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ACCURATE SOIL WATER CONTENT MONITORING IN REAL TIME WITH APPROPRIATE FIELD CALIBRATION OF THE FDR DEVICE "DIVINER 2000" IN A COMMERCIAL TABLE GRAPE VINEYARD

***J. Haberland[1], R. Gálvez[2], C. Kremer[3], C. Zuñiga[4] and Y. Rudolffi[5]**

[1]Universidad de Chile, Facultad de Ciencias Agronómicas, 8820808, Av. Santa Rosa 11.315, Santiago, Chile

E-mails: [1]jhaberla@uchile.cl [2]rogalvez@uchile.cl [3]cristiankremer@gmail.com [4]agua.copiapo@gmail.com [5]yrudolffi@gmail.com ([*]*Corresponding Author*)

Abstract: The purpose of this study was to determine the best field calibration method for the FDR device "Diviner 2000", and accurately monitor soil water content in real time in a commercial table grape vineyard growing the Thompson Seedless variety. Field calibration equations were obtained per depth (every 0.10m) and for the soil profile as a whole by contrasting normalised probe readings with the actual volumetric water content (gravimetric method) of three soil conditions i.e. dry, wet and saturated. The per-depth calibration was the most precise, and was used to monitor water content in real time. One access tube was located on the plant row, in three topographic locations: high (T1), middle (T2) and low (T3). Field capacity (FC) and permanent wilting point (PWP) were determined for each tube. The irrigation threshold chosen was a 30% depletion of available water (FC – PWP). Soil water content went beyond the threshold (water deficit) 54.0% of the time in location T1 whereas it went above FC (water excess) 46.8 % and 96.8% of the time in locations T2 and T3, respectively. Being appropriately field calibrated, the Diviner 2000 proves effective in accurately measuring soil water content in real time, which facilitates identification of different irrigation management needs in the field.

Keywords: Capacitance probe, calibration, soil water content.

INTRODUCTION

The growing competition for water resources has made it necessary to improve water use efficiency, especially in relation to irrigated agriculture, which consumes 87% of worldwide water resources (FAO, 2003). In order to maximise productivity, "production per unit of applied water" practices need to be adopted to reduce water losses (runoff, percolation and evaporation) and avoid water stress during periods when the crop is most sensitive (Intrigliolo *et al.,* 2007). The evaluation and measuring of soil water content are critical

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components of efficient irrigation management and help to establish better water preservation practices (Muñoz-Carpena *et al.*, 2004).

Soil water content affects plant growth and solute transportation in irrigated and non-irrigated agricultural systems. Consequently, agricultural production is more closely related to the available water in the soil than any other weather variable (DeJong and Bootsma, 1996) and an extensive effort has been made to determine and characterise the variables controlling water flow in the soil, and water absorption by the roots (Goldhamer *et al.*, 1999). Furthermore, localised and high-frequency irrigation systems modify root growth patterns as well as water absorption by the plant, due to their particular water distribution pattern in the soil (Bryla, 2004).

Girona *et al.* (2002) state that monitoring available water content in the soil is essential to schedule irrigation due to the high variability of plant response, wetting patterns, soil depth and root exploration in high-frequency irrigation systems. Among other factors, appropriate irrigation scheduling requires soil water content measuring in real time.

The gravimetric method is the most precise method used to determine soil water content (Gardner, 1986), however, it is disruptive and laborious, and does not allow the measurement of water content in real time. Several non-invasive methods have been developed, including neutron thermalisation (Greacen, 1981), tensiometers and electric resistance sensors (Lowery *et al.*, 1986; Spaans and Baker, 1992; Seyfried, 1993; Hanson *et al.*, 2000). Fairly recent technologies can measure soil water content continually, such as the Time Domain Reflectometry (TDR) (Topp et al., 1980; Cassel *et al.*, 1994) and electric capacitance or Frequency Domain Reflectometry (FDR) (Robinson and Dean, 1993; Fares and Polyakov, 2006).

The goal of this study was to obtain the best field calibration method for the FRD device “Diviner 2000” to accurately monitor soil water content in real time in a commercial table grape vineyard growing the Thompson Seedless variety.

MATERIALS AND METHODS

The field trial was carried out in a commercial table grape orchard growing the Thompson Seedless variety (San José de Marchigüe, Region O´Higgins, Chile), with double-line drip irrigation and emitters every 1m. The soil of the trial belongs to the coarse loam, mixed and thermic family of the *Vitradic Durixerolls* (CIREN, 1996). Field observations were performed in two soil phases.

An FDR probe Diviner 2000 (Sentek Pty Ltd, Adelaide, SA) was normalised to obtain a scaled frequency (SF) or normalised and then calibrated in the field. For the normalisation, sensor frequencies in PVC tubes were observed when in contact with air (F_a) and in contact with water at 22°C (F_w). The soil frequency (F_s) was used to obtain SF in Equation 1, which in turn was used to obtain the volumetric soil water content (Θ_w) in Equation 2.

$$SF = (Fa - Fs) / (Fa - Fw) \quad (1)$$

$$SF = A\theta w^B \Leftrightarrow \theta w = \sqrt[b]{(SF / a)} \quad (2)$$

In order to obtain a complete range of soil water content, three soil water content conditions were generated: dry (P1), wet (P2) and saturated (P3), 7m apart from each other. Condition P1 was never irrigated, P2 was analysed with its current water content and P3 was flooded until saturation and readings were done after a 48-h drainage period was allowed. Two access tubes (PVC pipes, 0.5m length, 56.5mm interior diameter) were installed for each soil condition, 6m apart (Figure 1), following manufacturer instructions. A double-ring rubber plug was installed at the bottom of each tube to avoid water and/or vapour entering into the access tube. The final arrangement of access tubes was 7x6m (Figure 1).

Three frequency readings were done every 0.1m in depth in each access tube. Immediately after, two soil samples were taken from the soil profile using metallic cylinders, 0.30m from each reading point. Samples were taken within the area of influence of the sensor (0.03m from the access tube). Water content using the gravimetric method (W) and bulk density (Db) using the cylinder method were obtained for each soil sample, and the volumetric water content was estimated using Equation 3.

$$\theta w = WDb \quad (3)$$

A regression analysis was done between the values of volumetric water content and the normalised frequencies provided by the device, in order to obtain calibration equations. The regression analysis provided a determination coefficient. The standard error estimate (root-mean-square error, RMSE) between the actual water content of the samples and the estimates was determined for each calibration equation.

The soil water content was measuring on a real-time basis using the most precise equation(s) obtained during the field calibration. One access tube was located on the plant row on three topographic locations: high (T1), middle (T2) and low (T3) (Figure 2). Readings were done at 0.6m depths in locations T1 and T2, and 0.5m in location T3.

Soil phase 1 was observed in location T1 and soil phase 2 in locations T2 and T3. The water retention curve was determined for both soil series, which provided field capacity (FC) and permanent wilting point (PWP) values. The appropriate irrigation threshold reported for the table grape is 30% of available water (AW = FC – PWP) depletion.

The field trial followed the farmer's irrigation schedule. The criteria considered by the farmer included general field observations and plant evapotranspiration measuring with data collected from a local weather station and a crop coefficient from FAO. Table 1 shows the soil water content (mm) at each topographic location at field capacity (FC), permanent wilting point (PWP) and the irrigation threshold (at 30% AW depletion).

RESULTS AND DISCUSSION

Field calibration

Table 2 presents the results of the lineal regression determined by contrasting values of volumetric water content obtained from the SF readings and the gravimetric method, for each depth and soil profile as a whole (0 to 0.6m). The regression showed a high level of adjustment to a power function, and coefficients a and b were obtained for Equation 2.

The field calibration per-depth equations showed a high correlation for the first 0.40 m of depth (R^2>0.91), whereas the correlation decreased ($R^2 < 0.75$) deeper in the soil profile. The soil profile calibration equation showed an intermediate correlation (R^2=0.81) regarding the per-depth equations.

Several studies with FDR devices under laboratory conditions have found calibration equations with higher determination coefficients for the soil profile than the one observed in this study. Paltineanu and Starr (1997) obtained an $R^2 = 0.992$ with the device EnvironSCAN, and Groves and Rose (2004) obtained R^2 ranging from 0.97 to 0.93 for different soil profiles with a Diviner 2000. Da Silva et al., (2007) concluded that per-depth calibrations show better correlation coefficients and minimise the RMSE value. On the other hand, Morgan et al., (1999) found a calibration equation with $R^2 = 0.831$ for the device EnviroSCAN under field conditions, similar to the results reported by Haberland et al., (2014) ($R^2 = 0.98$, in a clay and loam clay soils, RMSE 0.05 $cm^3 \cdot cm^{-3}$) and in this study.

Bulk density is essential to determine volumetric soil water content, a basic element in the calibration process. The determination of bulk density is among the main factors increasing variability of soil water content measurements (Hu et al., 2008). It is expected to find more precise results under laboratory conditions, where bulk density determination can be more accurate and where newly developed methodologies, such as that described by Haberland et al., 2014, ensure precise calibration.

Actual soil water content measured versus probe estimates

The probe provides water content values per depth, and for the soil profile by adding the values obtained at different soil depths. The actual soil water content values were compared to the values provided by the device with the different calibration options (Figure 3).

Figure 3 shows that both per-depth and profile field calibrations were more precise and behaved more closely to the actual soil water content than the manufacturer calibration. The calibration per depth showed the smallest variations in most of the cases.

Variations in the profile field calibration were always under 10%. In turn, per-depth field calibration showed variations lower than 13%; similar results were found by Haberland et al., (2014), in which estimates presented a 13.76% error, and by Anderson et al., (2010), underestimating by 9.1%.

Soil water content values under the manufacturer calibration were greater than 54% and presented variations when using one or other calibration. However, the per-depth measurement variations, from which the profile measurements come, were similar to the calibration option. This incongruence is due to the overestimation of the actual soil water content that the manufacturer calibration presents in almost every case. Therefore, per-depth variations were additive, whereas in the field calibrations the measurements were compensated. Several authors conclude that the field calibration of the Diviner 2000 is more representative of the soil water content than the manufacturer calibration (Burgess et al., 2006; Da Siva et al., 2007; and Haberland et al., 2014).

Soil water content monitoring

Figures 4, 5 and 6 represent soil water content on T1, T2 and T3, respectively, throughout the summer season, measuring using the per-depth calibration. The horizontal lines on the graphic area represent the soil water content at FC and the irrigation threshold of each. Therefore, the area in between represents adequate soil water content, and any value above or below represents a water excess or water deficit, respectively.

Figure 4 shows that location T1, the highest topographic location, had adequate water content 38.1% of the time, water deficit 54% of the time and water excess for the remainder (7.9%). This is because water easily drains to lower points in the field, especially given the soil texture observed in soil phase 1 – sandy loam that gets coarser in depth.

Location T2 had adequate soil water content 38.7% of the time, water excess 46.8% of the time, and water deficit for the remainder (14.5%) (Figure 5). This can be explained by the observation point's location at a lower topographic level, where it receives water draining from higher points. Additionally, the soil phase of this location shows a hardpan restricting drainage in depth: therefore, water excess does not easily clear. Thus, soil water content is generally higher than that observed in location T1.

Location T3, at the lowest topographic point in the field and a shallower depth (0.50m), also presents a hardpan This means that this soil profile receives water drained from the higher topographic areas, has limited drainage due the hardpan observed and the lowest water holding capacity of the three locations. This explains why adequate soil water content was observed only 3.2% of the time, whereas water excess was observed for the remainder of the time (Figure 6).

CONCLUSIONS

The probe Diviner 2000 is highly sensitive to soil water content variation per depth as well as in the soil profile as a whole. The correlation found was better in the first 0.40m (R^2>0.91) than at 0.50 and 0.60m (R^2<0.75). The calibration equation for the whole profile is moderately precise (R^2>0.81) in relation to the per-depth calibration equations. Field calibrations were more precise than the manufacturer calibration in determining actual soil water content per depth and across the whole profile.

When properly calibrated, the probe Diviner 2000 proves to be effective to accurately measuring soil water content in the field in real time. When used at different points in the field, the probe helps to detect different irrigation management needs depending on the soil conditions of the specific location, such as water holding capacity and ability to drain.

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Tables and Figures

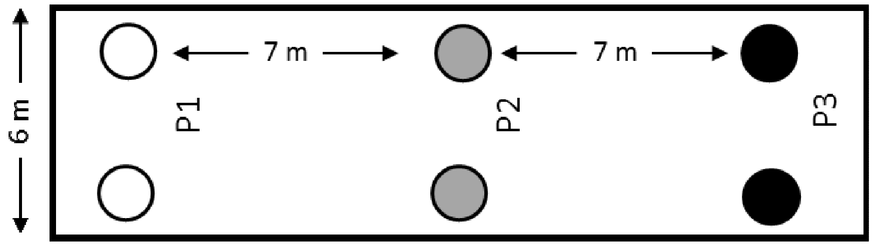

Figure 1. Distribution of the access tubes for field calibration.

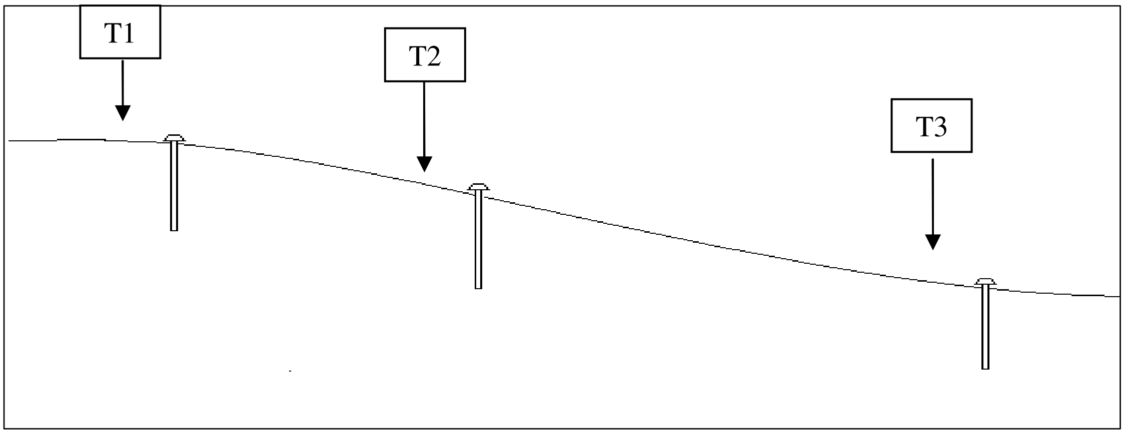

Figure 2. Representation of the three topographic locations of access tubes for the soil water content measuring in real time.

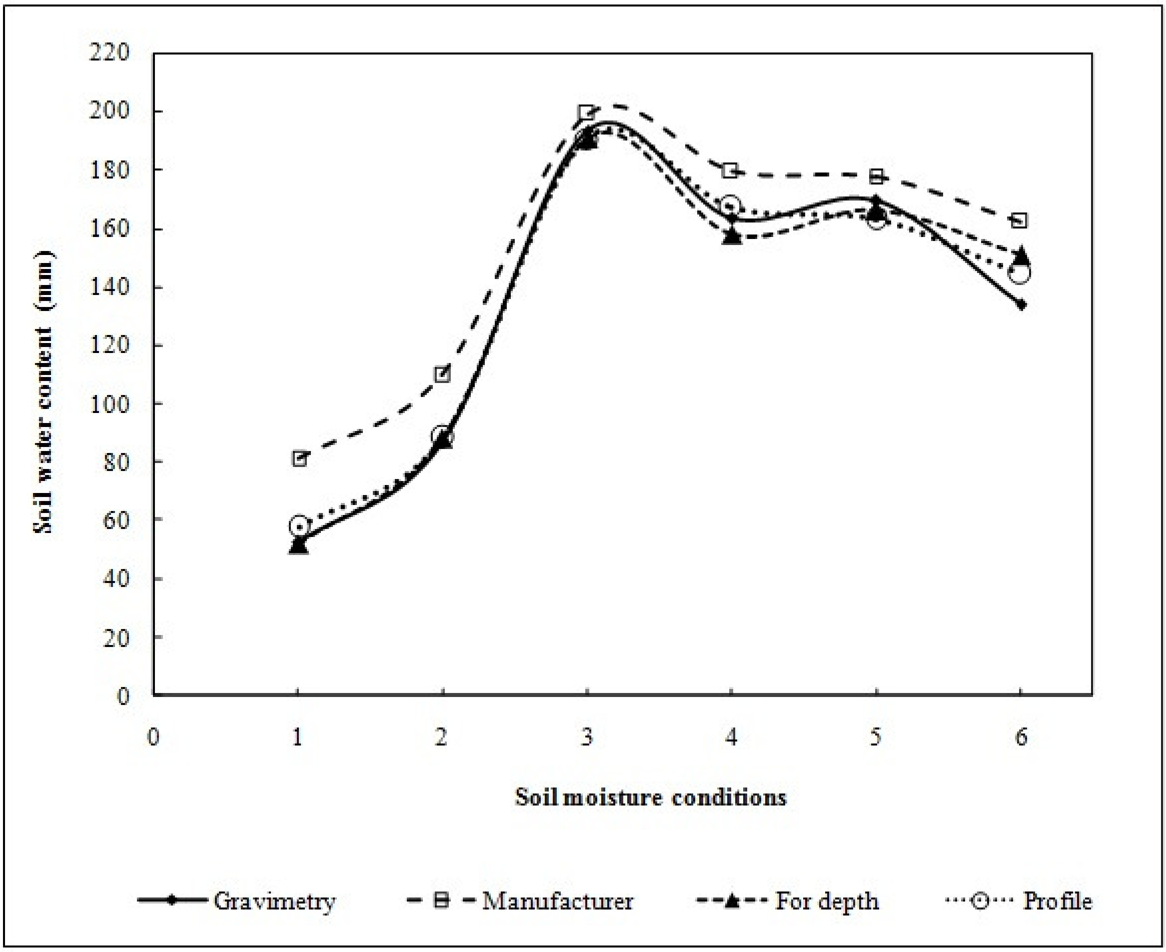

Figure 3. Soil water content estimates (mm) from different calibration equations (manufacturer, per depth, soil profile) and the actual soil water content determined by the gravimetric method from the six reading points evaluated (two reading points per water content conditions)

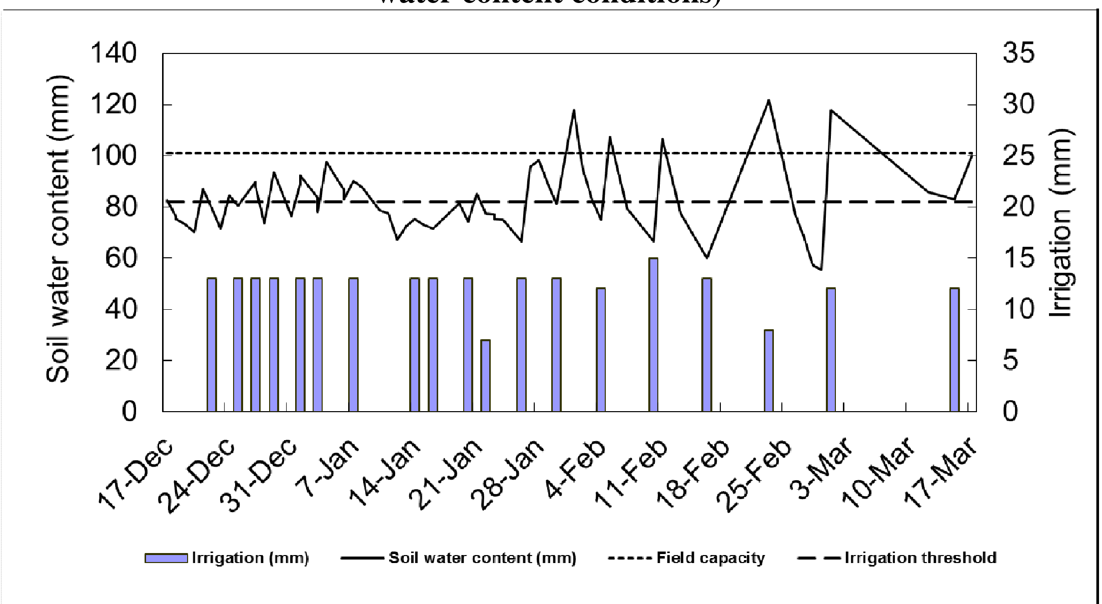

Figure 4. Soil water content measuring in the soil profile in location T1 with a Diviner 2000 calibrated per depth.

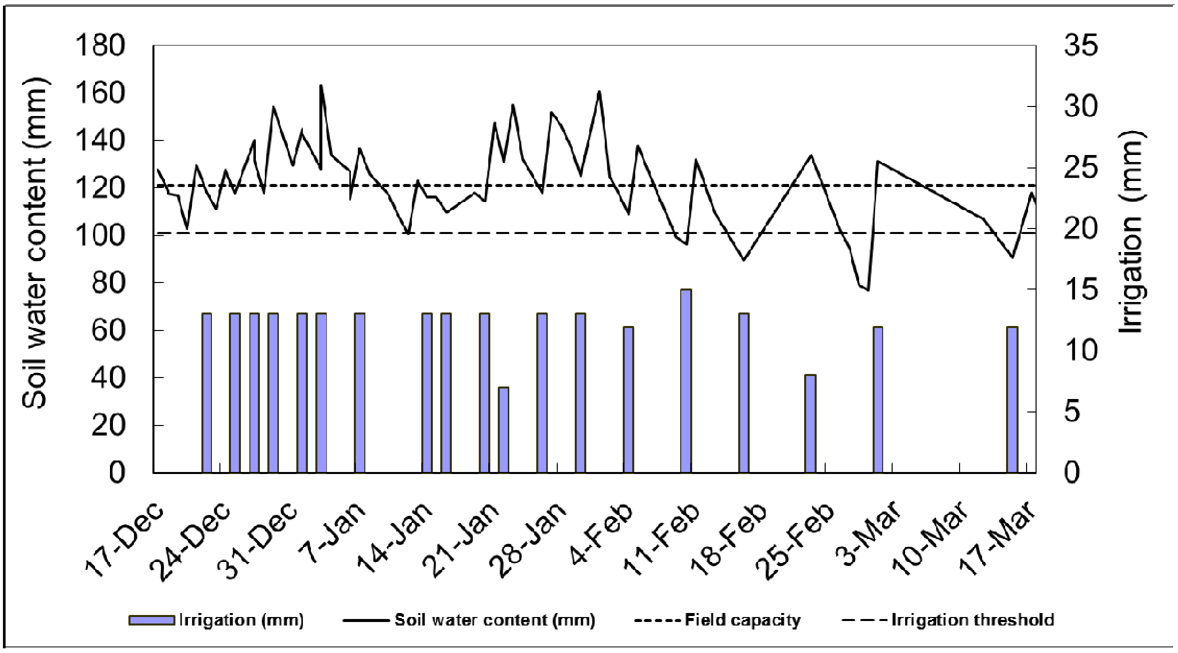

Figure 5. Soil water content measuring in the soil profile in location T2 with a Diviner 2000 calibrated per depth

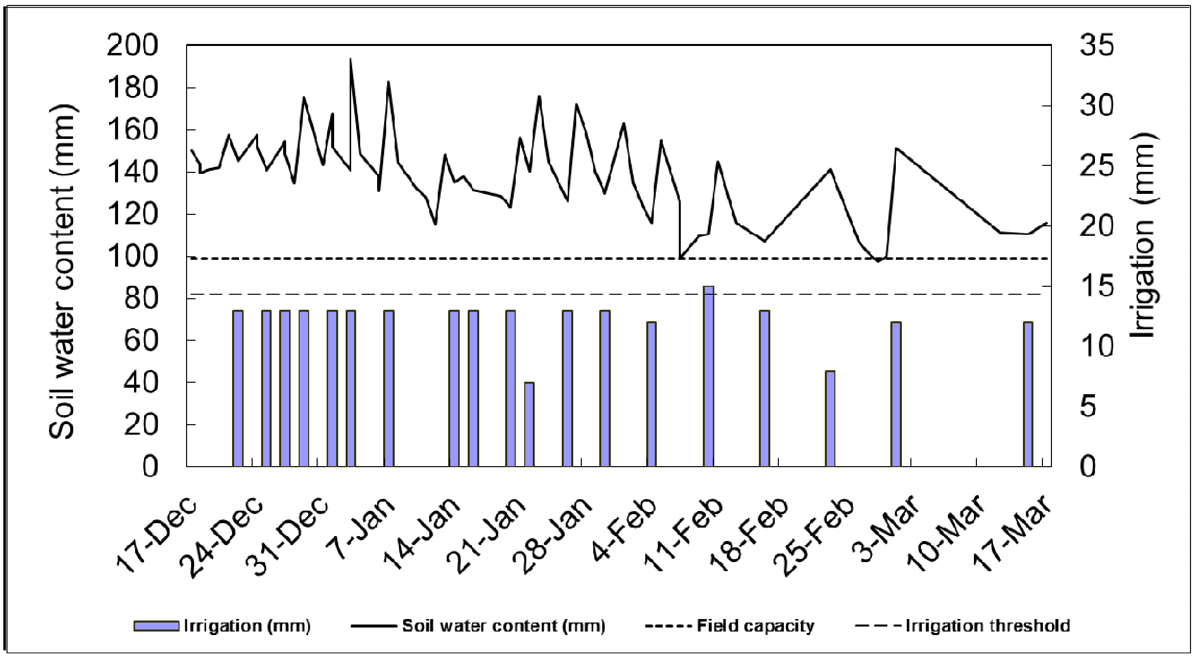

Figure 6. Soil water content measuring in the soil profile in location T3 with a Diviner 2000 calibrated per depth

Table 1. Depth, Soil series FC, PWP and Threshold of each observation point

Access tube	Depth (m)	Soil series phase	Soil Water Content (mm)		
			FC	PWP	30% Threshold
T1	0.60	1	101.00	37.85	82.06
T2	0.60	2	121.10	54.40	101.09
T3	0.50	2	99.10	42.20	82.03

Table 2. Calibration equations per depth and whole profile

Depth (m)	Coefficient a	Coefficient b	Calibration Equation	R2	RMSE
0.10	0.3130	0.3106	SF=0.3130 θw0,3106	0.9255	0.0177
0.20	0.3014	0.2988	SF=0.3014 θw0,2988	0.9143	0.0429
0.30	0.3477	0.2697	SF=0.3477 θw0,2697	0.9619	0.0320
0.40	0.4150	0.2168	SF=0.4150 θw0,2168	0.9390	0.0401
0.50	0.5294	0.1450	SF=0.5294 θw0,145	0.7342	0.0642
0.60	0.4884	0.1593	SF=0.4884 θw0,1593	0.5882	0.0780
(0-0.6 m)	0.3734	0.2470	SF=0.3734 θw0,247	0.8125	0.0467