Control of Growing Medium Water Content and Its Effect on Small Seedlings Grown in Large Containers

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Results of an experiment carried out in a tunnel house confirm that real-time operational monitoring of water content in a peat–vermiculite substrate is possible using equipment based on the principles of time domain reflectometry. Irrigation management can still be easy despite the use of air-slit containers. Soil water content can be significantly reduced without affecting tree seedling development. Small seedlings, which have low soil water requirements and a large quantity of water in each cavity, may explain these results. However, reduction in soil water content did not prevent roots from growing from one cavity to the next. Tree Planters' Notes 48 (3/4): 48-54; 1997.

During the last 20 years, public and private nurseries have developed expertise based on the production of small seedlings cultivated in low-volume cavities- 50 cm^3 (3.1 in^3) and 110 cm^3 (6.7 in^3). However, for the last 5 years, the trend in techniques has been in moving towards growing large seedlings (Dancause 1995) in containers with a large cavity volume— > 200 cm^3 (12.4 in^3) (Gingras 1993). More recently, important studies have led to the refinement of air-slit containers that improve air pruning of roots (Ford 1995; Gingras 1993).

Presently, substrate water content is maintained at too-high a level due to the combination of 2 operational factors. First of all, in the first year, a small seedling with low water requirements growing in a large root plug capable of holding a large quantity of water is produced in a tunnel house. Second, due to the presence of slits all along the cavities, there is a tendency to over-irrigate cultures in order to compensate for the rapid drying of containers located at the edge of the tunnels (Biernbaum 1992; Ford 1995). This situation results in the specific problem of inadequate pruning of the root apexes along the slits, which is followed by root colonization from one cavity to another in the first year. In the second year, it is then difficult to extract the seedlings. This problem may be caused by the sturdiness of the roots of white spruce—Picea *glauca* (Moench) Voss—or lower efficiency of root air pruning (Ford 1995). However, it is not clear that producers have sufficient knowledge of the real water requirements of the species that they cultivate (Tyler and others 1996), particularly in terms of root development (Biernbaum 1992).

Several studies have underlined the role played by water in tree seedling development (Heiskanen 1993; Langerud and Sandvik 1991; Khan and others 1996; Rao and others 1988) and the impact of the combination of water and fertilizer (McClain and Armson 1976; Tyler and others 1996) on tissue concentrations. In 2 recent studies on Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco) and Scots pine *(Pinus sylvestris* L.), respectively, Khan and others (1996) and Heiskanen (1995) emphasized the negative effects on seedling growth of keeping peat too moist. The development of better irrigation schedules therefore provides significant cultural benefits, that is, improved seedling quality (Heiskanen 1995; Khan and others 1996; Seiler and Cazell 1990), reduced leaching of fertilizers (Cresswell 1995; Pelletier and Tan 1993) and a decreased incidence of disease (Beyer-Ericson and others 1991). In this context, regular monitoring of water content remains a prerequisite for establishing efficient irrigation management (Cresswell 1995; Or 1995; Phene and others 1989; Werkhoven 1993). However, the absence of reliable and precise technologies has limited the development of operational methods for measuring peat water content.

In 1995, a new generation of field equipment using the principles of time domain reflectometry (TDR) was found to have some success in container-grown tree seedling productions (Lambany and others 1997). It was nevertheless difficult to determine water content in the peat–vermiculite mixture used. It is possible that the problem originates in the substrate used, although studies demonstrate that TDR functions adequately in this organic medium (Pépin and others 1992); it is also possible that the single-diode probes were inoperable in a container characterized by an alternation of space, air, and peat (Lambany and others 1997).

Given the context described above, this study has 2 aims. On the one hand, it attempts to evaluate the operation of equipment that, except for being equipped with 2-diode probes, is identical to that used in 1995. On the other hand, the study attempts to specify the effect of reducing peat water content on plant morphology, particularly on root development.

Material and Methods

In May 1996, white spruce seedlings—Picea *glauca* (Moench) Voss, provenance 94P64—were sown in air-slit containers (IPL 25-350A). The substrate was made up of a mix of peat (Nyrom type B), vermiculite, and water (volumetric ratio 3:1:1) adjusted to an approximate density of 1.1 g/cm^3 (0.63 oz/in^3).

In July, after thinning and planting out of seedlings, an experimental design was set up comprised of 2 treatments in tunnel no. 21: in one, the substrate water content was maintained at 25% (cm^3 H_20/cm^3 peat) (43% of saturation weight of the container) and in the other at 40% (57% of saturation weight of the container). Normally, such percentages do not lead to either a drying out or an excessive saturation of the substrate that would be harmful to seedling growth (Gonzalez and d'Aoust 1990). Each treatment was replicated 6 times and distributed randomly in the units, which comprised 72 containers. In order to reduce edge effects, buffer zones were set up between each replication. The experiment took place over a period of 15 weeks, from mid-July to the end of October.

Relative air moisture and peat water content. Relative air moisture (percent) in the tunnel house was recorded using 2 HMP35C probes (Campbell Scientific) installed 2 m (6.6 ft) from the soil. A data logging system (Campbell Scientific Model CR-10) was programmed to compile data obtained from a probe every 5 minutes and to calculate hourly averages. Mean daily and monthly moisture levels were determined by a program developed using SAS™ software.

Substrate water content was monitored with an MP-917 (ESI Environmental Sensors Inc., Div., Victoria); each probe was made up of 2 stainless steel rods (length, 39 cm or 15.4 in; diameter, 3.17 mm or 0.12 in) and equipped with 2 diodes (figure 1). The first was incorporated at the base of the probe and the second was attached manually to the ends of the rods. Each probe was inserted horizontally through the 5 cavities halfway up the container. The principle of water content estimation (percent, vol/vol) inside a medium made up alternately of air and water has been described previously (Lambany and others 1997; Young 1995). In each replication, 2 moisture probes were placed in distinct, randomly selected containers.

The following measurements were made weekly, in the morning, in each replication: reading from each of the 2 probes Monday and Friday (total: 12 probes/treatment) and a reading from 1 probe on Wednesday (total: 6 probes/treatment). Once the line from the equipment to the fixed probe was established, 2 consecutive measurements were taken to verify the reproducibility of the results. If the difference between the 2 values obtained was greater than 2%, a third reading was made. The 2 closest values were then used to calculate the averages. When the water content of the 25% and 40% treatments decreased in the center of the cavities to below 22% and 37%, respectively, irrigation was carried out with a motorized robot (Aquaboom Harnois model) used at a pressure of 2.3 kg/cm^2 (32 lbs/in^2).

Depending on the characteristics of the device (nozzle model, ramp height, spacing between nozzles and robot speed), the robot's return trip increased the water content of the substrate by approximately 1.6% vol/vol. When irrigation was carried out in the morning, a second measurement was then taken in the early afternoon to validate the prescription made earlier. In this experiment, constant water content levels were maintained at the center of each cavity for each of the schedules. By using this approach, nutrient leaching could be limited while maintaining substrate fertility at an optimal level so as to ensure the development of the seedling.

a

Figure 1—*Characteristic of a 2-diode probe (a) and insertion of a probe through 5 cavities of an air-slit container (b).*

Seedling morphology. On October 21, the height (centimeters) and diameter (millimeters) of each tree seedling were measured (15 seedlings/replication, 90 seedlings/treatment). Each root system was digitized individually with a scanner (Hewlett Packard ScanJet 4C/T model, 500 dpi resolution). WinRhizo ™ (version 3.2) software was used to analyze the image and quantify the total length (centimeters) of the roots according to their diameter (15 classes: 0 to 1.5 mm). The aerial and underground parts of the seedlings were then put into separate groups of three (5 groups of stems and roots/replication), oven-dried (60° C) and weighed (milligrams). To evaluate root pruning, 5 containers per replication and per treatment were selected randomly within the design (total: 30 containers per treatment). For each container, all roots coming out of the slits of the cavities and crossing from one plug to another were removed and counted.

The Student t-test (t-test) or the Kolmogorov-Smirnov test were performed on the data using SAS software (version 6.11). The non-parametric Wilcoxon test was used instead of the Student t-test for data without a normal distribution. The significance level of the hypotheses was set at 5%. Normality of the data was tested using the Shapiro-Wilk test.

Results

Rapid and often large variations in the relative moisture of tunnel house air occurred during the season and often ranged between minimum and maximum values of 66% and 100%, respectively. Condensation on the canvases and formation of small drops of water on the polyethylene lining of the tunnel walls were noticed regularly. Monthly averages for July (partial), August, September, and October (partial) were 85.2, 82.5, 87.2, and 91.8%, respectively.

Between July 12 and October 11, regular fluctuation in peat substrate water content of each treatment was observed (figure 2). Standard deviations recorded during the monitoring were generally similar; parallel profiles and a systematic absence of overlap of the standard deviations indicate an adequate differentiation between the 2 treatments (data not processed statistically). Data synthesis confirmed that targeted water contents of 25% and 40% at the beginning of July were reached and maintained precisely during the season (table 1). Standard deviations varied little from one treatment to the next. Means obtained from the sub-sampling carried out on Wednesdays (table 1) remained slightly lower than those recorded in the complete sampling done every Monday and Friday (table 1). Reducing the number of measurement points by half had little effect on the value of the standard deviations of each treatment.

The analysis of morphological data confirms that water content did not have significant effects on height, diameter and seedling mass at the end of the first growing season (table 2). More specifically, between September 16 and October 21, a period characterized by a significant growth in root mass (treatment 25% vol/vol = 120%; treatment 40% vol/vol = 121%), water content had no visible effects on this parameter (data not presented).

The majority of roots in the two treatments had diameters of 0.2 to 0.3 mm and 0.3 to 0.4 mm (figure 3). Water contents had no significant effects on the general profile

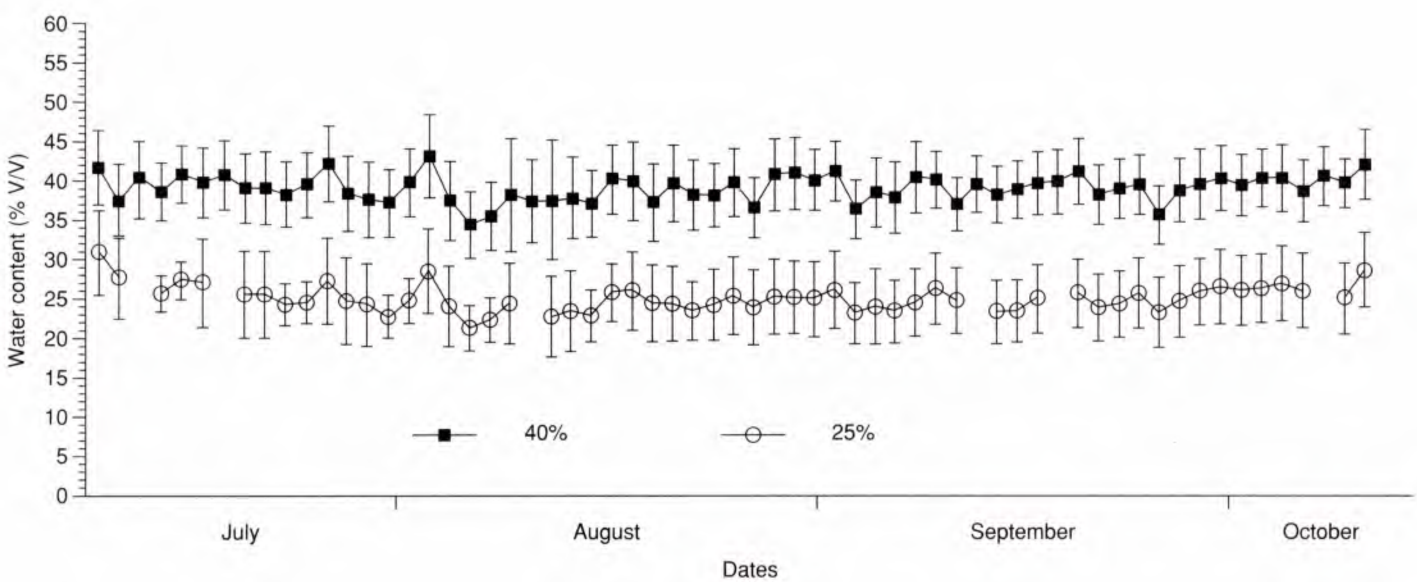

Figure 2—*Variations in peat substrate moisture of air-slit containers according to water content.*

Table 1—*Average water contents measured in peat substrates according to sampling intensity and 2 water content levels (values are means ± standard deviation)*

	Treatments	
Sampling period	25% v/v	40% v/v
Monday, Wednesday, & Friday	25.2 ± 4.6	39.2 ± 4.5
Wednesday (6 measurements/treatment)	24.4 ± 3.6	38.7 ± 4.1
Monday & Friday (12 measurements/treatment)	25.4 ± 2.4	39.3 ± 4.6

Table 2—*Morphological characterization of white spruce seedlings grown at 2 substrate water contents*

	Treatments	
Parameters	25% v/v	40% v/v
Stem length (cm)	7.7 a	8.1 a
Root collar diameter (cm)	1.85 a	1.90 a
Stem dry masss (mg)	485 a	519 a
Root dry weight (mg)	190 a	196 a

When the table is read horizontally, different letters represent significant differences at $P = 0.05$ (Student *t*-test); crop of 90 seedlings/treatment (15 seedlings/ replication × 6 replications).

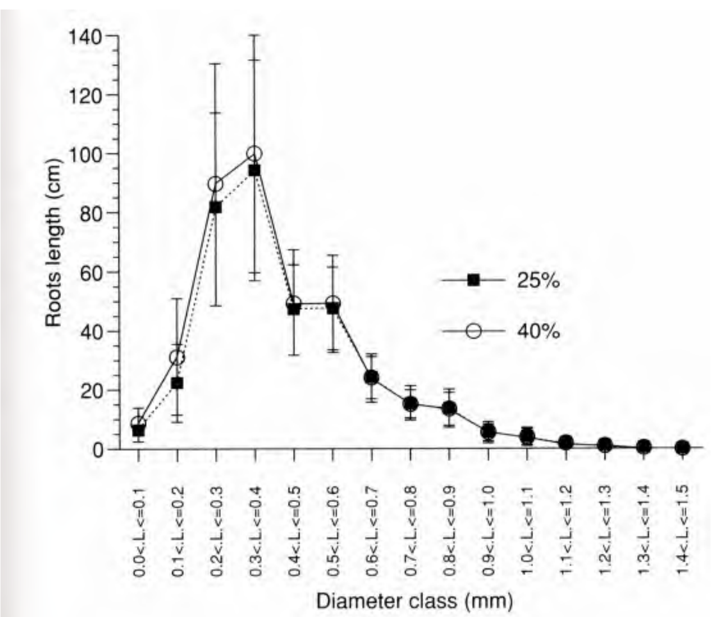

Figure 3—*Total root length per diameter class in seedlings grown at 2 water contents.*

of root classes ($P >$ Ksa = 0.9883). However, as the figure shows, the means of the largest root classes (0.1 to 0.9 mm) had large standard deviations.

Finally, water contents had no significant effect on the number of roots that grew from one cavity to another ($P >|T|$ = 0.4527). The number of roots recorded for water contents of 25% and 40% were 4.9 (cv = 2.8) and 5.7 (cv = 3.8), respectively. These roots tended to be located in the upper part of the cavities where the space between the cavities is narrower. With this model of container, water content levels are generally lower at this spot than in the center or at the bottom of the cavity.

Discussion and Conclusion

The high relative humidity in the tunnel house is caused mainly by 3 factors. First, the peat remains a constant source of moisture. Second, evapotranspiration of a high number of seedlings, despite their small size, regularly releases water into the ambient air. Third, the 3 canvases located on each side of the tunnel house are closed alternately during the day. This technique reduces air circulation and maintains high moisture and temperature conditions, which favor the plants' steady development (Landis and others 1992).

The precise monitoring of water carried out during 4 months confirms that the water content in an organic substrate can be measured accurately using TDR (Pepin and others 1992; Werkhoven 1995). The reading of more than 3,000 measurements taken in real time (15 sec/ measurement) indicates that the MP-917 is a reliable and precise field instrument. The addition of a second diode at the end of each probe improves the quality of reflection of the electromagnetic signal (Hook and others 1992) and allows a more accurate estimation of wave propagation delay (Young 1995). Results indicate that the erroneous values recorded previously (Lambany and others 1997) with a similar device, but equipped with a single diode, were probably due to incorrect identification of the end of the probe, in particular in a medium that was alternately made up of air and peat. The need to take a third reading on only 1.8% of all of the data indicates that the algorithms used to calculate water content were very reliable. However, it should be noted that it was particularly difficult to attach a second diode to the end of the rods and that there was corrosion on the copper parts of the diode. These problems caused the recording of outliers in 0.24% of the measurements. The probe's conical end explains the inadequate attachment of the second diode while a constantly moist environment under the containers produces progressive corrosion of the copper poles.

The regular water content profiles and constant standard deviations may be explained by several factors.

First, uniform peat density was maintained in the potting room. Such homogeneity creates a more uniform vertical moisture gradient in the root plugs (Heiskanen 1993). The height of the cavity allows the water to percolate more efficiently (Bilderback and Fonteno 1987) and a possibly more homogeneous air-water ratio at the cavity's mid-depth to be maintained (Landis and others 1989). Second, the motorized robot ensures a uniform application of water and fertilizing solutions compared to a jet spraying system (Landis 1994; Landis and others 1989). Third, by maintaining a high air moisture level and minimizing evapotranspiration from each seedling, variations in peat water content were limited substantially given the large quantities of water contained in each cavity. Finally, 2 other factors helped maintain more uniform moisture profiles in each of the treatments: (1) sample points placed in each of the homogeneous sectors and (2) for each probe, an average water content measured in peats of 5 adjacent cavities. The results tend to confirm that, in spite of the presence of slits along the cavities, the use of an air-slit container does not create particular problems of water content control. This finding supports the approach that favors the application of special irrigation in this type of culture: an extra one for the edges and the other for the entire production. In this way, the risks of overirrigating may be minimized and seedling quality, particularly that of the roots, may be improved.

The fact that similar results were obtained for the complete (Monday and Friday) and partial (Wednesday) sampling may be explained by the particularly homogeneous growing conditions and rigorous irrigation management during the experiment. In an operational context, based on these results, irrigation schedules with a reduced number of measurement points within each tunnel house could be developed. In the medium term, it will be possible to precisely establish the water requirements of each species cultivated (Wraith and Baker 1991). However, this recommendation can still be applied to irrigation systems that use a motorized robot.

The 15% reduction of substrate water content does not affect the morphology of white spruce seedlings. These results confirm those of Khan and others (1996) in their study on Douglas fir within a similar moisture range (29 to 53%). However, other studies have found that optimal growth in red pine—*Pinus resinosa* Ait.— is generally achieved with high water contents (Timmer and Armstrong 1989; Timmer and Miller 1991). In similar conditions, Heiskanen (1995) observed deficient growth in Scots pine. These contradictory results may reveal the different biological needs of cultivated species. However, although saturated substrates generally allow higher growth in the aerial part, other equally important factors should motivate producers to define a water content level that takes more than the single criterion of morphology into account (Biernbaum 1992; Herms 1996). Resistance to water stress, cold, insects, and disease should be noted. Some researchers have observed that the available air-water ratio in the peat should always be situated within a range fluctuating between 20 to 30% vol/vol (Bugbee and Frink 1986; Verdonck and others 1983). More specifically, Verdonck and others (1983) mention that in order to ensure balanced seedling growth, air content remains the most important factor to be controlled in peat substrates. However, within the moisture ranges used in the present experiment, this did not seem to be a limiting factor for ensuring the adequate growth of white spruce. These results seem to confirm that the slow growth of a small seedling in the first year, as Heiskanen (1993) has underlined, may justify the application of a more conservative irrigation schedule. Bik (1973) points out that maintenance of adequate oxygen concentrations in the root environment is ensured mainly by evapotranspiration from the needles. Small seedlings produced in a large cavity make it difficult to achieve this objective during the first year. In this context of seedling cultivation in air-slit containers, water content levels should be maintained below the field capacity.

Decreasing water content does not change root development in white spruce. Increased porosity of the substrate and consequently of oxygen concentrations (Liang and others 1996), as a result of reduced water content, do not seem to change the root structure at the end of season. Timmer and Armstrong (1989) noted that maintaining a high water content promotes the production of more fibrous roots in red pine; however, results of the study by Tyler and others (1996) on cotoneaster and by Gonzalez and d'Aoust (1990) on black spruce—Picea *mariana* (Mill.) B.S.P.—were similar with regard to lower water contents. Two factors may explain the development of a similar root structure despite the maintenance of different water contents in the present study. First, it is possible that this species is less sensitive to increases in the air-water ratio, particularly in an air-slit container. Second, it is possible that reducing water content does not produce a great enough impact to modify the significant development of roots during autumn.

The decrease in water content neither eliminates nor reduces the number of roots that cross through the air space between the cavities. This result may be explained by 3 hypotheses. First, the space between the 2 cavities remains small in the upper part of the container, which allows the roots to cross the gap more easily. Second, the environment under the containers is closed despite the presence of an adequate air space, which possibly favours the maintenance of a high air-moisture level even when substrate water content is lower. However, given the experimental design used, no conclusion could be reached regarding whether the roots are in fact able to survive winter conditions because of their probable later development in the autumn. Third, the cavities have slits characterized by a line angle which is not necessarily optimal for containing roots that grow close to the opening (Gingras 1997). Thus, these 3 factors appear to have a greater influence than actual water content on the development of this type of root.

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