Irrigation management to enhance the quality, efficiency, and survival of transplanted nursery trees

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Abstract

The tree nursery industry is the largest water consumer in the ornamental horticulture sector in Canada. In most nurseries, subjective irrigation scheduling protocols have conditioned the trees to receive daily irrigation, however, rising environmental concerns and cost of water have prompted the industry to reduce its use of water. These water saving effects on plants still remain uncertain. This study examined the effects on tree growth, tree size and price changes due to water savings in *Acer rubrum* and *Thuja occidentalis* in a container production system. Nursery standard, mild, moderate, and high water stress treatments were applied via drip irrigation and based on cumulative vapour pressure deficit (CVPD) thresholds previously established. The leachate mass (kg) was collected from each stress treatment and compared to the nursery standard to establish relative changes in water savings. Tree growth was measured as caliper (*Acer rubrum*) or height (*Thuja occidentalis*) and the influence on selling pricing of the tree was determined. *Acer rubrum* exhibited a water savings of 50, 74 and 81% from the mild, moderate and high stress treatments respectively which resulted in a: 15% increase, 16% decrease, and 58% decrease in mean caliper growth (mm) this season. The reduction in tree caliper did not affect the final selling price. *Thuja occidentalis* had exhibited a water savings of 68, 84, and 89% from the mild, moderate, and high stress treatment, this reduced height growth by 36, 57, and 80%, respectively, which resulted no change in price for this season. These preliminary results indicated that each species have different water requirements. *Acer rubrum* caliper did not benefit from excessive application of water while *Thuja occidentalis* heights were more dependent on the water application. Significant water savings were realized in both cases which resulted in no economic penalties. Water savings over several seasons may allow nursery plants to improve survivability by conditionling. Additional work needs to be done to further confirm the plants' water usage characteristics and further refine irrigation management practices.

Keywords: irrigation scheduling, water-use, water management, stem psychrometer, plant water status, drip irrigation

INTRODUCTION

Water resources in Canada although abundant, are still limited by quality, quantity, and cost in all industry sectors. As an example, the tree nursery industry is the largest consumer of water within the ornamental horticulture sector (Deloitte and Touche, 2009), subjective irrigation scheduling being one of the largest factors. With rising concerns of water quality, quantity, and cost, the nursery industry is encouraged to improve its water usage by upgrading infrastructure (automation and irrigation systems) and meeting the guidelines for best management practices for irrigation management.

At the basic level irrigation scheduling is based on a function of how much and how often water is required by the plant (Linacre and Till, 1969; Evans et al., 1996; Doorenbos and Pruitt, 1977). Irrigation can be scheduled in one of two methods: 1) subjectively based on daily observation such as leaf wilting, leaf colour, soil dryness, and weather conditions; or 2) direct plant responses (Howell and Meron, 2007). Conventionally, nursery growers use subjective methods to schedule irrigation due to simplicity and low costs. Scheduling irrigation based on direct plant responses requires the ability to monitor plant water relations, specifically the plant water potential (Ψ).

Several techniques have been developed to measure the water potential of a plant, which provides an integrated response to all environmental conditions that affect the plant. One technique used to measure the plant water potential is the temperature corrected in situ stem psychrometer (Dixon and Tyree, 1984). This technique is the most field applicable and responsive method for monitoring plant water potential (Tran et al., 2015) and combined with the PSY1 data logging system provides a non-destructive, automated, and wireless method to measure and monitor plant water potential (ICT International Pty. Ltd., Armidale, NSW, Australia). Several studies have used the stem psychrometer for: modeling environmental water use (Wang et al., 2016; Yang et al., 2012), quantifying water relations for a range of plant species (Zotz and Andrade, 1998; Nizinski et al., 2013), and developing plant-based irrigation schedules (Tran et al., 2015; Tran, 2016). Plant-based irrigation schedules using the stem psychrometer have shown that the relationship between cumulative water potential and cumulative vapour pressure deficit (measured by conventional weather station) during daylight hours was predictable and provided a reliable means of estimating plant water stress. This supports the establishment of irrigation management strategies for a wider range of nursery plants based on the plants water needs rather than subjective irrigation protocols which can result in over watering and resource waste.

Overall, plant productivity (growth) determines the selling price of a tree and measures the efficacy of horticultural management strategies including irrigation scheduling. It is common practice for Canadian tree nurseries to increase water applications during hot or dry weather conditions to ensure the plants have a sufficient supply of water to avoid any growth limiting water stress. Unfortunately, this leads to inefficient use of water resources and leaching of nutrients from the containers restricted root zone. If tree nurseries are to reduce water use, the amount of water savings must demonstrate a positive change in both tree growth and selling price. Therefore, the objective of this study was to examine the effects of nursery tree growth (i.e., caliper or height), selling price and water savings in a container production system by comparing a subjective irrigation schedule to a plant-based irrigation schedule designed to predict plant water stress and avoid production and quality limiting levels.

MATERIALS AND METHODS

Tree growth, as measured by caliper or height (species dependent) of two nursery species were assessed based on irrigation schedules triggered by cumulative vapour pressure deficit (CVPD) thresholds (Tran, 2016). The irrigation schedule ranged from a nursery standard (daily irrigation) to a high stress threshold for each tree species. Differences in tree growth, tree size, water savings, and selling price were evaluated by comparing these values to those plants under the standard nursery irrigation protocol as the baseline.

Site and plant material description

The study was conducted at a tree nursery located in Waterdown, Ontario, Canada (43°21’24.231”N; 79°54’34.568”W). *Acer rubrum* ‘Red sunset’ (red maple) and *Thuja occidentalis* ‘Smaragd’ (emerald pyramidal cedar) were selected as representative deciduous and evergreen species, respectively. Each tree was grown in a container with a potting capacity of 38 L (10 gallon) and arranged as an in ground system (pot-in-pot). The potting media was a mixture of: peat moss (PM), composted pine bark (CPB), and leaf and yard waste compost (WC) (Gro-Bark, Milton, Ontario, Canada).

Irrigation management

Water was supplied through a controlled pressure valve, set to 25 PSI and distributed via drip irrigation. Each container was given a single emitter stake which sprayed water in a fan shape. The drip emitters were calibrated to verify the homogeneous water distribution across the field plot. The average water output of a single emitter was 0.19±0.01 L min^{-1} (5.7 L 30 min^{-1}). Each irrigation event had a duration of 30 min and was scheduled as either the nursery standard, mild, moderate, or high stress.

Tree growth measurements and selling price categories

Tree growth measurements of caliper and/or height were the industry's conventional means of classifying selling price categories for nursery trees. Red maple caliper and cedar height measurements were measured twice during the season, initially in June 2015 and at the end of September 2015. Caliper measurements were taken 30 cm above the root ball of the plant which followed the nursery technique. These measurements were made with CD-4" BS digital caliper (Mitutoyo, Tokyo, Japan). A dark line was drawn on the stem where the initial measurement was made to ensure successive measurements were taken at the same location and orientation. Height measurements were made with a conventional measuring tape where the tape stretched from the edge of the container to the peak of the cedar trees.

The nursery considers two factors when determining the selling price of a tree: container size and tree size (measured by caliper or height). Container sizes used by the nursery ranged from 1 to 25 gallon containers, in this study only 10 gallon containers were evaluated. The selling price was selected based on measured tree sizes (species dependent) that fell into incremental grades summarized in Table 1. Each grade represented the minimum range of tree size for each selling price. Frequently, subjective assessments were applied if trees fell between the designated grades.

Table 1. Nursery price guidelines for a single *Acer rubrum* 'Red sunset' and *Thuja occidentalis* 'Smaragd' tree potted in 10 gallon container. Prices were categorized into grades based on minimum tree sizes measured by caliper or height (species dependent) with a buffer of 2.5 mm for caliper measurements and 5 cm for height measurements.

***Acer rubrum* – red maple**	
Caliper grade ± 2.5 (mm)	**Selling price ($)**
30	227
35	246
40	252
***Thuja occidentalis* – cedar**	
Height grade ± 5 (cm)	**Selling price ($)**
125	76
150	99
175	127
200	159

Leachate collection and analysis

Prior to a triggered irrigation event, a leachate collection system was prepared on 5 trees in each treatment. Potted trees were removed from their in-ground socket containers and lined with a black plastic bag. Before placing the lined container back into its original socket, two 20-cm wooden blocks were placed on either side of the socket to elevate the container. The elevated container prevented the root zone from having any contact with the catchment water. After each irrigation event, a 10-min buffer time was provided to allow leachate water to fully drain before the catchment bag was removed and weighed. The weight of each bag was measured with a PM 16 scale (Mettler-Toledo, Greifensee, Switzerland).

Throughout the growing season, leachate was sampled at 4 random periods between July 10, 2015 and September 1, 2015, for each irrigation treatment. During the sampling period, leachate was collected from 5 trees for each irrigation schedule. The mean of all 4 collection periods (*n*=20) were used to determine the leaching fraction of the container to demonstrate the percentage water lost to the environment. The total number of irrigation events and volume estimates were based on the number of irrigation events. Using the drip emitter calibration and the number of irrigation events, the total volume of water was estimated for the nursery and used as a baseline for comparing the water applications for each irrigation treatment schedule.

Statistical analysis

Statistical analysis was conducted using R version 3.2.3 (R Foundation for Statistical Computing, Vienna, Austria). A Tukey's multiple means test was used to analyze and compare the mean differences in tree growth through the growing season (June 2015 to September 2015) and tree sizes. The mean from each treatment level was based on 12 trees measured at the start and end of the experiment. The p-value from each multiple test was not adjusted with a type I error rate of 0.05.

RESULTS

Tables 2 and 3 summarize the volume of water applied, relative water savings, relative tree growth, mean tree growth, mean size, and relative selling price changes in both species. Nursery irrigated trees represented the baseline that compares the irrigation treatments to determine relative changes. The nursery irrigated trees showed no reduction in water applications, tree growth, tree size, and selling price because these trees represented the baseline that was used to compare assigned irrigation treatments in both tree species.

Table 2. A table summarizing the total volume of water applied (L), percentage of water savings, relative percent change in mean caliper growth compared to nursery irrigated trees, mean caliper growth (mm) from June 2015 to September 2015, mean tree size measured by caliper (mm) and relative change in selling price for a single *Acer rubrum* – red maple tree. The percentages and measurements from each irrigation treatment were compared to the nursery irrigation baseline.

Irrigation treatment	Total water application (L)	Water savings compared to nursery baseline (%)	Relative change in mean caliper growth (%)	Mean caliper growth from June 2015 to September 2015 (mm)	Mean tree size measured by caliper (mm)	Relative change in selling price (%)
Nursery	803	0	0	3.53±0.32[a]	35.63±0.57[a]	0
Mild	402	49.94	+15.01	4.06±0.50[a]	36.06±0.78[ab]	0
Moderate	210	73.85	-16.14	2.96±0.44[a]	34.24±0.47[a]	0
High	150	81.32	-58.07	1.48±0.24[b]	33.51±0.62[ac]	0

Tree growth and size were compared among all treatment levels and between the nursery irrigated trees, mild, and moderate stressed trees they were not significantly different in a multi-comparisons test. However, tree growth of the high stressed trees was significantly different from nursery, mild and moderate irrigated trees (p=0.0003, p=0.0001, and p=0.0487), while the tree size was different from only mild stressed trees (p=0.0298). Although the mild irrigated trees showed a 15% increase in caliper growth (4.06±0.50 mm) compared to the nursery baseline (3.53±0.32 mm), the tree size at the end of the growing season (36.06±0.78 mm) was not a sufficient change the selling price. However, the mild stressed trees had a water savings of ~50%. Moderate and high stressed trees both showed a 16% (2.96±0.44 mm) and a 58% (1.48±0.24 mm) reduction in caliper growth. At the end of the growing season, the tree size did not change the selling price of the tree (34.24±0.47 and 33.51±0.62 mm) however, there was a water savings of ~74 and 81%, respectively.

Table 3. A table summarizing the total volume of water applied (L), percentage of water savings, relative percent change in mean height growth compared to nursery irrigated trees, mean height growth (cm), mean size measured by height (cm) and selling price for a single *Thuja occidentalis* - cedar tree. The percentages from each irrigation treatment was compared to the nursery irrigation baseline.

Irrigation treatment	Total water application (L)	Water savings compared to nursery baseline (%)	Relative change in mean height growth (%)	Mean height growth from June 2015 to September 2015 (cm)	Mean tree size measured by height (cm)	Change in selling price (%)
Nursery	803	0	0	14.06±1.34[a]	153.86±2.40[a]	0
Mild	256	68.12	-36.27	8.96±1.03[b]	150.80±2.02[a]	0
Moderate	132	83.56	-57.32	6.00±1.23[b]	147.50±2.89[a]	0
High	90	88.79	-80.22	2.78±0.70[c]	147.70±1.80[a]	0

Height growth was significantly different in all irrigated treatments in a comparison to the nursery irrigated trees ($p=0.0216$, $p<0.0001$, and $p<0.0001$, respectively). Between the mild and moderate stressed treatments there were no significant differences, however comparing both stress treatments to the high stressed trees there was a significant difference ($p<0.0001$ and $p=0.0128$, respectively). Tree sizes showed no differences between all treatment levels. Although the changes in growth for mild, moderate and high stressed trees were reduced by 36, 57, and 80% respectively and no changes were seen in selling price, these reductions had a water savings of 68, ~84 and ~89% overall.

DISCUSSION

Canadian nurseries determine the price of a tree based on tree growth, rarely considering the cost of water resources. A comparison between subjective (daily) and weather-based irrigation scheduling protocols yielded only small differences in tree growth that could affect the selling price of a tree. Although these changes in growth, size and selling price were small, the water savings for the mildest stress treatment were significant enough to mitigate both water costs and environmental impacts.

Improving water use in the Canadian nursery industry requires a balance between water applied versus tree growth gained. Although the results of this study showed that reducing irrigation rates by 80% had little or no effect on the ultimate selling price of the commodity, it must be considered that the results were based on a single growing season. If that the trees were monitored for several seasons, the accumulated growth from each irrigation treatment would likely be sufficient to modify the selling price of each species. In addition, reducing the water applications may allow plants to condition and improve their post-transplant survival. The study also demonstrated that different species responded different to reductions in water applications. Cedar trees, representing evergreen species, maintained productivity and quality with much less water than their deciduous counterpart in the nursery setting. Thus, species specific water management strategies are indicated and much more work is required to address the fine-tuning of irrigation management strategies across the nursery sector.

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