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The Thin Green Line:

A Symposium on the State-of-the-Art in Reforestation

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The Thin Green Line

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Turning Off the Tap: Controlling Nutrient Leaching, Growth and Hardening of Containerized White Spruce Seedlings Through Irrigation Management

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Introduction

Water is a very precious resource. In arid and semi-arid regions of the world, where water resources are scarce, water conservation is a primary concern. On a global scale, 500 000 ha are lost annually due to poor irrigation practices (Burger 2003). In regions where supplies of fresh water are more abundant, over-irrigation and groundwater contamination from agricultural and nursery runoff are more pressing concerns.

Prudent irrigation and fertilization management can diminish costs of containerized forest seedling production and minimize groundwater contamination. Through diligent monitoring of substrate water contents during the growing season, substantial irrigation water savings can be achieved without adversely affecting seedling quality (Lamhamedi et al. 2000, 2001a, 2002, 2003; Stowe et al. 2001; Bergeron et al. 2004). Although the quantity of chemical fertilizers used in forest nurseries is small, when compared to agricultural and horticultural applications, leaching of nitrogen and other minerals is a constant concern (Juntunen et al. 2002; Juntunen 2003). Nitrate is the most common contaminant. North American standards limit nitrate levels in drinking water to 45 mg/l (10 mg/L as NO_3-N) (USEPA 2004; Health Canada 2003), whereas the European Community and the World Health Organization have established maximum nitrate concentrations at 50 mg/l (11.3 mg/L as NO_3-N) (European Community 1998; World Health Organization 1993). To our knowledge, the amount and content of mineral leachate has not been monitored on a continuous basis over an entire growing season in a container forest nursery.

There are six public and 19 private forest nurseries in the province of Quebec. Of the 162 million plants that were seeded in the spring of 2005, 94% (152 million plants) will be cultivated in containers. Over 26 million white spruce (*Picea glauca* (Moench.) Voss) seedlings (16.5% of total production) will be produced in the 2005-2007 production cycle. This is second only to black spruce (*Picea mariana* (Mill) BSP) (85 million seedlings: 52.4% of production). White spruce is an important commercial species which is used for both lumber and pulpwood. Although the species is adapted to a variety of edaphic and climatic conditions, it grows best if it has an adequate supply of well-aerated water. It demands higher soil fertility than other conifers growing on the same sites (Nienstaedt and Zasada 1990) and is sensitive to periods of water stress. Crops of white spruce seedlings exhibit heterogeneous growth. This is thought to be due to both genetic and environmental factors (Labbé 2004, Lamhamedi et al. 2005a).

Containerized seedlings are produced on a two-year cycle in Quebec. The plants are habitually seeded in May. Two to four seeds are placed in each container cavity, depending on the seedlot. The seeded containers are placed directly into an unheated polyethylene-covered tunnel (opacity: 45%). After a five week establishment period, the germinants are thinned to one plant/cavity. The seedling containers, which are elevated 12 cm above the surface to facilitate rhizosphere aeration, remain under the tunnel for the remainder of the first growing season, an average of about 150 days. During this period the plants are irrigated and fertilized by boom sprinklers with a coefficient of uniformity ≥ 95%. In mid-October the tunnel cover is removed to promote hardening and the seedlings are moved outside for the winter. The plants are grown outdoors, under unsheltered conditions, during their second growing season. Pivoting or pop-up sprinklers and tractor-mounted booms are used for irrigation and fertilization, respectively (Labbé 2004, Lamhamedi et al. 2005a). The coefficient of uniformity for sprinkler irrigation systems varies between 39% and 92%. The question that naturally comes to mind is whether or not there is a relationship between the heterogeneous growth of white spruce seedlings observed during their second growing season and heterogeneous substrate water contents caused by less than adequate water distribution by sprinklers.

Labbé (2004) found that substrate water content in an outdoor bed of containerized seedlings exhibits both spatial and temporal variability. The growing medium is exposed to wind and rain. Because the seedling crop is not homogeneous, both the interception of water droplets and evaporation from the substrate surface are not uniform. Nursery managers have a tendency to over-irrigate to prevent dry spots developing in the seedling bed. This induces leaching of mineral nutrients from the substrate and the subsequent addition of more fertilizers to compensate for these losses. The white spruce seedlings in this study showed a large variability in height growth at the end of the second growing season. It was hypothesized that maintaining uniform substrate water contents throughout the production cycle would limit leaching, and aid in the production of homogeneous seedling lots.

Water also plays an important role in the fall and spring, as the plants harden and deharden, respectively. During these periods seedlings are kept outdoors, unsheltered from temperature extremes. In recent years, freezing temperatures have been experienced as early as September 2 and as late as June 4 at Pampev Inc., the private forest nursery where the present study was conducted. Because the seedlings are not insulated by snow cover and are not fully dormant, they are at risk of being damaged by frost. Millions of seedlings are lost due to frost damage each year. In Quebec, these losses may account for 5% to 30% of a seedling crop. The best protection against frost damage is to irrigate the seedlings. As water freezes around the stems and branches, it releases energy. This phenomenon maintains the temperature of the shoot tissue ≥ 0°C. To maintain a consistent layer of protective ice, irrigation must be continued throughout the period of frost risk. This type of protection requires large quantities of water, much of which is leached into the water table. If nursery managers had a simple tool to help them predict whether or not their plants were at risk, they would only irrigate when absolutely necessary.

The desire to reduce the amount of water used in forest seedling production prompted the installation of an experiment in a crop of (2+0) white spruce seedlings grown under semi-controlled conditions in a tunnel. The objectives of the present study were to:

(i) quantify the amount of mineral leaching from containerized white spruce seedlings grown under three different irrigation regimes (30%, 40% and 55% v/v) and to determine the effect of substrate water content on their growth, nutritional status and acquisition of frost tolerance, and

(ii) develop a hardening schedule specific to (2+0) white spruce seedling production in southern Quebec (ecological zone 2bT, Saucier et al. 1988).

Materials and Methods

A completely randomised-block experiment consisting of six repetitions of three irrigation regimes (IR) was installed on April 30, 2002 in a crop of air slit containerized (IPL 25-350A; IPL®, Saint-Damien-de-Bellechase, QC; 25 cavities/container, 350 cm3/cavity) white spruce seedlings growing in an unheated polyethylene-covered tunnel at Pampev Inc., a private forest nursery located in Saint-Louis-de-Blandford, Quebec (46º25'N 72º00'W), about 100 km south west of Quebec City. The sheltered conditions eliminated the effects of wind and rain and allowed us to control irrigation inputs and to monitor leaching and seedling morphophysiological variables over the seedlings' second growing season.

Three different irrigation regimes (30%, 40% and 55% v/v; cm^3 water/cm^3 substrate) were maintained between May and October 2002. Substrate water content was monitored six times a week for the duration of the experiment with a MP-917 soil moisture system (ESI Environmental Sensors Inc., Victoria, B.C.) (Fig. 1), which is based on the principles of time domain reflectometry (TDR) (Topp and Davis 1985). The seedlings were irrigated and fertilized using a motorized boom system (Aquaboom, Harnois Industries, Saint-Thomas-de-Joliette, Quebec) equipped with 32 nozzles (models 8006 and 8008, Harnois Industries, Saint-Thomas-de-Joliette, Quebec) (Fig. 2). Each pass of the boom increased the substrate water content by ±1% v/v. To verify the irrigation treatment, the substrate water content measurements were repeated thirty minutes after irrigation as suggested by Lambany et al. (1996). Substrate fertility was monitored and adjusted bi-weekly using PLANTEC software (Girard et al. 2001). This insured consistent substrate nutrient levels among the three IR throughout the growing season. Eleven destructive samplings of five seedlings/IR/block (90 seedlings) were made on a bi-weekly basis between May and October 2002. Seedling height, root collar diameter, shoot and root biomass, and tissue N contents were monitored. Seedling growth was later modeled using allometric models. These models describe the relative growth rate of each variable of interest.

The soil solution leaching through one seedling container per experimental unit was captured in a 4-litre plastic bottle on a continuous basis between the months of July and October 2002. The bottles were emptied once a week and the quantity of leachate was noted. The solution was analyzed to determine the amounts of N-NO_3, N-NH_4, P, K, Ca and Mg present in the leachate.

The kinetics of bud formation of one seedling/IR/block was monitored beginning on July 29. Beginning in mid-September, the ratio of drymass/fresh mass of the shoot apex was calculated for five seedlings/IR/block. The latter measurement has been shown to be an excellent indicator of a seedling's degree of hardening and frost tolerance (Lamhamedi et al. 2005b).

On September 16 and 30 and October 14 and 28, seedlings were subjected to artificial frost tests to monitor the evolution of hardening and the acquisition of frost tolerance. On each sampling date 240 seedlings were harvested and four seedlings/IR/block were frozen at each of the target temperatures (+4°C, -4°C, -8°C, -12°C and -20°C). Root plugs were left intact during the freezing procedure to simulate the seedlings' state under natural conditions of frost risk in a nursery.

Immediately following the artificial frosts treatments electrolyte leakage measurements were made on two shoot apices/IR/block, and water loss tests were conducted on two root systems/IR/block. These two procedures measure the extent of damage to the cell membranes. Once cells have been damaged by frost, they are unable to retain fluid and electrolytes. A morphological assessment of frost damage was also conducted. Seedlings were repotted and grown under ideal conditions for 21 days. The acquisition of frost tolerance was measured by assessing the amount of needle mortality as well as the capacity of the seedlings to produce new white roots over the bioessay period.

Results and Discussion

All seedling containers were saturated to a uniform water substrate content (± 60% v/v) before the experiment was installed. Frequent monitoring permitted us to maintain three distinct irrigation regimes (IR30%, IR40% and IR55% v/v) throughout the sampling period (Fig. 3). During the growing season, the standard deviation of the water content measurements varied between 1.1 and 9.2%.

The total amount of irrigation (L/m^2) applied to maintain the three treatments was 223.69, 235.03 and 282.85 L/m^2 for IR30%, IR40% and IR55%, respectively. Twenty percent more water was used for IR55% than for IR40% (Fig. 4).

Neither seedling height (Fig. 6) nor root biomass (Fig. 7) growth was affected by substrate water content. On the last sampling date (October 24, 2002) there was no significant difference among the absolute seedling heights of the plants grown under the three IR. The mean heights of the seedlings grown under IR30%, IR40% and IR55% were 34.95 cm, 35.94 cm and 35.65 cm, respectively at the end of their second growing season. There was a marked increase in the dry biomass of the root tissue at the beginning of August (Fig. 7). This coincided with the end of the period of rapid shoot elongation and the onset of bud formation, which was similar for all three irrigation regimes.

Figure 1. *Determination of substrate water content in an IPL-25-350A seedling container using the MP-917 soil moisture system.*

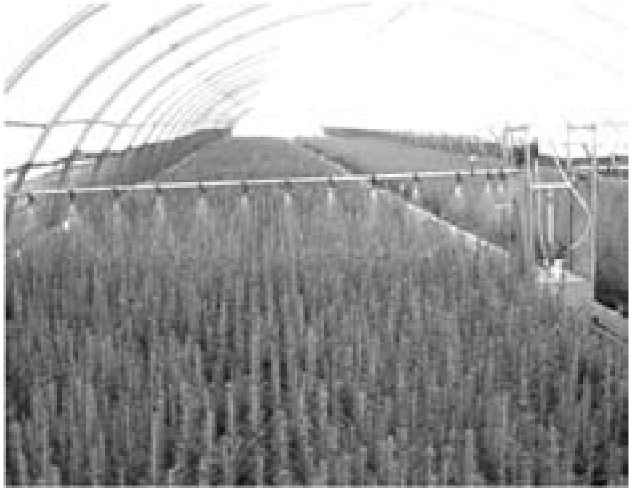

Figure 2. *Irrigation of (2+0) white spruce seedlings under tunnel conditions by a Aquaboom motorized boom system.*

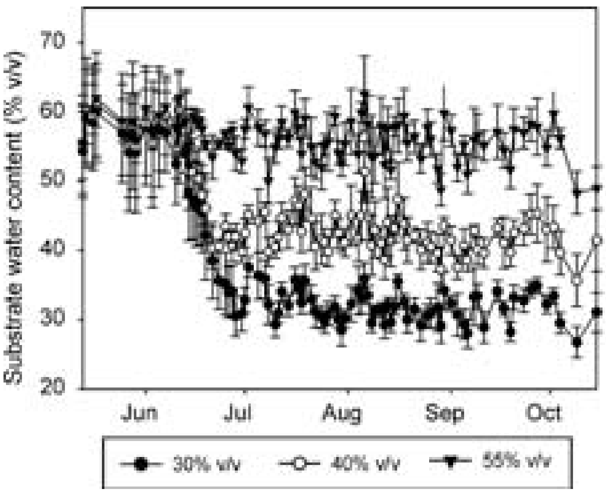

Figure 3. *Evolution of substrate water content under three irrigation regimes.*

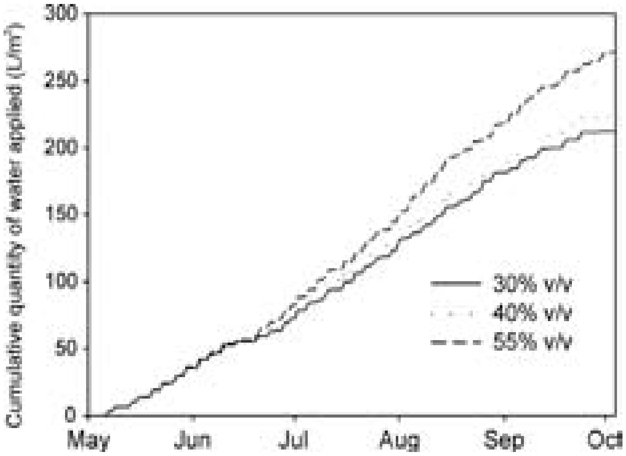

Figure 4. *Cumulative quantity of water applied to (2+0) white spruce seedlings in the form of irrigation.*

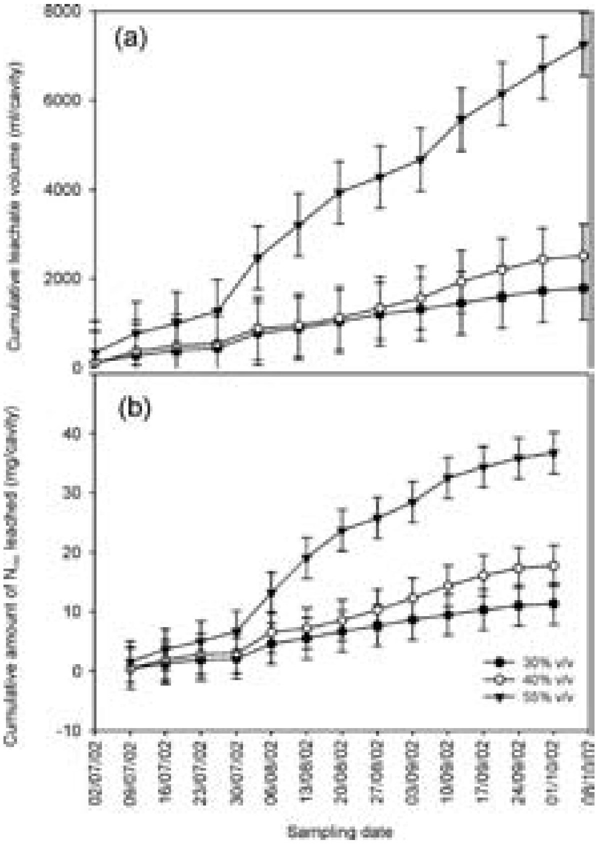

Figure 5. *(a) Cumulative total leachate volume and (b) amount of N (N-NO3 + N-NH4) leached from the seedling containers.*

Carbon allocation between root and shoot tissue was unaffected by a decrease in substrate water content. The same regression equation was used to model the relationship between the above- and below-ground components of the seedlings grown under the three irrigation regimes (Fig. 8).

The evolution of bud formation and the results of the electrolyte leakage and root water loss tests were similar for all three irrigation regimes, indicating that the acquisition of frost tolerance is unaffected by substrate water content. From these results, as well as the assessments of tissue damage and new root growth during the 21 day bioessay, threshold temperatures that root and shoot tissues can tolerate without sustaining frost damage can be determined for each sampling date. These temperatures can then be associated with the corresponding dry mass ratio of the shoot apices on the individual sampling dates to produce a hardening schedule (Fig. 9). Given the dry mass ratio of the shoot apex, the level of frost tolerance of root and shoot tissues can be easily read from the hardening schedule, making it a useful tool under operational forest nursery conditions. The rate of acquisition of frost tolerance can also be calculated directly from the schedule. For example, between September 16 and 30, shoot tissue increased its frost tolerance by 0.3ºC/day, whereas between October 14 and 28, the frost tolerance increased by 0.9ºC/day (Fig. 9). It is important to note that the hardening schedules are designed to underestimate seedling frost tolerance for a given date and, therefore, guarantee that tissue will not be damaged at temperatures warmer or equal to those stated on the schedule. Nursery managers

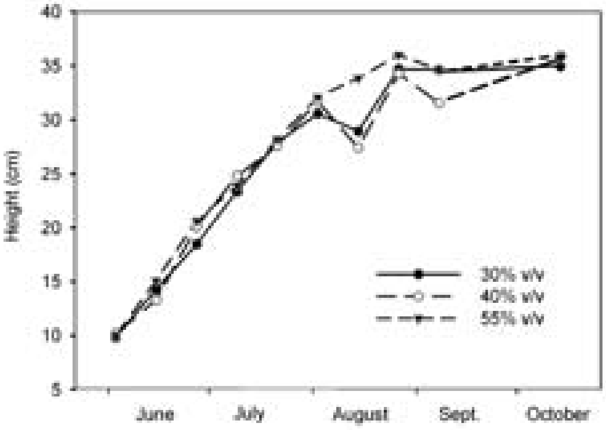

Figure 6. *Evolution of seedling height growth over the growing season.*

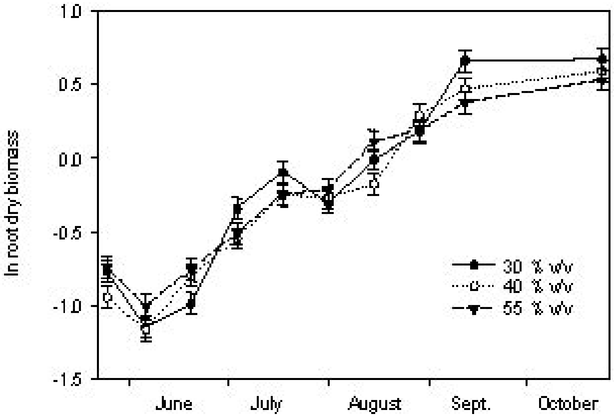

Figure 7. *Evolution of relative root biomass growth over the growing season.*

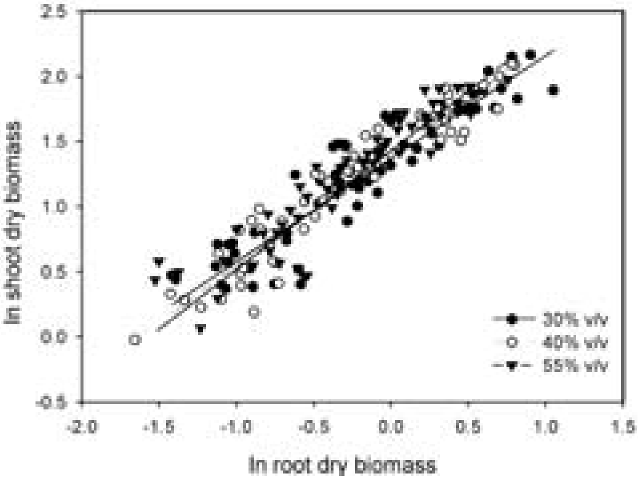

Figure 8. *Allocation of carbon between root and shoot tissues of (2+0) white spruce seedlings grown under three irrigation regimes.*

now have two choices when they learn of an impeding frost: (1) to run from sprinkler to sprinkler insuring that water is flowing and that a layer of ice is constantly being formed on the seedlings throughout the period of frost risk or, (2) to measure the dry mass ratio of the shoot apex on a regular basis and determine from the hardening schedules whether or not the seedlings will be able to sustain the forecasted temperature without irrigation and water wastage.

Conclusions

Reducing volumetric substrate water content from 55% to 40% does not have a significant effect on seedling growth, carbon allocation, tissue nitrogen content, end of season morphology, or the acquisition of frost tolerance. However, this irrigation strategy will result in a 20% reduction in water usage and, more importantly, reduce the total leachate volume by 65% and quantity of N leached by 52%.

The water content of peat/vermiculite (3/1) substrate should be maintained at 40% v/v during the second growing season for (2+0) white spruce seedlings. This strategy does not compromise seedling growth or physiological processes, yet limits leaching of water and mineral nutrients, and reduces the risk of groundwater contamination. The best way of controlling substrate water content is to grow seedlings under sheltered conditions for both the first and second growing season. New tunnel covers are being developed that maximize the ratio of red to infrared radiation transmitted. This growing environment, which is currently being used on an experimental basis by Pampev Inc. in Alberta, not only facilitates the use of highly efficient irrigation systems, but it also moderates the vapour pressure around the plants and shelters them from wind and rain, two elements that complicate irrigation management.

Hardening schedules, specific to individual ecological zones, can be developed using routine morphophysiological assessments, and measurements of the dry mass ratio of shoot apices over the hardening period. The schedules will help forest nursery managers to determine the level of frost tolerance the seedlings have attained and, therefore, reduce the amount of irrigation water used during periods of autumnal frost risk.

References

Bergeron, O, Lamhamedi, M.S., Margolis, H.A., Bernier, P.Y. and Stowe, D.C. 2004.Irrigation control and physiological responses of nursery-grown black spruce seedlings (1+0) cultivated in air-slit containers. HortScience 39: 599-605.

Burger, P. 2003. Désertification et société civile: Repères pour comprendre et agir. CARI Centre d'Actions et de Réalisations Internationales, France.

European Community 1998. Official Journal JO L330 (05.12.98). Council Directive 98/83/EC on the quality of water intented for human consumption. Adopted by the Council, on 3 November 1998. http://www.lenntech.com/EU's-drinking-water-standards.htm. Consulted July 9, 2005.

Girard, D., Gagnon, J. and Langlois, C.G. 2001. Plantec: un logicel pour gérer la fertilisation des plants dans les pépinières forestières. Gouvernement du Québec, Ministère des Ressources naturelles. Forêt Québec. Direction de la recherche forestière. Note de recherché forestière No.111.

Health Canada 2003. Summary of guidelines for Canadian drinking water quality. April 2003. http://www.hc-sc.gc.ca/hecs-sesc/water/pdf/summary.pdf. Consulted July 9, 2005.

Juntunen, M.-L., Hammar, T. and Rikala, R. 2002. Leaching of nitrogen and phosphorus during production of forest seedings in containers. J. Environ. Qual. 31: 1868-1874

Juntunen, M.-L., Hammar, T. and Rikala, R. 2003. Nitrogen and phosphorus leaching and uptake by container birch seedlings (Betula pendula Roth) grown in three different fertilizations. New For. 25: 133-147.

Labbé, L. 2004. Analyse géostatistique de la variabilité spatiale des teneurs en eau du substrat en relation avec la croissance et la nutrition minérale des semis d'épinette blanche (2+0) irrigués par les asperseurs. Mémoire de matrîse. Faculté de foresterie et de géomatique. Université Laval. 93p.

Lambany, G., Robidas, L. and Ballester, P. 1996. Measurement of soil water content in a peat-vermiculite medium using time domain reflectometry (TDR): a laboratory and field evaluation. Tree Plant. Notes. 47: 88-93.

Lamhamedi, M.S., Labbé, L., Margolis, H.A., Stowe, D.C., Blais, L. and Renaud, M. 2005a. Spatial variability of substrate water content and growth of white spruce seedlings. Soil Sci. Am. J. (in press).

Lamhamedi, M.S., Lambany, G., Renaud, M., Veilleux, L., and Plamondon, S. 2000. Gestion de l'irrigation en pépinière et evaluation des semis d'épinette blanche produits dans les récipients à parois ajourées. Gouvernement du Québec, Ministère des Ressources naturelles. Forêt Québec. Direction de la recherche forestière. Mémoire de recherche forestière no. 138. 36p.

Lamhamedi, M.S., Lambany, G., Margolis, H.A., Renaud, M., Veilleux, L., and Bernier, P.Y. 2001a. Growth, physiology, root architecture and leachate losses in containerized Picea glauca seedlings (1+0) grown in air-slit containers under different irrigation regimes. Can. J. For. Res. 31: 1968-1980.

Lamhamedi, M.S., Margolis, H.A., Renaud, M., and Veilleux, L. 2003. Effets de différentes régies d'irrigation sur la croissance, la nutrition minérale et le lessivage des éléments nutritifs des semis d'épinette noire (Picea mariana) (1+0) produits dans les récipients à parois ajourées Can. J. For. Res.33 : 279-291.

Lamhamedi, M.S., Renaud, M. and Margolis, H.A. 2002. La réflectométrie dans le domaine temporel : une technique d'optimisation de l'irrigation et de réduction du lessivage en pépinières forestières au Québec. Cahiers Agricultures 11: 275-283.

Lamhamedi, M.S., Renaud, M. and Veilleux, L. 2005b. Élaboration des seuils de tol érance au gel des plants d'épinette blanche 1+0 en pépinièere forestièere selon les régions écologiques du Québec. Gouvernement du Québec, Ministère des Ressources naturelles et de la Faune. Direction de la recherche forestière. Mémoire de recherche forestière no. 147. 52p.

Nienstaedt, H. and Zasada, J.C. 1990. *Picea glauca* (Moench.) Voss. *In* Silvics of North America Volume 1. Conifers. Agricultural Handbook 654. *Edited by* R.M. Burns and B.H. Hankala. USDA Forest service, Washington, DC. Pp. 204-234.

Saucier, J.-P., Bergeron, J.-F., Grodin, P. and Robitaille, A. 1998. Les régions écologiques du Quebec mériodional (3° version). Supplement to L'Aubelle, no. 24. 12p.

Stowe, D.C., Lamhamedi, M. S. and Margolis, H. A. 2001. Water relations, cuticular transpiration, and bud characteristics of air-slit containerized Picea glauca seedlings in response to controlled irrigation regimes. Can. J. For. Res. 31: 2200-2212.

Topp, G.C. and Davis, J. L. 1985. Time domain reflectometry (TDR) and its application to irrigation scheduling. *In* Advances in Irrigation vol. 3. Academic Press. New York, pp. 107-127.

USEPA 2004. Drinking water standards. http://www.epa.gov/safewater/standards.html. Consulted July 9, 2005.

World Health Organization 1993. WHO's Guidelines for Drinking-water Quality. Geneva, 1993. http://www.lenntech.com. Consulted July 9, 2005.