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Temperature and Salinity Effects on Measurements of Growing Media Moisture Content Carried Out with TDR and Capacitance Probes

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Abstract

The irrigation of pot crops requires considerable monitoring because the autonomy of the water reserve of the growing media is low in relation to plant water requirements. Computerized systems for irrigation management are therefore under investigation at this time. Time Domain Reflectrometry (TDR) is used to directly measure the water content of a soil. For growing media, the relationship between the dielectric constant K_a and the water content is valid provided that the calibration equation, generally polynomial, is established for each medium. Thus, the practical use of this equipment in horticulture can be proposed, but its high cost remains a major obstacle. That is why we are looking for other less expensive alternatives that work on a similar principle. Two types of material (TDR and ECH_2O capacitance probe) were tested at four different water potentials (-1, -5, -10 and –20kPa), in two growing media (peat/perlite and peat/bark mixtures). In order to check their reliability under different operating conditions, measurements were carried out at two average temperatures (14.1 and 24.5°C) and at three increasing salinities; the growing medium was moistened with a solution containing 0.1 and 2 g/L of soluble fertilizer. The results showed the non-sensitivity of TDR under environmental conditions, except to the growing medium composition, and the high sensitivity of ECH_2O probes to salinity. This material also requires an individual calibration of each probe, but is not sensitive to the temperature and to the type of growing medium. It is also much less expensive than TDR.

INTRODUCTION

Soilless culture requires precise monitoring of the moisture content of the growing medium because the quantity of water available to the plant is low as a result of the limited volume of the growing medium explored by the roots. The water content of the growing medium varies rapidly, ranging from a value close to saturation just after irrigation, to a dryness level that varies according to climatic demand (potential evapotranspiration).

Thus, precise moisture monitoring is necessary to quantify the water resource and to follow its evolution, in order to be able to apply adapted irrigation means when this resource becomes too low.

The measurement of growing medium water potential by tensiometry has been used with success (Rivière et al., 1991). Below a specified potential, commonly established at -10k Pa, the roots of the plant have increasing difficulty in absorbing the water retained by the growing media. Irrigation recommendations can therefore be established on the basis of this threshold. Tensiometry is well understood at the experimental level but it has met with resistance among growers because of the relative complexity of its installation.

The measurement of growing media moisture content by Time Domain Reflectometry (TDR) could be an alternative to tensiometry. Originally used to test electric cables, the use of TDR in soil studies rapidly developed as of the 1980s because it is relatively simple to use and measures volumetric moisture with a low degree of uncertainty (Whalley, 1993). The principle of this technique is to measure the apparent dielectric permittivity (K_a) of the soil using a probe with several (from two to four) metal rods inserted in the ground. The transmission time of the electromagnetic waves running through these rods is a function of the length of the rods, which is known, as well as of the dielectric constant K_a. The soil is a medium made up of three phases: solid, liquid and gas. The value of K_a is a function of the equilibrium between these three phases. It ranges from 3 to 7 for solid matter, 1 for air and 80 for water. Therefore, the value of K_a for a specific medium is highly correlated with its water content by a direct relationship that can be calculated.

These equations are either polynomial (Topp et al., 1980) or linear (Ledieu et al., 1986), in the case of soil.

For growing media with peat, perlite and bark, some calibration curves (polynomial) have been obtained under laboratory conditions (Morel and Michel, 2004).

The dielectric constant K_a can also be calculated from measurements made with capacitance probes. Whereas the TDR probe measures the transmission time of an electromagnetic wave train running through the medium, the capacitance probe measures the time of charge of a capacitance inserted in the medium, where the tension applied to this capacitance is known.

However, regardless of the method used to measure K_a, the difficulty is to link this value to the actual growing medium moisture content by a reliable calibration curve. What is the influence of the conditions of the actual growing medium while measurements are being taken and, in particular, temperature and salinity?

The purpose of this present study was to try to answer this question.

MATERIAL AND METHODS

Measurements were made in two sphagnum peat-based mixtures, at two temperature levels and three salinity levels.

Probes

Two probe models were used for the test (Fig. 5):

- An 8-cm-long TDR probe (Time Domain Reflectometry): Trace 6050X1 from Soil Moisture Equipment Corp., CA, USA.
- A 10-cm-long ECH2O 10 capacitance probe from Decagon Devices, Inc., USA.

For each probe model and each trial, three probes were used in order to obtain three replications for each measurement.

Growing Media

Measurements were made on two different mixtures:

- 75% Irish sphagnum peat (0–10 mm) and 25% perlite,
- 75% Irish sphagnum peat (0–10 mm) and 25% composted bark of maritime pine (5–10 mm).

Temperatures

Measurements were successively carried out at two different average temperature levels for each trial:

- 14.1°C
- 24.5°C

Measurements were made in a laboratory facing north.

These two temperature levels were obtained by taking advantage of the actual climatic conditions at the time and by heating the room when necessary.

Salinity

The soils were soaked for 24 hours in three solutions with increasing salinity:

- Water (E.C.: 0.4 mS/cm),
- Peters water-soluble fertilizer solution, 1 g/L, E.C.: 1.3 mS/cm,
- Peters water-soluble fertilizer solution, 2 g/L, E.C.: 2.57 mS/cm.

Excess water was drained off by gravity.

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Applied Water Potential

Moistened substrates were placed on a suction table and were subjected to increasing potentials: -1, -5, -10 and –20 kPa. The protocol used was based on the standardised European method, EN 13041, which defines how to saturate the substrate and to then measure the water content for a potential of -1 kPa.

Equilibrium time between two successive potentials was 48 hours.

The moisture content was given in the results by the volumetric water content. The shrinkage was very weak during the test with the used mixtures; therefore, the substrate volume was regarded as constant.

RESULTS

TDR Probes

1. Temperature Impact. An ANOVA was carried out on the K_a values, obtained at low and high temperatures, for the peat/perlite mixture, under low salinity conditions. The difference between treatments was not significant: error probability = 0.178, with K_a = 10.84 at T° = 14.1°C and K_a = 10.56 at T° = 24.5°C.

2. Probe Impact Itself. A comparison of the K_a values, measured by each probe, was carried out by ANOVA, under low temperature and salinity conditions, for both substrates. In both cases, the differences between probes were not significant.

For the peat/perlite mixture, error probability = 0.972, with K_a = 11.32 for Probe 1, 10.37 for Probe 2, and 10.82 for Probe 3.

For the peat/bark mixture, error probability = 0.899, with K_a = 13.80 for Probe 1, 13.62 for Probe 2, and 11.92 for Probe 3.

We know that the dielectric constant K_a measured by TDR depends on the substrate material in which the probe is placed (Morel and Michel, 2004). The relationship established between K_a and the real moisture content for both studied mixtures shows that it effectively depends on the substrate (Fig. 1). The probe accuracy is very high for both substrates ($R^2 > 0.98$).

3. Salinity Impact. The calibration curves established between K_a and the real moisture content on the basis of a growing medium moistened with water alone remained valid for both the peat/perlite mixture and the peat/bark mixture, regardless of the substrate salinity (Fig. 2). Thus, salinity did not affect the TDR signal.

Capacitance Probes

1. Temperature Impact. An ANOVA was carried out on the values measured directly by ECH_2O probes, at low and high temperatures, and under low salinity conditions for both peat/perlite and peat/bark mixtures. The difference between treatments was not significant in either case:

Peat/perlite mixture: error probability = 0.685, where V_{ECH2O} = 949.95 mV at T°= 14.1°C and V_{ECH2O} = 930.92 mV at T° = 24.5°C.

Peat/bark mixture: error probability = 0.170, where V_{ECH2O} = 961.69 mV at T°= 14.1°C and V_{ECH2O} = 1038.32 mV at T° = 24.5°C.

2. Probe Impact Itself. We attempted to establish a relationship between measurements carried out with capacitance probes and real moisture content (by taking the values obtained at high and low temperatures into account). As can be seen on Fig. 3, the relationship differs according to the probes used for both mixtures studied. The response curve is almost identical for Probes 1 and 2, whereas it is completely different for Probe 3. A specific calibration is therefore necessary for each probe. Furthermore, the probe accuracy is not constant (weaker for probe 3 in peat/perlite mixture with $R^2 = 0.619$).

3. Growing Media Impact. A comparison by ANOVA between values obtained at low temperatures on perlite and bark-based mixtures was carried out. Given an error probability of 0.789, the difference between growing media was not significant; the mean value was 949.96 mV for the mixture with perlite and 961.69 mV for the mixture with bark. A calibration equation, independent of the growing medium but specific to each probe, could therefore be established between the calculated Moisture Content (MC_{cal}) and the value measured directly by ECH_2O probe (V_{ECH2O}):

Probe 1: $MC_{cal} = 0.0732*V_{ECH2O} - 34.917$ ($R^2 = 0.9744$)

Probe 2: $MC_{cal} = 0.0717*V_{ECH2O} - 32.467$ ($R^2 = 0.9618$)

Probe 3: $MC_{cal} = 0.1208*V_{ECH2O} - 60.456$ ($R^2 = 0.9719$)

4. Salinity Impact. For each probe, the growing medium moisture content was calculated from the calibration equations given above, for the three increasing salinity values. Since the capacitance probe was not sensitive to temperature or to the type of substrate, all the measurements corresponding to these treatments were taken into account.

Fig. 4 clearly shows that the capacitance probe is very sensitive to the salinity. Indeed, for the same real moisture content, the calculated moisture content also increases when the salinity increases, and in a very significant way. Thus, for example, for a real moisture content of 60%, the calculated moisture content is 78% for a substrate moistened with the 1.3 mS/cm solution, and 91% for a substrate moistened with the 2.5 mS/cm solution.

Thus, the calibration curve established with a growing medium moistened with only water is no longer valid for a growing medium fertilised with a nutrient solution.

DISCUSSION

Both types of equipment tested in this trial presented real advantages for measuring the moisture of growing media, but they both have some disadvantages as well.

TDR turns out to be very reliable and the measurements are neither dependent on the temperature nor on the salinity, at least for the tested values which correspond to normal growing conditions. On the other hand, the type of growing medium strongly influences the measurements, requiring a specific calibration for each mixture or at least for groups of mixtures (Morel and Michel, 2004). Moreover, this equipment remains expensive and is not accessible to growers at this time.

The ECH_2O capacitance probe does not have this last disadvantage since its price is completely accessible to growers. Moreover, it is neither sensitive to temperature nor to the materials making up the substrate, at least for those tested. Thus, a specific calibration curve for each substrate is not necessary. On the other hand, a preliminary calibration of each of the probes is necessary because one of the three probes gave values totally different from the others in our trial. This type of probe also has the important disadvantage of being sensitive to salinity. The calibration carried out with a growing medium with a low salt load is thus no longer valid with a fertilizer-enriched substrate. This disadvantage may not be that important since growing media are always fertilised when cultivated. If the salinity value remains relatively constant during cultivation, we can thus envision a calibration, not with a substrate moistened with water but, instead, with a nutrient solution representative of that used under real growing conditions. If the salinity values present high amplitudes during cultivation, as in rockwool pads for instance, it is not possible to use this material, unless to correct the measured moisture content by calculation with a specific calibration equation. However, this method demands an adaptation of the irrigation software. This material must also be very sturdy, the validity of which still remains to be shown.

CONCLUSION

The continuous measurement of growing media moisture content remains a major concern for growers in order for them to be able to optimize irrigation. Other old methods already exist, such as tensiometry, which appeared to be advantageous at the experimental level but which has not been particularly successful with growers. The new equipment studied in this article has obvious advantages but some disadvantages as well, particularly in relation to its cost (in the case of TDR), its sensitivity to salinity (for the capacitance probes), and the necessity of a specific calibration for each probe or in relation to the substrate. We must still verify the behaviour of these two methods under real growing conditions, as well as the reliability of the measurements obtained.

ACKNOWLEDGEMENTS

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Figures

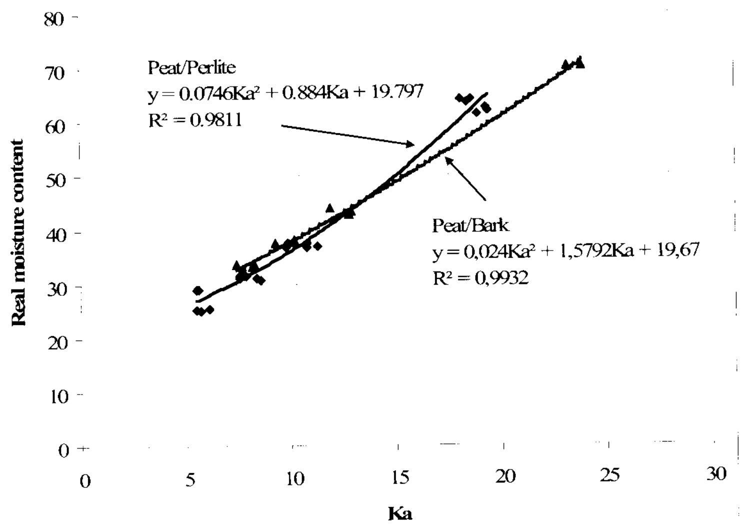


Fig. 1. TDR - Polynomial regression between the dielectric constant K_a and the real moisture content measured on two growing media (peat-perlite and peat-bark), with three probes and at two average temperatures (14 and 24°C).

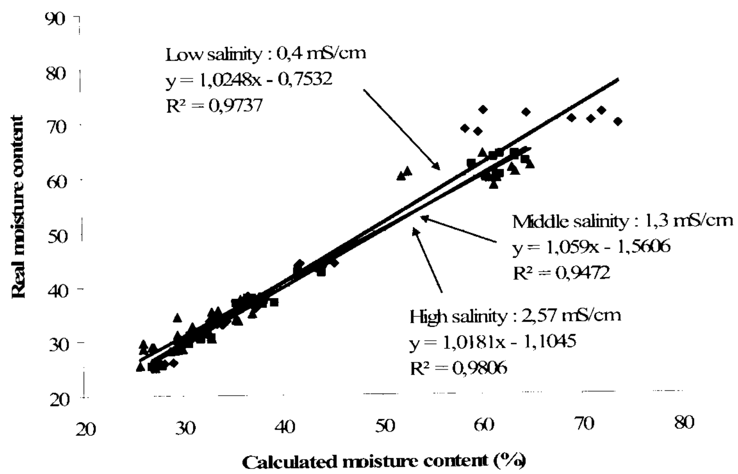
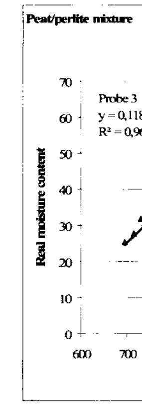


Fig. 2. TDR - Effect of three salinity levels on the moisture content measurement, in two growing media (peat-perlite and peat-bark mixtures), with three probes and at two average temperatures (14 and 24°C).



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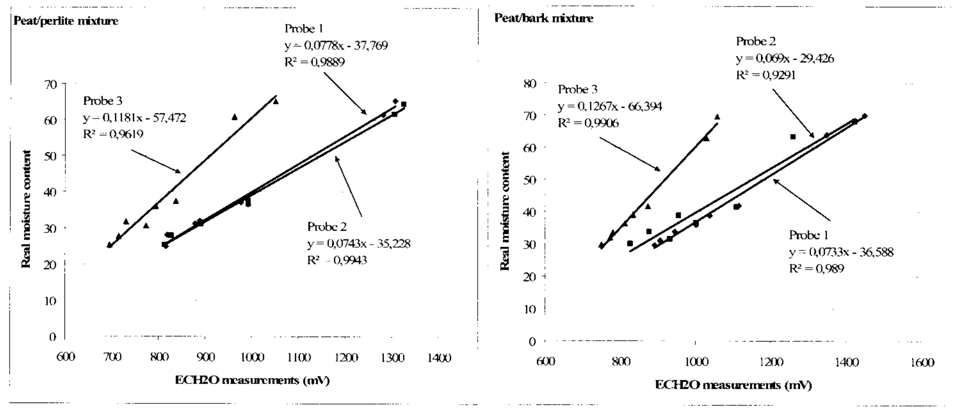

Fig. 3. ECH_2O - Calibration curves established for three probes, in different conditions (in peat-perlite mixture and peat-bark mixtures, at two average temperatures (14 and 24°C)).

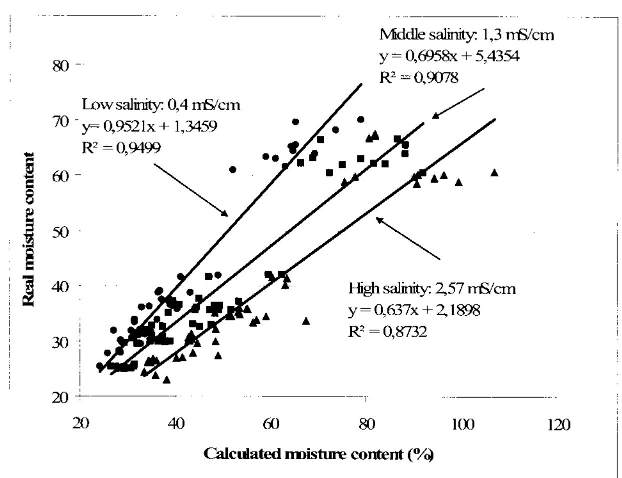

Fig. 4. ECH_2O - Effect of three salinity levels on the moisture content measurement, in two growing media (peat-perlite and peat-bark), with three probes and at two average temperatures (14 and 24°C).

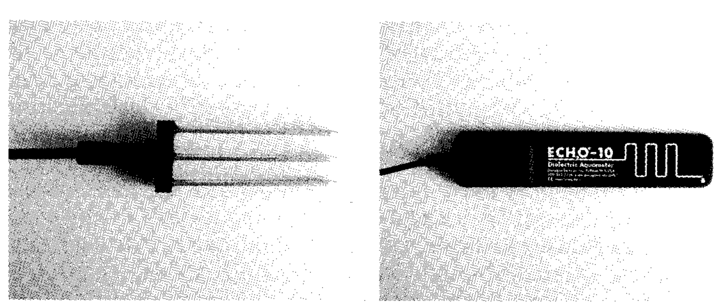

Fig. 5. The materials tested (TDR and ECH_2O capacitance probe).