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Measurement of Soil Water Content in a Peat-Vermiculite Medium Using Time Domain Reflectometry (TDR): A Laboratory and Field Evaluation

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In Quebec, Canada, the estimation of soil water requirements in container tree seedling production is generally based on a qualitative approach. However, recently the development of large seedling cultivation and the use of air-slit containers have made nursery irrigation more complex. In order to improve irrigation management ice evaluated the use of time domain reflectometry (TDR) equipment to measure the volumetric content of substrates. Trials carried out show that this type of equipment can be used to measure substrate water content in real tune. Comparison with measures of soil water content determined gravimetrically corn firms that measurements obtained by TDR are very precise. Tree Planters' Notes 47(3): 88-93; 1996.

More than 115 million shippable container tree seedlings are produced annually in the various private and public nurseries of Quebec, Canada. During recent years, particular emphasis has been put on developing cultural management of different species based on their specific nutritional needs (Langlois and Gagnon 1993).

Although irrigation techniques have been constantly improved for production in tunnel-style greenhouses, few studies have been undertaken to determine the seasonal soil water requirements of seedlings during the growth period. Nevertheless, irrigation plays an important role in seedling physiology (Heiskanen 1993; Langerud and Sandvik 1991; Rao and others 1988). Soil biology (Nielsen and others 1995) and substrate properties are also affected by media water content (Haase and Rose 1994; Heiskanen 1993; Langerud and Sandvik 1988; Nielsen and others 1995). For this very reason, the precise measurement of soil water content in the root zone should be an essential prerequisite to the establishment of effective nursery irrigation management (Schmugge and others 1980).

The lack of development in this area of tree seedling production can be attributed, firstly, to the difficulty in routinely quantifying the water content of peat substrates. Gypsum blocks, tensiometers (Pelletier and Tan 1993), xylem potential (Jacobsen and Schjonning 1993; Nielsen and others 1995), and the gravimetric technique (Herkelrath and others 1991; Nielsen and others 1995) are direct or indirect measurement methods that are often time-consuming, difficult to apply in nurseries, and sometimes destructive.

Secondly, during the last 20 years, production of small seedlings in closed containers (that is, without slits) has generally posed few irrigation problems for nursery managers. However, for the past 3 years, cultivation of large seedlings (Gingras 1993b) and the use of air-slit containers (Gingras 1993a) have significantly altered moisture conditions in the peat-vermiculite medium used. Because the latter is characterized by low water-holding capacity under conditions of high water-potential, moisture levels inside the cavities often oscillate between drying conditions that are harmful to the seedling and saturation conditions that can result in inadequate aeration (Heiskanen 1993). This recent problem thus makes it necessary to develop an empirical approach for evaluating soil water content in container production.

During recent years, researchers have focused on time domain reflectometry (TDR), the principles of which were developed by Fellner-Feldegg (1969). TDR has several advantages: it is simple to use (Tope and others 1980); it is little affected by soil conditions such as density (Tope and Davis 1985), temperature (Pèpin and others 1995; Topp and Davis 1985), and salinity (Hook and others 1992; Topp and Davis 1985; Topp and others 1980); and it can be used in peat substrates (Anisko and others 1994; Pèpin and others 1992). In 1993, a new generation of equipment based on the principles of time domain reflectometry and operating with a single-diode probe (which had been improved for the study of complex media) was put on the market. Given this context, the present study aimed at 2 specific objectives: first, to measure, in the laboratory, the precision of this equipment and the reproducibility of results obtained under different conditions; and second, to evaluate the applicability of this equipment under operational conditions in a tunnel seedling production facility.

Materials and Methods

Two specific trials-a laboratory trial and a tunnelhouse trial-were carried out to meet the objectives of this study.

Laboratory trial. In order to determine the precision of the equipment used, we measured the water contents of different substrates by time domain reflectometry (TDR) and gravimetry under different moisture conditions and at different times. The trial was carried out on 3 types of peat:

peat 1– Sogovex light sphagnum peat moss (company 1)
peat 2– sphagnum peat moss (company 1)
peat 3– Canadian sphagnum peat moss (Fafard Ltd.)

Because the precision of the equipment studied may vary according to substrate water content, moisture levels of 25, 37.5, and 50%, respectively, were applied to each peat according to the following volumetric proportions of peat-vermiculite– water: mix 1, 3:1:1; mix 2, 3:1:1.5; and mix 3, 3:1:2. These were prepared on the eve of the experiment, then homogenized for 30 minutes the following morning in a concrete mixer immediately before the measurements were taken.

Containers used in the experiment were polyvinyl chloride (PVC) cylinders that were 7.5 cm (3 in) in diameter and 42 cm (16.5 in) high and had an average volume of 1905 cm^3 (116.3 in^3). Because the density of growing medium may be a significant factor in variability, the following method was used for filling the tubes: the substrate was poured to the top with one of the prepared mixes; the cylinder was then dropped twice from a height of 10 cm (3.9 in) from the ground; and then mix was added to the top and the compaction operation was repeated.

Measurement by reflectometry was carried out with an MP-917 (GS Gabel Corporation, ESI Environmental Sensors Division, Victoria, BC) equipped with single-diode probes made from 2 parallel stainless steel rods that were 39 cm (15.4 in) long and 3.17 mm (0.12 in) in diameter. These probes were placed vertically at the center of the cylinders. The probes and the equipment were interconnected with a 25-cm (9.8-in)-long coaxial line. The *ViewPoint*™ software (version 1.35) allowed the values of certain internal parameters of the equipment specific to the peat medium to be maximized.

For each of the peats and each prepared mix, percentages of volumetric water were measured every 15 minutes-at 0, 15, 30, 45 and 60 minutes-with the MP-917. After each measurement, the peats of 4 tubes (or 5 tubes, peat 1 and 2, mix 1) were extracted and their water content determined by gravimetry (weight difference) (ovendried at 225 /C (437 /F) for 24 hours). All water contents were expressed as percentages (cm^3 H_2O/cm^3 peat × 100 or % v/v).

Tunnel-house trial. Black spruce seedlings— *Picea mariana* (Mill) BSP— 1+0 starting their second year of growth and produced in air-slit containers (IPL 25-350A) were monitored during the 1995 season. Three irrigation schedules were determined in order to test the reliabilitv of MP-917: dry (30%, v/v), moderate (40%, v/v) and wet (50%, v/v). During the autumn period, percentages aimed at were lowered to 20, 30, and 40%, respectivelv. Twenty-one containers per schedule (block) were placed inside a polythene tunnel-style greenhouse. In each of the 3 blocks, 5 single-diode probes were placed in specific locations: 1 at the center of the block (low drying) and 4 others on the periphery (high drying). Each probe was inserted horizontally through the slits of 5 cavities halfway up the container (figure 1). It can be seen from the diagram that each probe alternately passes through specific air and peat spaces. Since the estimation of water content only takes into account the portion of the probe that is situated in the substrate, 2 parameters in the *Environmental Sensors* software (version 1.35) must be changed: the total length of the rods and a factor A, defined as the displacement time (nanoseconds) of the electromagnetic signal in the air. This value is substracted from the total displacement time of the probe. A fertilization schedule applied weekly (Blue White injector Model VS-1860) ensured adequate growth of the seedlings during the summer (total application by seedling: 60.0 mg N (2.1 $\times 10^{-3}$ oz), 19.23 mg P (0.7 $\times 10^{-3}$ oz), and 8.63 mg K (0.3 $\times 10^{-3}$ oz). At the end of July and in mid-September, readings were taken at set times: 8:30, 11:00, 13:00, and 15:00, respectively. Irrigation was applied using a mobile ramp (Harnois, Aquaboom model on a ground rail) equipped with 22 nozzles (Model 8006; except at ramp ends, when Model 8010 was used). Temperatures (in Celsius) were recorded with a data logger (Campbell Scientific Model CR-10) fitted with temperature sensors (Model 107B). In each block, a sensor was placed in the air at seedling level and another in the substrate. Measurements were taken every 5 minutes and average hourly temperatures were subsequently calculated.

Results

Laboratory trial. Figure 2 shows the results of paired comparison of all water measurement data using the MP-917 and gravimetry. For each of the mixes, a slight point dispersion can be noted even though slight skewing is observed with the increase in water content in the substrate. The average percentages of water measured with the MP-917 were 22.4, 47.6, and 58.2%, respectively, whereas the gravimetry measurement

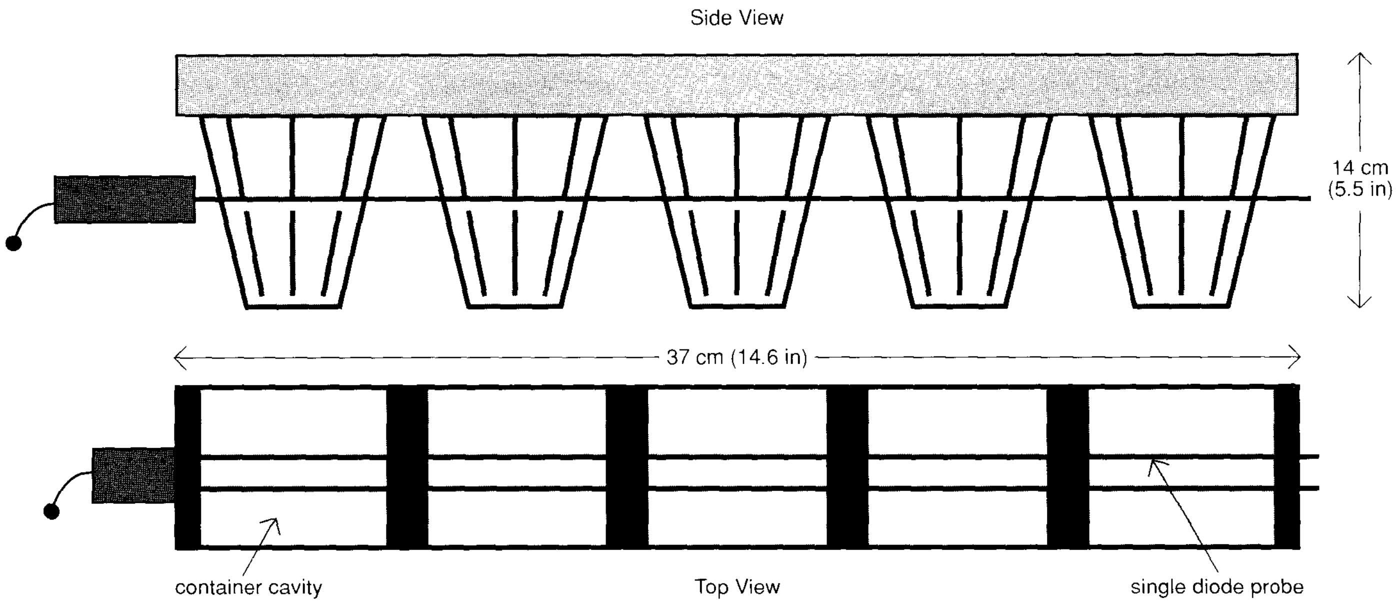

Figure 1—*Diagram of installation of single-diode probes through 5 cavities of an air-slit container.*

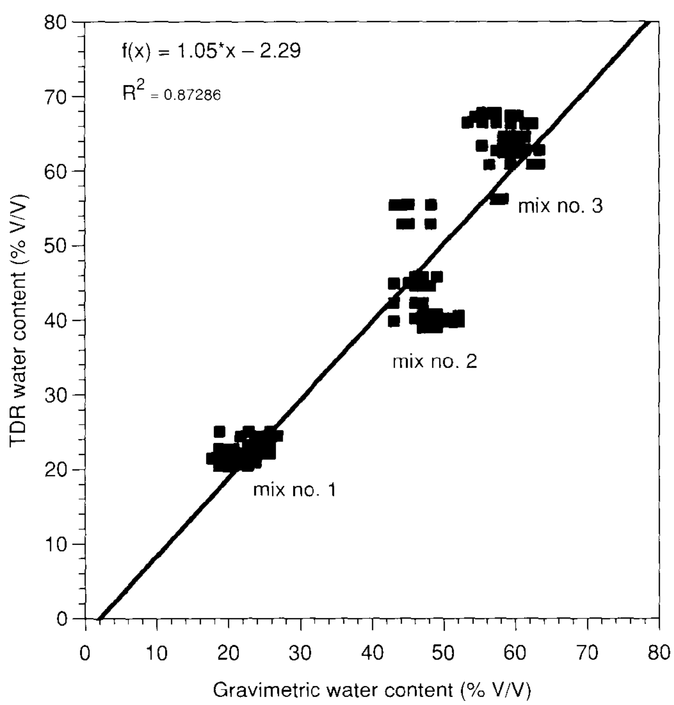

Figure 2—*Relationship between water content measured by volumetry and by gravimetry (pooled data on peat types, mixes, and times).*

values were 22.2, 42.0, and 62.3%. Graphically, a linear relationship can be outlined on a preliminary basis from the 3 clouds of points.

Detailed data analysis indicates that regardless of the measurement method used, there was little difference between the water contents of the 3 peats for the same mix and specified time. However, when measured with the MP-917, a gradual increase of water content in certain samples (peat 1 and 2; mix 2 and 3) was observed in the time. Detailed data analysis also indicates that the MP-917 does not skew water content values in one direction or another in comparison with those obtained by gravimetry.

With the exception of mix 1, water content measured by the two methods was higher than the theoretical values established for each of the mixes used (mix 1, 250; mix 2, 37.5%; mix 3, 50%).

Tunnel-house trial. Between July 24 and August 1, water content increased and decreased regularly (figure 3). These rapid daily cycles are related to particularly hot atmospheric conditions observed in the tunnel house during the summer (average weekly minimum and maximum temperature: substrate, 18.2 /C (64.8 /F) and 26.6 /C (79.9 /F); air, 16.6 /C (61.9 /F) and 30.2 /C (86.4 /F) and the frequency of irrigations (represented by the vertical dotted lines on the graph). Measurements of the dry control obtained from the probe situated in the centre of the block indicate that soil water content was maintained globally at the established target value (30%). However, for the moderate (40%) and wet (50%) controls, the percentages measured were generally exceeded from July 25-28 but were gradually reached around July 29. Results for the probes placed at the edge of each block confirm that adequate moisture levels for the moderate and wet controls were maintained. Nevertheless, water contents remained higher than 30% for the low control. For the latter, it was necessary to carry out supplementary irrigations so as to prevent excessive drying of the growing medium. This was noted in particular on July 26, when water content reached 60%. Results for the same irrigation control confirm that the level of water content varies according to the containers' position inside a block. The reproducibility of results obtained with the MP-917 equipment at short intervals confirms that the sensitivity of the system used is good. However, it should be noted that normal readings of water content could not be obtained for 12% of all probes (15) installed in the design.

During autumn, the decrease in water content was more gradual than that observed in July (figure 3). A single irrigation was carried out during this period, reflecting cooler temperature conditions at the end of the month (data not analyzed for this period). This less-demanding environment is expressed in an adequate modulation of the 3 irrigation schedules. For the probes situated at the center of the blocks, at this period of the year, the initial targeted percentages for the moderate and wet moisture controls (30 and 40%, v/v) were generally reached, except during the period preceding the September 20 irrigation. However, for the low control, water contents remained lower than the recommended target value (20%). From September 20 onwards, no measure could be taken of the low control with the probe installed in the container. At the edge of the blocks, tendencies similar to those observed at the centre of the compartments were observed: targeted moisture percentages were reached for moderate and wet controls and values below 20% in the peats of the low control were obtained. As in July, consistent differences in water content between containers positioned at the center and at the edge of the blocks were observed. Technically, abnormal or excessively low readings were recorded on certain specific probes.

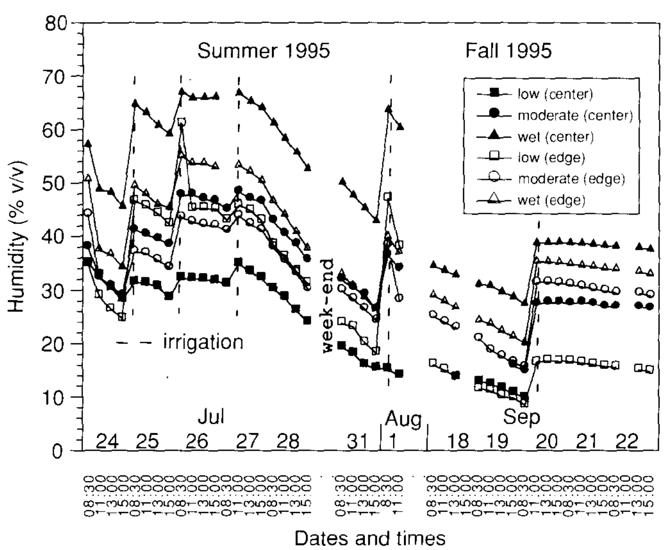

Figure 3—*Variation in water content in July and September in peats of air-slit containers according to 3 irrigation controls and 2 measurement points.*

Discussion and Conclusions

Trials carried out in the laboratory and outside in the tunnel house during the summer and autumn of 1995 indicate that the MP-917, a field instrument based on the principles of time domain reflectometry, allows rapid, precise, and reproducible measurement of volumetric water content in peat substrates. Similar percentages measured by reflectometry and gravimetry under different conditions confirm those observed in previous studies (Dasberg and Dalton 1985; Ledieu and others 1986; Topp and Davis 1985; Topp and others 1980, 1984, 1988) but refute those obtained by Jacobsen and Schjonning (1993). The adequate results observed during this trial indicate that the algorithms used by the MP-917 allow the exact estimation of water content in the peat-vermiculite medium within established moisture ranges. Similar water content results observed in 3 peats may be explained by the fact that although they originate from 3 different sources, they show identical physical properties: similar saturation rates and densities (data obtained from retention curves).

The slight increase in point dispersion in mixes 2 and 3 is possibly due to the fact that in more humid conditions, 2 internal parameters of MP-917 were not optimized. In these conditions, the estimation routine carried out by the equipment is more difficult; thus a greater variability of results was observed.

The gradual increase of water content over the period of 1 hour may be explained by 2 specific physical processes: compaction of the peat caused by the insertion of the rods and progressive replacement of air spaces by free-running water surrounding the rods (Knight 1992).

For this trial, the length of the rods of each probe was established according to the dimensions of the containers used. In the conditions tested, the length of the rods did not appear to be a factor limiting the precise measurement of water content. Comparative tests (not discussed in this article) carried out with the MP-917 and a Tektronic (Model 1502b) equipped with shorter probes (2 and 3 rods) with mixes 1 and 2 also indicate that the length of the rods does not seem to be a factor limiting the estimation of water content. The specific properties of the material used remain more significant (Heimovaara 1993).

The reliability of MP-917 observed in the laboratory was confirmed in the tunnel-house trial. The results obtained from monitorings carried out during periods when the water evaporation and evapotranspiration rates of seedlings vary, indicate that it is possible to target specific moisture levels within a limited range. Probes proved to be very sensitive to hourly variations of water content; however, special attention must be paid to the parallel alignment of the rods. The incorporation of a diode at the base of the probe ensures adequate reflection of the signal with a greater amplitude; moreover, the addition of this piece minimizes errors associated with the speed of propagation and reduces background noise (Hook and others 1992), which is often significant in this type of substrate. However, despite this technical improvement, for some of the probes, negative, overly high, and very low values were obtained. This problem, which is particular to the substrate used, is caused by an erroneous evaluation of the end of the probe by the equipment (Chambers 1996). The addition of a second diode at the end of the rods could possibly eliminate this specific recurrent problem.

The tunnel-house trial brought out 2 interesting points with regard to seedling production in air-slit containers. Firstly, significant differences in water content were observed between the centre and edges of the compartments. Therefore, appropriate water management should be developed in order to reduce these differences. Secondly, the different dynamics of evaporation and evapotranspiration observed between the periods of July and September confirm that it is possible with this type of equipment, to introduce sequential modeling of irrigation based on specific needs of seedlings and as a function of their particular phenology. Finally, in the context of the development of air-slit containers, more rigorous irrigation management opens up interesting prospects for improving the structure and pruning of roots.

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