.1, p. 1-73.

Girona, J.; Mata,M.;Fereres, E.; Goldhamer, D.A.; Cohen, M. Evapotranspiration and soil water dynamics of peach trees under water deficits, Agricultural Water Management, v.54, n.2, p.107-122,2002.

Groves, S.J.L; Rose S.C.L. Calibration equations for Diviner 2000 capacitance measurements of volumetric soil water content of six soils. Soil Use and Management, v.20, p. 96-97, 2004.

Heng, L.K.; Cayci, G.; Kutuk, C.; Arrillaga, J.L.; Moutonnet, P. Comparison of soil moisture sensors between neutron probe, Diviner 2000 and TDR under tomato crops. In: SYMPOSIUM OF TOWARDS

Integrated Soil, Water and Nutrient Management in Cropping Systems: The role of nuclear techniques, 59., Bangkok, 2002. Proceedings. Bangkok, Soil Science, 2002, CD-ROM.

Leib, B.G.; Jabro, J.D.; Matthews, G.R. Field evaluation and performance comparation of soil moisture sensors. Soil Science, v.168, n.6, p.396-408, 2003.

Meyer, W.S.; Green, G.C. Plant indicators of wheat and soybean crop water stress. Irrigation Science, v.2, p.167-176, 1981.

Morgan, K.T.; Parsons, L.R.; Wheaton, T.A.; Pitts, D.J.; Obreza, T.A. Field calibration of a capacitance water content probe in fine sand soils. Soil Science Society of America Journal, v.63, p.987-989, 1999.

Paltineanu, I.C; Starr, J.L. Real-time soil water dynamics using multisensor capacitance probes: laboratory calibration. Soil Science Society of America Journal, v.61, p.1576-1585, 1997.

Polyakov, V.; Fares, A.; Ryder, M.H. Calibration of capacitance system form measuring water soil content of tropical soil. Vadose Zone Journal, v.4, p.1004-1010, 2005.

Sentek. Calibration of Sentek Pty Ltd soil moisture sensors. Stepney: Sentek Pty Ltd, 2001.

Sentek. Diviner 2000: user guide version 1.21. Stepney: Sentek Pty Ltd, 2000.

Wraith, J.M.; Or, D. Temperature effects on soil bulk dielectric permittivity measured by time domain reflectometry: Experimental evidence hypothesis development. Water Resource Research, v.35, p.361-369, 1999.