ESTIMATION OF AVAILABLE WATER AND EVAPOTRANSPIRATION OF POTTED PLANTS WITH A FREQUENCY-DOMAIN SENSOR

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Abstract

The relation between volume fraction water (θ) of different peat-based growing media and permittivity (or dielectric constant ε) was determined using a frequency-domain (FD) sensor. After calibration in two organic mixes, θ could be estimated in rooted mixes in pot volumes ranging from 0.5 to 4 liter.

Marketable plants had a θ within the range 0.5 - 0.65 after a subirrigation period of 10 minutes (θ at capacity). Wilting point was at θ 0.12-0.20 for the potted ornamental plants *Spathiphyllum, Chrysanthemum, Chamaecyparis* and *Viburnum*. With the use of FD measurements, evapotranspiration of potted plants was determined under different transport and consumer conditions. Evapotranspiration varied between 7 and 91 g/pot.day for the crops. By dividing the amount of available water (derived from pot volume and difference between θ at capacity and at wilting point) with evapotranspiration data, potential transport time of potted plants was estimated to be at least 8 days. Both increased relative humidity (70 versus 40%) and decreased temperature (5 versus 15^{0}C) decreased evapotranspiration during transport simulation up to 50%.

Given the standard deviation in θ of 0.03-0.06 and desired accuracy (e.g. 0.05) it was calculated that 7-23 pots had to be measured in order to obtain a reliable sample estimation of water content. Application of the FD-sensor include quality control in the grower- retailer- consumer chain and on-line feed-back irrigation control.

Keywords: *Chamaecyparis*, *Chrysanthemum*, dielectric constant, moisture content, keeping quality, permittivity, *Spathiphyllum*, *Viburnum*

1. Introduction

During the last decades, technical innovations in potted plant production have resulted in amongst others advanced climate and fertigation control, automated transport and tracing and tracking systems. Despite these high-tech facilities, knowledge of e.g. transpiration by potted plants during production and post-harvest conditions are limited (Otten *et al.*, 1999). When (evapo)transpiration and available water can be estimated, irrigation may be optimised, and water stress and loss of concomitant economical benefits may be avoided, both during production and during post-harvest conditions.

For irrigation control and estimation of available water, tensiometers have been used (e.g. Lieth and Burger, 1989). However, tensiometers require frequent calibration and have laborious installation procedures, which limits it's use as a hand held meter. For direct estimation of water content, T(ime)D(omain)R(eflectometry) and F(requency)D(omain) sensors have become available over the last decade (e.g.

Gaskin and Miller, 1996; Whalley, 1993). The techniques are based on the determination of the dielectric properties (or permittivity) of a medium, and portable meters have become available. Among these, a FD sensor was introduced which simultaneously measures permittivity, temperature and bulk-EC. Particularly the latter may be used to estimate medium EC, which offers useful extra information in horticultural practice (Hilhorst, 1998).

The aim of the study was to investigate the possibility to estimate water volume of the medium by using the FD sensor and to estimate evapotranspiration during different post-harvest stages in order to be able to predict potential transport duration.

2. Materials and methods

2.1 Sensor description

The FD-sensor used has been developed at IMAG (WUR, The Netherlands) and will be marketed by delta-T (www.delta-t.co.uk). The sensor consists of three rods of which the outer two are interconnected. An oscillator in the sensor body applies a 20 MHz sinuoidal signal along the rods which extends in the medium. Since the dielectric constants of water (ca. 80) and air (1) differ, the water content of the medium around the rods determines how much of the signal radiates in to the medium and how much is reflected. The resulting voltage between the rods is used to calculate ε of the medium between the rods.

Besides measuring ε, the sensor measures temperature and bulk-EC, which allows to estimate EC of pore water. A more detailed description is given by Hilhorst (1998). In the setup used (photo 1) the sensor was connected to a hand-held computer (PSION Workabout) providing the necessary software and 5V power supply.

2.2 Laboratory calibration of organic growing media

In order to relate volumetric fraction water (θ) to permittivity (ε) in organic media, PVC rings (height 7.5 cm, diameter 7 cm; volume 288 ml) were used. For filling and settling, an additional ring was placed on top of this ring. At the bottom side, the rings were closed with permeable cloth. After weighing the rings, the rings were filled with two growing media according to a standardized method (Wever and Pon, 1990).

After saturation, the samples were subjected to either 0, -10, -32 or -100 cm pressure head. After 24 h, the top rings were removed, and the bottom rings were weighed. Permittivity measurements were performed per potting mix by vertically inserting the FD-sensor until the sensor rods were completely in the potting mix. Volumetric water content was determined by drying the samples for at least 48h at 105^0C (n=64).

2.3 Crop experiment

Permittivity measurements were conducted in a range of pot sizes containing different crops and media (Table 1). The crops were obtained from growers. After a subirrigation period of 10 minutes (defined as θ capacity) the plants were placed under transport conditions in the dark (at 5 or 15^{0}C and r.h. of 40 or 70%). Afterwards, the plants were placed in a climate chamber simulating consumer conditions (20^{0}C; r.h. 60%; light intensity 14 µmol.m^{-2}.s^{-1} during 12h).

For the estimation of volumetric water content plant fresh weight and soil dry weight (48h at 105^{0}C) and pot volume were determined at the end of the experiment. During a drying cycle weight of the pots and permittivity were simultaneously measured at different times. Wilting point was determined visually when the first and last plant of a sample showed signs of turgor loss. Several times (at arrival, 1 h after saturation, after transport, at wilting) permittivity readings and weight of the pots were recorded simultaneously in order to determine evapotranspiration and to relate permittivity readings with water volume as determined by weight.

3. Results

3.1 Calibration of different growing media

The growing media which were used contained either perlite or clay as additive, which resulted in large differences in bulk density, and slightly different water retension curves (Table 2). In combination with the calibration points of air ($\varepsilon = 1$) and water ($\varepsilon = 80$) a third-order polynomial was fitted through both growing media data (Fig. 1):

$$\theta = 3.8\ 10^{-6} * \varepsilon^3 - 5.31\ 10^{-4} * \varepsilon^2 + 3.07\ 10^{-2} * \varepsilon \qquad r^2 = 0.97 \qquad (1)$$

Subsequently it was tested whether this relation could predict water content in rooted growing media in different pot sizes and growing media from marketable plants obtained from growers. A large number of readings (>1250) was taken from the crops at different post-harvest stages (Fig. 2). The standard deviation in θ was at most 0.03-0.06. Coefficient of variation in θ was less than 10%. The best third-order polynomial fit through the origin was:

$$\theta = 5.2\ 10^{-6} * \varepsilon^3 - 7\ 10^{-4} * \varepsilon^2 + 3.6\ 10^{-2} * \varepsilon - 0.0477 \qquad r^2 = 0.95 \qquad (2)$$

Since (1) and (2) do not differ significantly, it shows that the generic relation (1) could be applied in 1) rooted media , and 2) in a wide variety of pot volumes. Subsequently, when the volume of the growing medium in the pot can be estimated, water volume can be estimated also (Fig.3).

3.2 Wilting point

Wilting point was determined when the first and the last plant had wilted of the sample (Table 4), and ranged between 0.12-0.20.

Evapotranspiration was determined with the use of the FD sensors during transport and consumer conditions (table 3). Highest evaporation was found under low (r.h. 40%) humidity and high (15^{0}C) temperatures during transport conditions. Not all crops reacted similarly to humidity and temperature during transport: *Chamaecyparis* showed hardly any response to increased humidity, whereas the other crops decreased evaporation by 40-50%. The effect of decreased temperature was mainly seen at low humidity. Since *Spathiphyllum* did not recover from the low temperature conditions, no data are available for this treatment.

As consumer simulation was performed only after transport simulation, water presumably was less available (water fraction after transport was between 0.19 and 0.56), thereby reducing evapotranpsiration compared to the saturated conditions at the start of transport conditions.

Depending on the transport conditions, potential transport time for the crops were in the range of 8-46 days. The minimum potential transport time at 15^0C and 40% r.h. was 8-23 days.

4. Discussion

The volume fraction water in a number of pot plants and pot sizes was estimated relatively accurately with the use of calibration (1). Assuming that the measured volume is predominantly 0.01 m around the rods, this would mean that at most 0.08 l is measured. Apparently, even in pot sizes with heights exceeding the rod length by more than 100% and with a volume of nearly 4 l such as in *Viburnum*, water volume could be estimated sufficiently accurate (Fig. 3). Only at very low water contents, where no data in the calibration procedure were available, (1) overestimated θ, possibly due to the dielectric properties of the growing media itself. However, under practical conditions these low θ values will not be reached easily.

Variation increased with water content. Standard deviation in θ at arrival from the grower was 0.03-0.05 whereas at wilting this was 0.01-0.03. To calculate the required number of permittivity readings (pots) to be taken in order to obtain a reliable estimate of θ or water volume, the standard deviation, desired accuracy and significance level have to be known (Owen, 1962). The highest standard deviation found in θ was 0.06. At a significance level of 0.05, 7 or 23 readings should be taken at a desired accuracy in θ of 0.10 and 0.05 respectively. For the average standard deviation of 0.04 the number of readings required would be between 9-12.

The data on evaporation show that evapotranspiration can be influenced dramatically by environmental conditions during transport conditions (Table 4). This, together with the large variation in transpiration due to other factors e.g. crop size, crop specific leaf characteristics, spacing and growing conditions, cast doubt on whether evapotranspiration can be estimated even roughly. It might therefore be far too ambitious to predict potential transport duration based on an estimate of evapotranspiration. However, the easy-to-use and rapid estimation of θ enables to establish quality procedures in pot plant production and post-production stages. For instance, a minimum water content could be required at different stages in the grower–auction–retailer–consumer chain, which offers possibilities for tracing and tracking systems.

Another application of the FD-sensor is its use as a feed-back controlling unit in the irrigation of potted plants. This may replace the more conventional periodical fertigation normally used by growers. By using a fixed permittivity as setpoint in this manner, *Nephrolepis* growth increased by avoiding water stress. Alternatively, growth regulation by drought stress was accomplished in *Impatiens* new Guinea by using a permittivity as setpoint (Baas, 2000).

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Table 1. Experimental variables of the experiment to verify laboratory calibration results and to determine evapotranspiration.

Potvolume *(ml)*	Pot height *(mm)*	Plant species	Plant weight *(g FW)*	Bulk density *(kg/m^3)*
550	89	*Chrysanthemum*	116	97
735	89	*Spathiphyllum*	145	111
309	70	*Chamaecyperis*	32	113
3733	158	*Viburnum*	498	132

Table 2. Physical characteristics of media used for laboratory calibration

medium	clay fraction	perlite	bulk density (kg/m3)	θ pressure head (cm) 0	θ -10	θ -32	θ -100	porosity
perlite-mix	0	0.25	79	0.66	0.61	0.40	0.28	0.98
clay-mix	0.05	0	249	0.68	0.61	0.44	0.35	0.95

Table 3. Water content at market stage, after subirrigation during 10 min. ($\theta_{capacity}$), and at first and last plant showing loss of turgor. Available water was calculated as Pot volume * ($\theta_{capacity}$-$\theta_{wilting\ first}$)

	Pot volume ml	θ grower	θ capacity	θ wilting first plant	θ wilting last plant	available water g/pot
Chrysanthemum	550	0.49	0.64	0.20	0.15	242
Spathiphyllum	735	0.50	0.63	0.19	0.15	323
Chamaecyparis	309	0.60	0.65	0.13	0.12	161
Viburnum	3733	0.47	0.51	0.17	0.15	1269

Table 4. Evapotranspiration and calculated potential transport time. Evapotranspiration under consumer conditions was determined after transport simulation. Note: *Spathiphyllum* pots were sleeved under transport simulation conditions, and did not survive 5^{0}C.

	transport simulation				consumer simulation
Relative humidity (%)	40	40	70	70	60
Temperature (^{0}C)	15	5	15	5	20
V.P.D. (g/kg)	6.3	3.3	3.2	1.6	3.0
light (μmol.m^{-2}.s^{-1})	0	0	0	0	14
	evapotranspiration (g/g.day)				
Chrysanthemum	0.18	0.10	0.09	0.11	0.19
Spathiphyllum	0.09	*	0.05	*	0.27
Chamaecyparis	0.59	0.43	0.53	0.41	0.28
Viburnum	0.18	0.11	0.11	0.09	0.15
	evapotranspiration (g/pot.day)				
Chrysanthemum	21	12	11	13	21
Spathiphyllum	14	*	7	*	39
Chamaecyparis	19	14	17	13	9
Viburnum	91	53	53	43	74
	potential transport time (days)				
Chrysanthemum	11	20	22	18	11
Spathiphyllum	23	*	46	*	8
Chamaecyparis	8	11	9	12	17
Viburnum	14	24	24	29	17

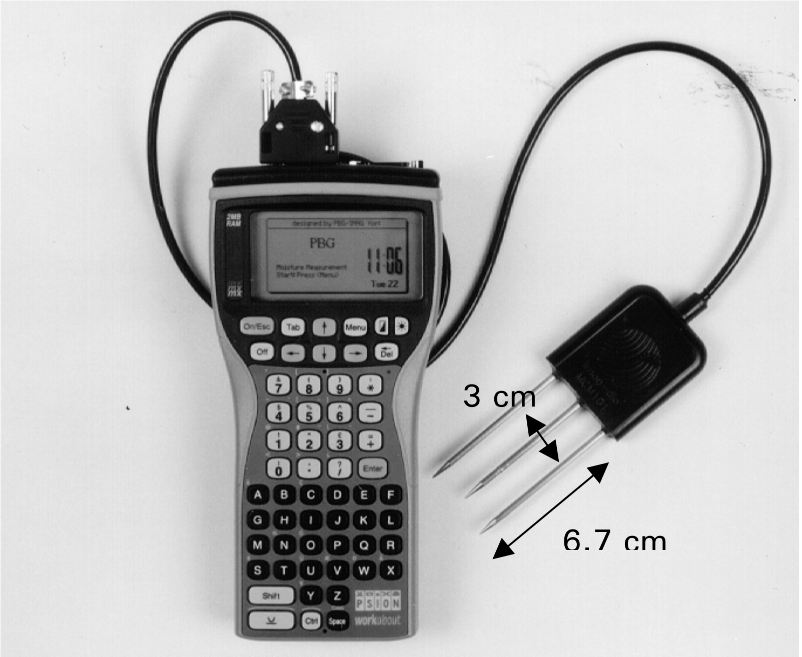

Photo 1. The FD sensor including logger as used in the experiments.

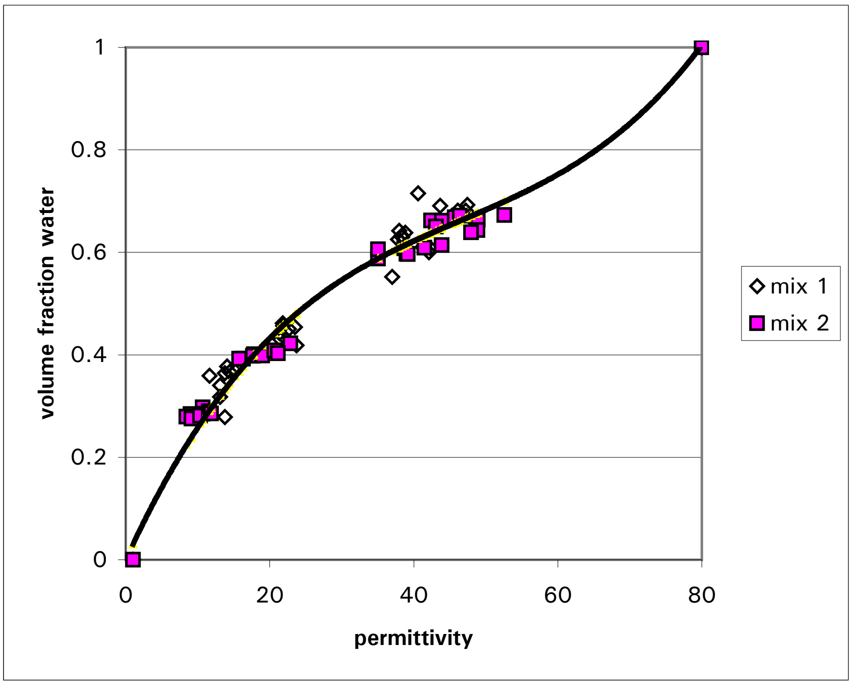

Fig. 1. Relation between permittivity and water fraction in non-rooted perlite containing (closed symbols) and clay containing (open symbols) organic mixes (see table 1).

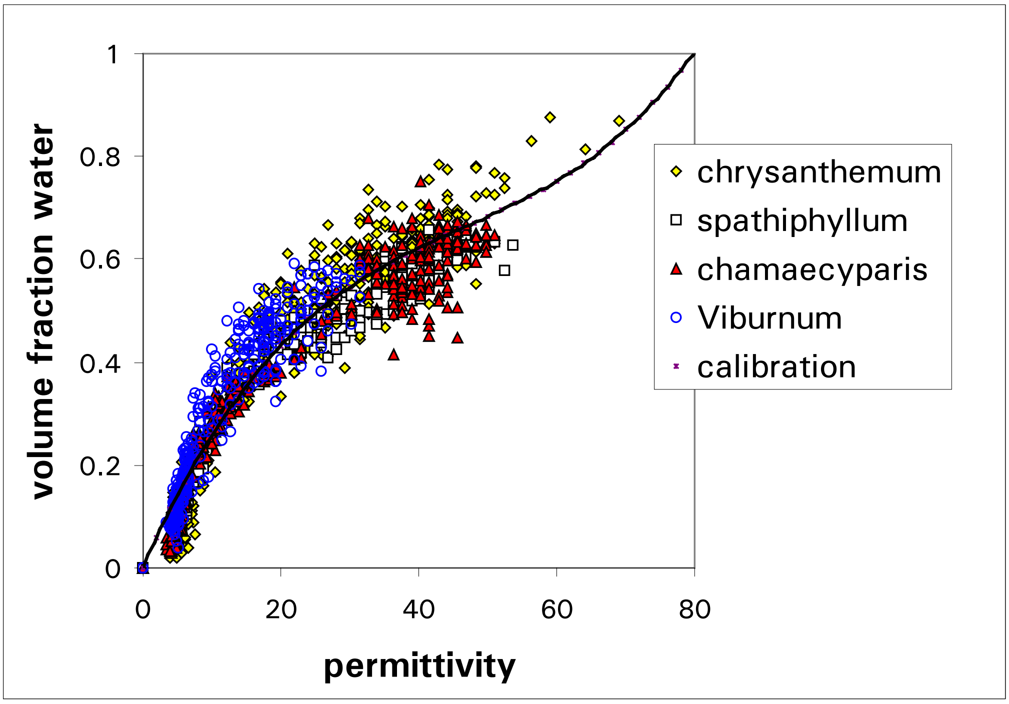

Fig. 2. Relation between permittivity and water fraction in rooted organic mixes.

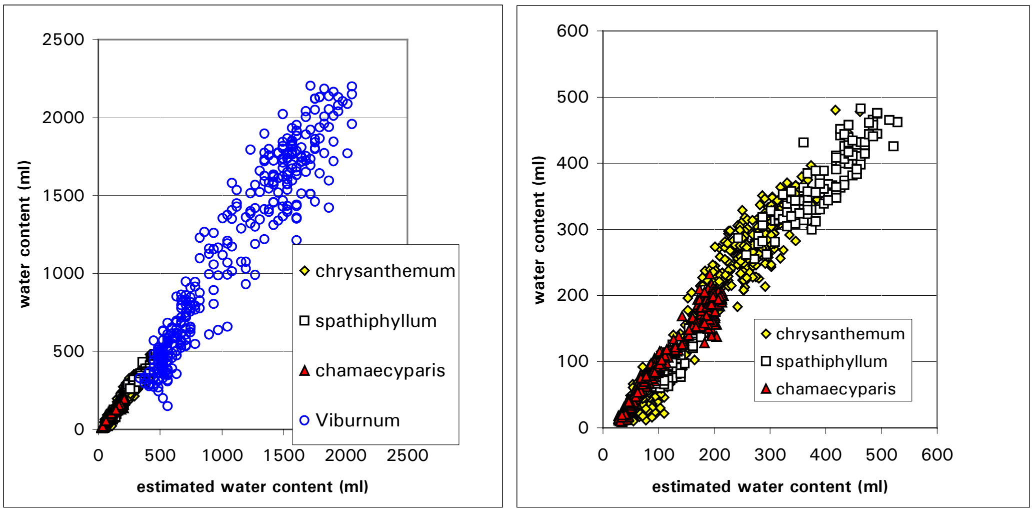

Fig. 3 Estimated water volume (from permittivity) compared to water volume (by weight) in pots of different volumes containing different crops (see Table 3).