[1]IN SITU MONITORING WATER CONTENT AND ELECTRICAL CONDUCTIVITY IN SOILLESS MEDIA USING A FREQUENCY-DOMAIN SENSOR

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Abstract

A previously developed frequency-domain (FD) sensor (Hilhorst et al. 1992, Acta Hortic. 304:209) with 4 cm long electrodes was calibrated under laboratory conditions in solution, rockwool and potting media. Linear relations between permittivity ε (dielectric constant) and bulk electrical conductivity (EC_b) were found in rockwool, allowing to estimate the EC of the medium solution (EC_{ms}) up to at least 6 mS/cm after temperature correction. Volumetric water content (θ) was highly correlated with ε after temperature and EC-corrrections (ε_c), and appeared to be independent of bulk density in mineral wool. The sensor was used for determining vertical differences in ε_c in 6.5 cm high rockwool cubes used for rose propagation.

In organic media such as potting soil used for ebb-and flow fertigation, linear relations between ε and EC_b were found as well. However, sensitivity to differences in EC_{ms} was lower in these organic media than in rockwool. EC_{ms} could be estimated reliably up to 3 mS/cm. The ε_c and EC_{ms} were measured in potting soil during ebb-and flow cycles under greenhouse conditions. This *in situ* measuring showed that EC_{ms} increased at decreased θ. Practical implications for use of the sensor are adressed.

Additional index words: ebb/flow cultivation, EC, hydroponics, root alcohol dehydrogenase activity, salinity

1. Introduction

A significant proportion of horticultural crops are grown in soilless culture. In 1995, 75% of the vegetables and 25% of the flower crops under glass in the Netherlands were grown in media other than soil, predominantly rockwool. By definition, potting and border plants are completely cultivated soilless, and grown in organic potting media. Irrigation in these cultivation systems can be done either by overhead irrigation such as drip irrigation (mostly vegetables and cut flowers) or sprinkler irrigation (mostly potting and border plants), or by subirrigation such as ebb/flow or capillary matting (potting plants). Frequency and amount of irrigation water is done by the growers >green fingers= and/or helped by climate-measuring (radiation) dependent models estimating crop transpiration (e.g. de Graaf and Van den Ende 1981). Commercial use of measuring equipment with regards to the water status in media involve the use of drain volume measurements, and - on limited scale - tensiometers. Recently, a frequency domain (FD) sensor was developed (Hilhorst et al. 1992), which measures permittivity ε (dielectric constant) at 20 Mhz in an electrical impedance. Since electrical conductivity and temperature influence the measured ε at this frequency, they are simultaneously measured, allowing correction procedures. Due to the large difference in ε for air (around 1) and water (around 80), and little influence of the soil matrix, ε can be related to volumetric water content θ.

The FD-sensor looked promising with respect to commercial use in growing media for a number of reasons:

- θ is measured instead of the tension as with tensiometers. In horticultural growing media differences in water content can be large (e.g. 10%) at small differences in tension (e.g. Da Silva et al. 1995); this limits the use of tensiometers
- the *in situ* estimation of the EC_{ms} is a potential advantage. EC_{ms} is an important indicator for the nutritional and/or salinity status in media of cut flowers and potting plants (Anonymous 1994). The on-line EC-measurement offers the possibility for corrections of the EC_{ms} by manipulating the EC of the applied nutrient solution without the need for taking and analyzing samples from the medium.
- since the measuring volume can be limited to a few cm, vertical and horizontal differences in water content and/or EC and/or temperature can be measured.

This study describes results of the calibration procedure developed for a number of salt solutions, mineral wools and organic media. Examples and interpretations of measurements in greenhouse trials are given.

2. Materials and methods

2.1 Calibration in NaCl solutions

The FD-sensor used (IMAG-DLO, Wageningen, The Netherlands) consisted of two 4*0.2 cm (l*diam.) electrodes. The distance between the electrodes was 2 cm with one temperature sensor (length 3.5 cm) positioned in between.

In the calibration procedure the readings ε of air and water at 19 ^{0}C were set at 0 and 100 respectively.

NaCl solutions of different conductivities were made. The EC of the solutions as corrected for the temperature (25 ^{0}C) were 0, 3, 5.9 and 8.7 mS/cm. A 500 ml beaker was filled with solution, and the temperature was raised on a heating plate. From ca. 20 ^{0}C up to ca. 35 ^{0}C the ε, EC and temperature were simultaneously measured with the FD-sensor.

2.2 Calibration in blocks of mineral wool

Rockwool blocks (10*10*6.5 cm, l*w*h) were saturated with nutrient solutions of 1.0, 2.0, 2.9, 3.9, 5.0 and 6.0 mS/cm. FD measurements were made within each block at tensions of 0, 6.5, 13 and 16.5 cm using rockwool. There were three blocks per individual treatment, and at each tension three measurements were made by placing the sensor vertically in the rockwool blocks.

In a second calibration procedure the influence of bulk density on ε was determined. Therefore, rockwool blocks of 58, 67, 71, 76 and 79, and a glasswool block of 51 kg/m^3

were used. Permittivity as measured horizontally in the middle of the blocks was related with θ of the blocks as determined gravimetrically.

2.3 Measurements in mineral wool during rose cutting production

Rose cuttings were rooted in blocks with bulk densities of 51, 71, and 79 kg/m^3. The cuttings were placed 3.7 cm deep in the blocks. After 19 days, blocks were weighed in order to determine θ. Roots were sampled from the cuttings, in which extractable alcohol dehydrogenase (ADH) activity was determined as an indicator of oxygen stress (Baas and Warmenhoven 1995; Baas et al. 1996).

In a seperate experiment vertical differences in ε were measured by placing the sensor horizontally in rockwool blocks at approximately 1.6, 3.3 and 4.9 cm above the surface.

2.4 Calibration in organic media

Two PVC cylinders (5 * 7 cm, h* diam.) were filled with organic medium. The rings were saturated with nutrient solution of a known EC. After 24 h, the top ring was removed from the bottom ring, so that a filled ring could be used for measurements. There were three rings per individual treatment, and three measurements were made by placing the sensor vertically in the medium. Consequently, measurements were made at another tension. The following media, tensions and EC=s were used:

medium	**tensions(cm)**	**EC saturation solution (mS/cm)**
ebb/flow peat	0, 13, 32, 100	0.5, 1.5, 2.5, 3.5, 4.6, 5.7
cocopeat	0, 10, 26	0.2, 2.1, 4.0, 5.5

Before measuring, 3-10 ml nutrient solution was sampled - using soil moisture samplers (Eijkelkamp, The Netherlands) connected to a vacuum blood sample tube - in which the EC was determined (EC_{sms}). Rings were subsequently weighed for determining θ. After the highest tension, the medium was pressed for sampling of solution for EC (EC_{ps}). Since differences between EC_{sms} and EC_{ps} were generally within 10%, the average value was defined as representing the EC_{ms}.

2.5 Measurements in organic media in greenhouse

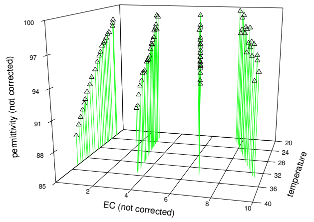
During a fertilizer trial with Kalanchoe potting plants cultivated in ebb/flow mixture, FD measurements were done with nine sensors in a multiplexer system. Fertigation was by means of ebb/flow with an interval of 48 hours. The sensors were placed vertically in the lower 2/3 of the pot (12* 9 cm, diam*h). Measuring interval was 12 hours during a six-week period. To compare estimated EC_{ms} with actual EC_{ms}, medium solution was obtained weekly after a flooding period using soil moisture samplers, and EC was measured.

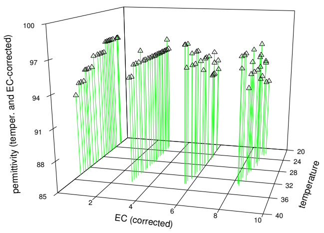
During a short period during the cultivation period the measuring interval was 3 hours to obtain more insight in fluctuations in temperature, EC_c and ε between irrigation cycles.

3. Results and discussion

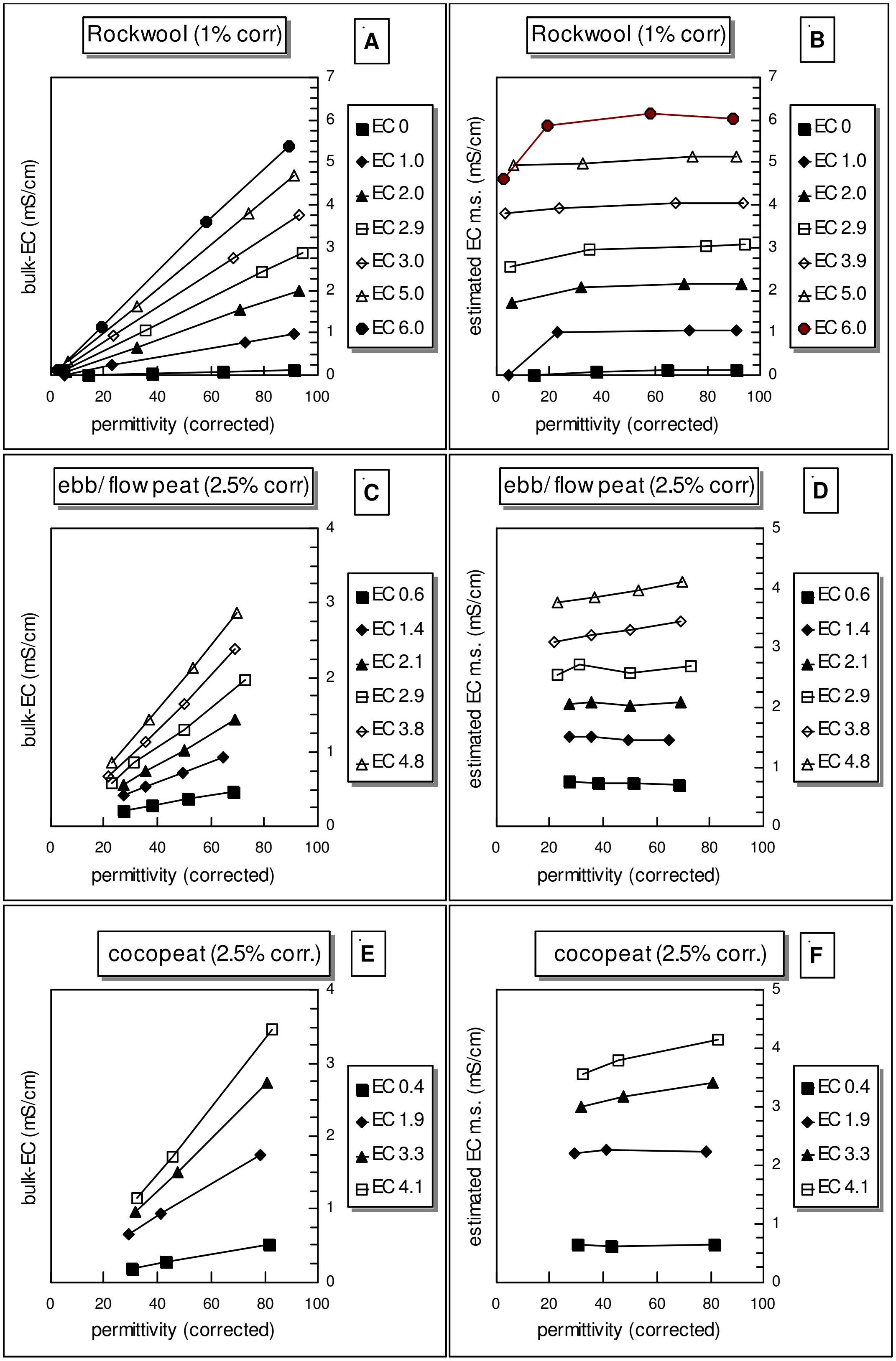
3.1 Calibration in NaCl solutions.

Results of the calibration procedure in different EC solutions are given in fig. 1. A relative temperature dependency of the measured EC of 2%/^{0}C was found. As can be seen in fig. 1, the temperature dependency of the ε was influenced by the EC, and was on average 0.5 units/^{0}C, which agrees with previously given data (Hilhorst et al. 1992).





Besides temperature, ε was also influenced by EC; on average an EC dependency of ε of 0.4 units per mS/cm was calculated. Using these data, corrections for EC and subsequently ε were calculated, resulting in temperature- and EC-corrected permitivity data ε_c (fig. 2). These corrections decreased maximal differences in ε from 13 to 4 units.


Rockwool (1% corr)
A
bulk-EC (mS/cm)
0
1
2
3
4
5
6
7
0
20
40
60
80
100
permittivity (corrected)
EC 0
EC 1.0
EC 2.0
EC 2.9
EC 3.0
EC 5.0
EC 6.0
Rockwool (1% corr)
B
estimated EC m.s. (mS/cm)
0
1
2
3
4
5
6
7
0
20
40
60
80
100
permittivity (corrected)
EC 0
EC 1.0
EC 2.0
EC 2.9
EC 3.9
EC 5.0
EC 6.0
ebb/ flow peat (2.5% corr)
C
bulk-EC (mS/cm)
0
1
2
3
4
0
20
40
60
80
100
permittivity (corrected)
EC 0.6
EC 1.4
EC 2.1
EC 2.9
EC 3.8
EC 4.8
ebb/ flow peat (2.5% corr)
D
estimated EC m.s. (mS/cm)
0
1
2
3
4
5
0
20
40
60
80
100
permittivity (corrected)
EC 0.6
EC 1.4
EC 2.1
EC 2.9
EC 3.8
EC 4.8
cocopeat (2.5% corr.)
E
bulk-EC (mS/cm)
0
1
2
3
4
0
20
40
60
80
100
permittivity (corrected)
EC 0.4
EC 1.9
EC 3.3
EC 4.1
cocopeat (2.5% corr.)
F
estimated EC m.s. (mS/cm)
0
1
2
3
4
5
0
20
40
60
80
100
permittivity (corrected)
EC 0.4
EC 1.9
EC 3.3
EC 4.1

3.2 Calibration of EC in rockwool blocks

In fig. 3A the results of the calibration in rockwool are shown. Linear relations between EC- and temperature corrected ε and temperature-corrected bulk-EC (EC_b) were found. When an EC-dependency of the ε of 1 unit per mS/cm was used, the estimated EC_{ms} corresponded well with EC of the saturation solution when extrapolating to an ε_c of 100 (figure 3B). Only at permittivities under 20 (which do not occur under practical growing conditions) EC_{ms} was underestimated.

3.3 Calibration of EC in organic media

Calibration in ebb/flow potting medium containing white peat and 15% perlite (fig. 3C) and cocopeat (fig. 3E) also revealed linear relations between EC_b and ε. EC_{ms} was estimated by extrapolating to an ε_c of 100 (figure 3D and 3F) using an EC-dependency of the ε of 2.5 unit per mS/cm. Up to an EC_{ms} of 3 mS/cm the estimation corresponded relatively well with the EC=s of the medium solution which had been sampled from the media. At higher EC values, and particularly at lower $\varepsilon_{c,}$ EC_{ms} was underestimated.

3.4 Calibration of water content in mineral wool

Permittivity ε (corrected for temperature and EC) as measured horizontally in the middle of 6.5 cm high blocks of mineral wool correlated well with θ of the whole blocks as measured gravimetrically (fig. 4). The influence of bulk densityof the mineral wool in the range 51-79 kg/m3 appeared to be negligable. An overall relation was calculated as:

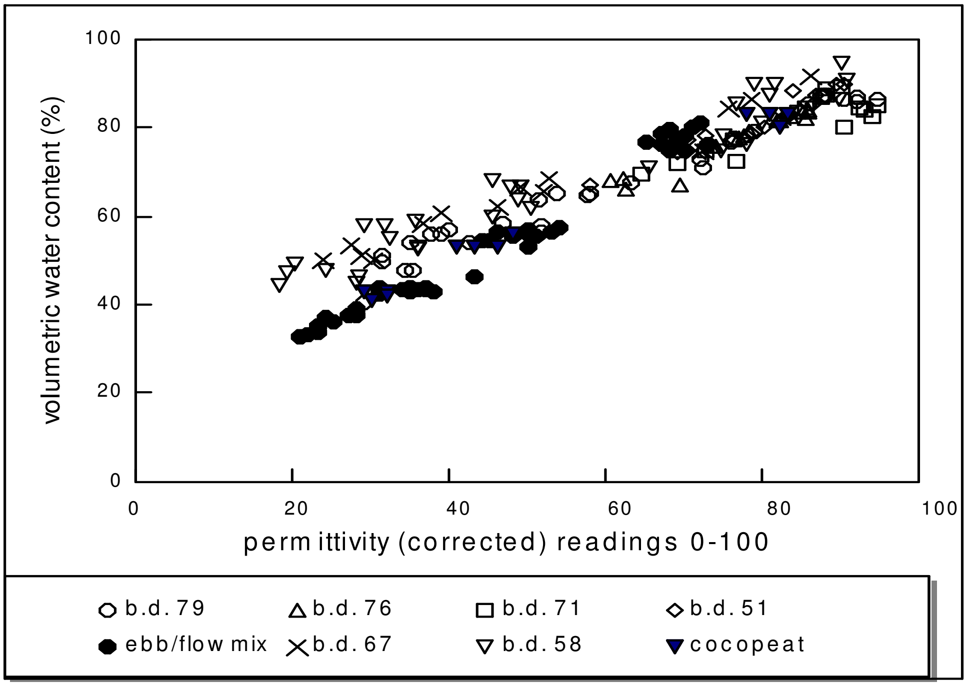
(1)$\theta = 9.3+2.01*\varepsilon_c - 2.5*10^{-2}*\varepsilon_c^2 + 1.4*10^{-4}*\varepsilon_c^3$ ($r^2 = 0.96$)

3.5 Calibration of water content in organic media

In fig. 4 the results of the calibration in cocopeat and ebb/flow potting medium are also given. An overall relation was calculated as:

(2)$\theta = 5.0+1.34*\varepsilon_c - 0.7*10^{-2}*\varepsilon_c^2 + 0.3*10^{-4}*\varepsilon_c^3$ ($r^2 =0.99$)

The calibration curve differs from the rockwool curve. It should be noted that the vertical positioning of the sensor in the calibration procedure, in combination with the lower height of the sample (5 cm cylinder instead of 6.5 cm of the rockwool blocks) may - at least partly - account for the difference between the equations at low ε_c.



<u>3.6 Vertical differences in ε in mineral wool</u>

ADH activity, extracted from rose roots grown in in the lowest 1/3 of blocks of mineral wool was especially low in medium 2 (tension of 6 cm was applied in this treatment), and high in medium 3 (table 1). Since ADH-activity is increased at low oxygen-availability, which itself is related to high water content (e.g. Gislerød 1983a), we wondered - since the roots were mainly in the lower 1/3 of the blocks - whether θ of the root zone was better related to ADH activity than θ of the whole blocks. Therefore, permittivities were measured at three heights in the blocks. A clear gradient in ε_c was found in all blocks, but this was particularly the case in medium 3. Root ADH correlated slightly better with ε_c measured in the lower and middle of the block, than with ε_c of the whole blocks. These results show that small-scale vertical differences in θ could be adequately detected with the ε_c measurement, and that this scale of measuring can have root physiological significance.

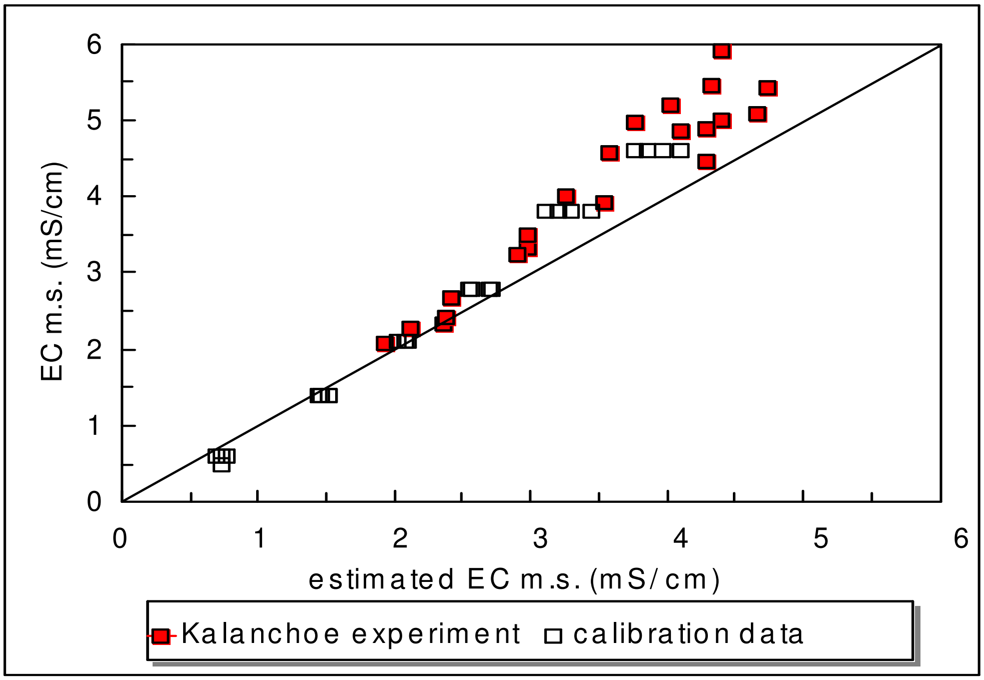
Table 1- ADH activity from roots of 19-day old rose cuttings propagated in different media and water content at day 19. Permittivities measured at different heights of the same 6.5 cm high media are also given. LSD = least significant difference at P=0.05. r.w.= rockwool; g.w. = glasswool

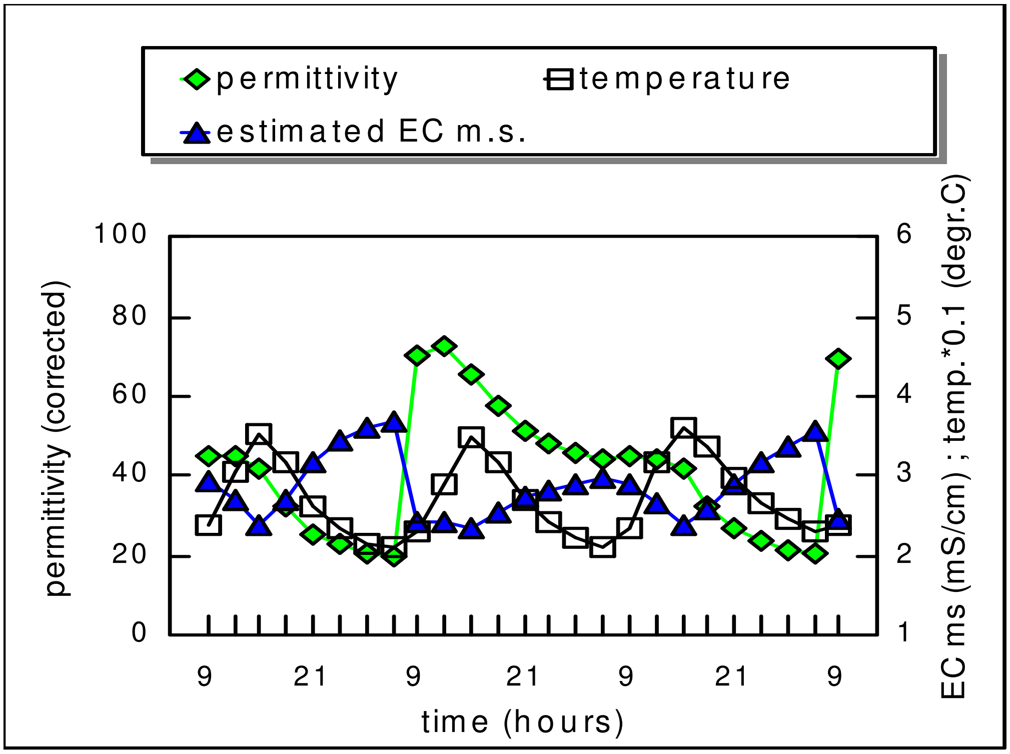
medium	root ADH (µmol NADH/g protein^{-1}.min^{-1})	θ	ε_c highest 25%	ε_c middle 25%	ε_c lowest 25%
1. r.w. 79 kg/m^3	898	70	46	67	78
2. r.w. 79 kg/m^3	440	43	14	21	31
3. r.w. 71 kg/m^3	1716	73	47	75	84
4.g.w. 51 kg/m^3	734	69	43	58	71
LSD	449	1	3	4	3

3.7 Measurements in organic media during greenhouse trials

The weekly measured EC as determined by soil moisture sampling after the flooding periods during a six-week period in a Kalanchoe cultivation were compared with the simultaneously measured EC_{ms} (fig. 5). EC_{ms} was underestimated by the FD-sensor at values higher than 3 mS/cm. This corresponds with the results obtained in the laboratory with the calibration (fig. 3D), indicating that under cultivation conditions (with roots in the growing medium) similar results are obtained.

In fig. 6 the results of a three-day measuring period are given. Temperature fluctuated between 20 ^{0}C at night and 37 ^{0}C in the afternoon. Clear effects of flooding periods (at 9 a.m. at day 2 and 4) on ε_c were apparent. Estimated EC_{ms} increased quite strongly when ε_c decreased below 40, which according to equation (2) corresponds with a θ of 49%. It should be noted that estimated EC_{ms} was actually underestimated (see fig.5), particularly at low ε_c. It can be deduced that actual EC_{ms} values just before flooding were approximately 4.5 mS/cm. These relatively high EC_{ms} values potentially decrease yields of horticultural crops due to salinity-induced water stress (e.g. Sonneveld and Van den Bos 1995). It is conceivable that higher growth rates at higher irrigation frequencies (Otten 1994) may be related to avoidance of these high EC_{ms} -values.




permittivity
temperature
estimated EC m.s.
permittivity (corrected)
100
80
60
40
20
0
EC ms (mS/cm) ; temp.*0.1 (degr.C)
6
5
4
3
2
1
9
21
9
21
9
21
9
time (hours)

3.8 Concluding remarks

After corrections for temperature and ε the FD-sensor proved to give an accurate estimation of EC up to at least 6 mS/cm in rockwool in θ ranges normally occurring in horticultural practice. In the organic media however, estimated EC_{ms} became less sensitive if the EC_{ms} exceeded 3 mS/cm. The EC advice for potting plants in the Netherlands is in the range of 0.31-0.88 mS/cm in the 1:1.5 volume extract method (Anonymous 1994). When these EC-values are recalculated in EC_{ms} values using a factor 2.77 (Sonneveld and Van Elderen 1994) the optimal measuring range would be 1-2.5 mS/cm, which still would be within the reliable measuring range of the FD sensor (fig. 5).

For monitoring the water status of growing media the sensor proved to give a reliable indication. Coefficient of variation in rockwool could be relatively high however, and ranged between 9 and 25%. Particularly at lower θ, the steep water retention curve of rockwool is responsible for these local differences in ε. Particularly when the sensor will be used for water management control, attention should be given to limiting this variation, e.g. by increasing the measuring volumes and/or multi-point measurements.

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