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A Comparison of Indirect Watering Devices for Benefiting Newly Transplanted Urban Trees

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Abstract. Three types of indirect watering devices were compared to evaluate their performance and to determine their benefits to newly transplanted river birch (*Betula nigra*) trees grown in containers with well drained compost in a controlled greenhouse experiment. Two examples of each device type were used to water trees in this study: upright bags, ring bags, and open tubs. Watering device characteristics, including purchase cost, weight, capacity, and drainage times, were measured prior to installing the devices around the trees. Tree stem heights and calipers, along with leaf coverage and leaf water potential, were measured to determine any growth or water stress differences associated with watering treatments. There was substantial variation in costs and drainage times among watering devices, with ring bags being the least expensive and draining water completely during the drainage test. However, there was no evidence that watering devices benefited tree growth, leaf rating, or water stress in comparison with direct watering, with the possible exception of Treegator ring bags, which may have reduced water stress marginally. Although water release from some of the indirect watering devices was much slower than direct watering, water release from all of the devices was completed within ten hours, which is too rapid to reduce the frequency of watering in our experiment. The major benefits of these devices are slower release of water to the soil, with reduced operator time required, and more infiltration into the soil and root zone, which avoids the surface runoff caused by quick hose (direct) watering.

Key Words. *Betula nigra*; Greenhouse; Indirect Watering Device; Leaf Water Potential; River Birch; Slow-Release Watering Device; Transplanting; Tree Growth; Urban Landscape; Water Stress.

Newly transplanted trees in the urban landscape (e.g., university campus, community park, city street) undergo significant stress during and after transplanting from the tree nursery to the planting site. One source of transplant shock for field-grown trees is reduced root surface area resulting from lifting trees out of the ground and the acclimation to the new site (Watson 1996). However, a more significant transplant-related stress is limited water availability in the planting site (Kramer 1987), a problem exacerbated by reduced root surface area. Usually, a tree receives an adequate supply of water when growing in the nursery. When a tree is transplanted, however, it is subject to a new soil environment that is commonly water limited. As such, it must grow enough new roots at the new planting site to access a limited water supply (Clark and Kjelgren 1990; Ferrini and Fini 2011). Transplanted trees that were grown in nursery containers can also suffer from transplant and drought stress because water tends to drain more quickly from the soilless media (Watson 1996).

Limited water availability hinders physiological functions in newly planted trees (Fichot et al. 2010). When adequate water is available, as in nurseries, transpiration allows water to move through the xylem conduits under tension (negative water potential). In contrast, when water becomes limited, as in the urban landscape, xylem tension increases to maintain its hydraulic conductivity. As xylem tension reaches a critical maximum threshold, cavitation may occur and disrupt water movement through xylem conduits (Tyree and Sperry 1989). To prevent cavitation, stomatal closure occurs in the leaves (Sperry et al. 2002), but this process comes at the cost of lower CO_2 availability in the photosynthetic apparatus, causing reduced carbon assimilation and hence reduced photosynthate for tissue maintenance and growth (Ryan et al. 2006). Water stress can also cause growth declines in plants indirectly via reduced cell enlargement associated with loss of turgor pressure (Ranney et al. 1991).

One way to reduce water stress associated with transplanting is to use supplemental watering during the tree establishment period at its new site. Regular and frequent watering is commonly recommended in most tree planting guides, especially during the first several months after transplanting (Lipkis 1990; Gilman 2002; Starbuck, 2006). Because a water source may not be available near a tree planting site, water may have to be hauled to the tree planting site several times per week. However, frequent watering, either by hand or by machines, can be time consuming and expensive, so this practice may not be optimal for tree planting projects in the urban landscape. An inexpensive watering method would be to install a device around the stem that can deliver water more slowly over a longer time period. Whatever the method being employed, slow watering is necessary to maximize infiltration through the soil profile and to minimize surface water runoff, thereby encouraging deep root growth and tree establishment. Reduced surface runoff also helps conserve water in the landscape.

Several types of watering devices are available to aid in tree watering, such as upright bags, ring bags, and tubs, which can typically hold 19 to 95 liters of water (depending on device design). For this study, the term "indirect watering devices" was used because water is delivered to the tree via a container with small holes at the bottom and not directly from a hose or poured bucket (direct watering). Other descriptions for these types of devices include passive watering, drip irrigation, slow-release or slow drip, and root feeder. These devices have the advantage of being filled up quickly and then releasing water either slowly but deeply to the tree roots over time, or directly to the root zone, both with the intended purpose of reducing water stress and facilitating successful transplanting. Furthermore, these devices are cost-effective and light in weight, allowing them to be readily installed around a tree. Despite these advantages, we are unaware of any studies that have compared different watering devices quantitatively to determine which device benefits the tree most in terms of decreasing water stress and increasing tree growth. Although there is one study that has compared watering systems for newly planted trees, the comparison was qualitative (e.g., rank scoring) rather than quantitative (Beginners Guide for Watering New Trees 2014), hence providing only subjective information for tree planters.

The purpose of this study was to evaluate and compare three different types of devices used to water newly transplanted river birch (*Betula nigra*) trees in a controlled greenhouse environment. In particular, the objectives of this study were to: 1) evaluate performance of indirect tree watering devices in terms of device characteristics and water delivery; and 2) compare watering devices to determine which device type has the most potential to benefit the tree in terms of reducing water stress and enhancing growth. We designed this study to simulate the use of indirect watering devices on newly transplanted trees in the urban landscape. Experiments were conducted in a greenhouse with container-grown trees in order to control for variations associated with natural precipitation, temperature, and soil. River birch was chosen as a candidate species for this study mainly because it tends to show water stress more readily than other species. Furthermore, river birch trees are relatively site-adaptable and aesthetically pleasing (color and appearance of bark and fall leaves), rendering them suitable for urban planting.

MATERIALS AND METHODS

Site

This study was conducted in a temperature-controlled greenhouse on the University of Arkansas at Monticello campus located in southeast Arkansas, U.S.A.

Watering Devices

Watering devices used in this study were flexible bags or rigid tubs that hold a given amount of water which is slowly released over time to the tree roots though holes in or near the bottom of the device. We examined two examples of each of the three commonly available types of slow-release watering devices: 1) upright bags (Treegator® and ArborRain®) (Figure 1, panels 1 and 2); 2) ring bags (Treegator® Jr. Pro and ArborRain®) (Figure 1, panels 3 and 4); and 3) open tubs (Tree I.V.® and Bioplex® Tree Ring Jr.) (Figure 1, panels 5 and 6).

The actual water holding capacity for the two upright bags (ranged from 58.7 to 62.5 liters) and the Tree I.V. tub (19 liters) was the same as rated (ranged from 19 to 75 liters), but less than rated for the two ring bags (ranged from 47.3 to 49.2 liters for the Treegator Jr. Pro and from 64.4 to 66.2 liters for the ArborRain). The Bioplex tub's actual capacity was 33.1 liters. This capacity discrepancy for the Bioplex tub necessitated adjustments of water volume for that tub

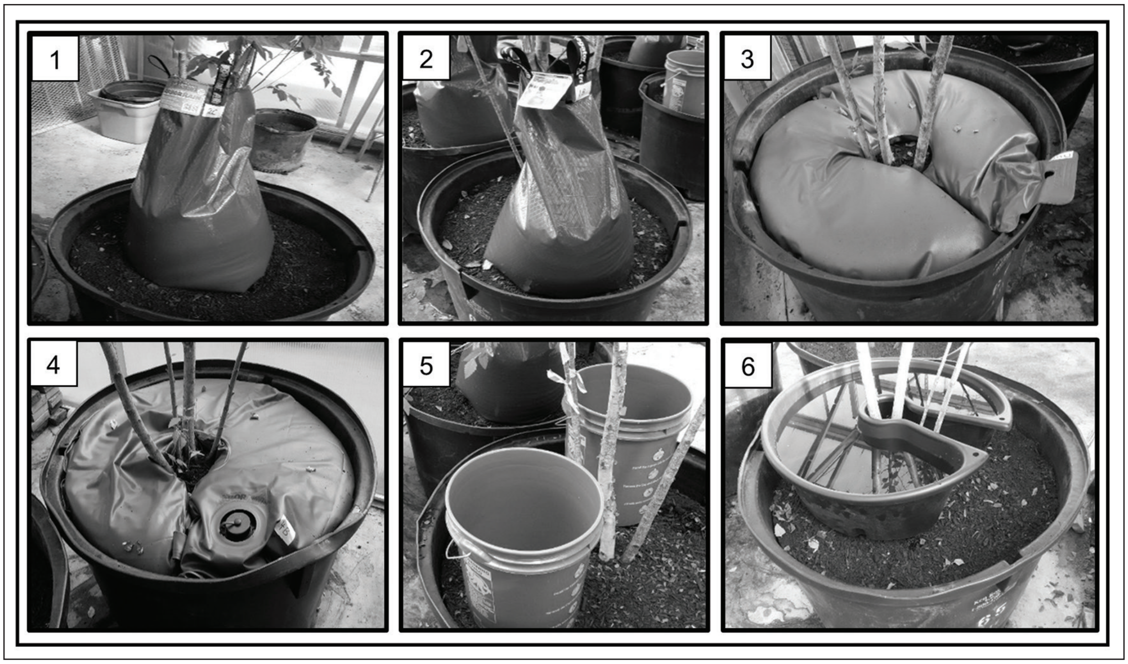

Figure 1. Examples of the six watering devices tested in this study: 1) Treegator® upright bag; 2) ArborRain® upright bag; 3) Treegator® Jr. Pro ring bag; 4) ArborRain® ring bag; 5) Tree I.V.® tub; 6) Bioplex® Tree Ring Jr. tub. (Panel numbers correspond to treatment numbers).

treatment when delivering water to represent an equal treatment effect, i.e., each unit was filled with 38 liters (10 gal) of water. The Bioplex units were each filled with about 30 liters of water, followed by another 8 liters after a portion of the initial 30 liters had drained out. For the Tree I.V. units, two devices (19 liters each) were used for each containerized tree to achieve the 38 liters (Figure 1). Two units of each of the six watering devices were measured and tested to evaluate their characteristics, including purchase cost, weight, capacity, and drainage times.

Capacity Tests

Each unit was filled to overflow with a measured quantity of water (varied by device, see Table 1), with the resulting actual water volume compared to the rated capacity indicated by the watering device manufacturer. The purpose was to determine if each device actually held the advertised volume of water.

Drainage Tests

Drainage tests were conducted on the watering devices to compare the actual time required to drain to the drainage time advertised by the manufacturer. Platforms were constructed that held the watering device on the upper level. Water that drained out of the device was captured underneath each device in a plastic wading pool mounted on an incline. The collected water drained out of a hole in the pool and into a calibrated tub. The cumulative volume of water that drained into the calibrated tub was recorded every thirty minutes until the device stopped draining. Note that drainage tests were conducted in the absence of soil assuming drainage rates for most of the devices would not be influenced by water infiltration through the medium (compost or other soil types) unless drainage holes of the device are blocked by soil particles or foreign materials. Actual drainage time of the Tree I.V. tub might be slower in fine textured soil, since it drains through a tube that is inserted into the soil.

Study System

Four-year-old river birch saplings (provided by Bemis Tree Farm located near Little Rock, Arkansas) were transplanted from #15 plastic containers (43 cm wide × 38 cm deep) into larger #65 plastic containers (81 cm wide × 56 cm deep) in early March 2017. The larger containers were needed to accommodate the watering devices. Each container was filled with a compost potting medium (American Composting, Little Rock, Arkansas) obtained through Bemis Tree Farm. We used compost for this study because it

Table 1. Weight, capacity, drainage, and cost characteristics of the six watering devices tested in this study.

	Treegator upright bag Tmt #1	ArborRain upright bag Tmt #2	Treegator ring bag Tmt #3	ArborRain ring bag Tmt #4	Tree I.V. tub Tmt #5	Bioplex tub Tmt #6
Empty weight, kg	0.36	0.36	0.68	0.91	0.77	1.36
Rated capacity, l	56-75	56-75	56	75	19	38
Actual capacity, l	58.7-62.5	59.6-62.5	47.3-49.2	64.4-66.2	18.9	33.1
# Liters drained	56	56	45	61	38 (2 tubs)	32
Rated drain time	5-9 hours	5-8 hours	5-8 hours	5-8 hours	10 minutes	2-3 hours
Actual drain time	8.5-9.5 hours	9.0-9.5 hours	9.0-9.5 hours	5.5-6.0 hours	2 minutes	35-40 minutes
Residual volume, l	1.5	1.9-3.3	1.0-1.5	0-0.5	1.0-1.9	1.0-1.5
Cost per liter	$0.36	$0.33	$0.44	$0.31	$0.88	$0.91

usually has high water holding capacity, allowing for the development of new roots capable of absorbing available water (Spomer 1981). From late March until late June (twelve weeks), each river birch container received a single watering of 38 liters per week via one of the watering devices or directly by hose. The watering schedule of once per week was intended to increase the possibility of any watering device differences becoming more apparent if slight water stress conditions developed due to any particular watering device. A volume of 38 liters was chosen because manufacturers' specifications showed that all tested devices would hold at least that much water (except the Tree I.V., which held only 19 liters per tub, so 2 tubs per tree were used for that treatment). Water was delivered to all containers on the same day each week.

Experimental Design

We tested the effectiveness of six watering devices (3 types × 2 manufacturers each) at delivering water to trees using a replicated greenhouse experiment on containerized river birch trees. Trees were placed in a greenhouse to eliminate influences of natural rainfall and soil variations had they been planted in the ground outside. A total of 21 river birch trees were used: 7 treatments (6 watering devices) and a control (water delivered directly via hose) replicated 3 times. To alleviate concerns that the proximity of the trees to the Kool Cell or exhaust fan may influence greenhouse microclimate and tree response, the three replications of seven treatments were blocked on location in the greenhouse relative to the Kool Cell and exhaust fan, resulting in a randomized complete block design.

Measurements

Tree-stem heights and calipers, along with estimated leaf coverage and number of leaves per cm, were measured initially and at the end of the three-month study period to determine any growth differences due to the watering treatment used. Stem heights were measured from the soil surface to the terminal bud, while stem calipers were measured at 15 cm (5.9 in) above the soil surface (average of two perpendicular measurements). Estimated leaf coverage (leaf rating) was judged visually by dividing each stem into three equal sections (lower, middle, and upper), and then estimating the percent extent of green leaves covering each stem section, starting at the first green or brown leaf. For example, if a stem section had 60% green leaf coverage and 40% brown leaves, that section would receive an estimate of 60%. To estimate the number of leaves per cm, four side branches were selected randomly on each tree. At the beginning and end of the study period, each branch's length was measured and the number of leaves was counted.

Pre-dawn leaf water potential, which indicates tree stress caused by water deficiency, was also measured for each tree near the end of the study period (week 11) to compare the effectiveness of the watering devices from a physiological standpoint. During that week, water potential measurements were recorded early morning one day after watering, four days after watering, and seven days after watering (immediately before the next water delivery). Water potentials were measured with a Model 600 Pressure Chamber, PMS Instrument Co.

Statistical Analysis

Main effects of watering devices on growth (stem heights and calipers) and ratings (leaf coverage and number of leaves per cm) variables as well as on water potential were analyzed with one-way analysis of variance (ANOVA) using generalized linear model (GLM) procedures. In the case of significant variation ($P \leq 0.05$), means were separated with Tukey's multiple range test. Linear regression analyses were employed to examine relationships between growth and ratings variables and water potential as an approach to evaluating the overall benefits of watering devices in terms of enhanced growth and/or reduced water stress regardless of treatments. Only response variables having significant relationships with water potential are reported. The significance of relationships was determined by $P \leq 0.05$. All analyses were conducted using R statistical package v. 3.4.2 (R Core Team 2017).

RESULTS AND DISCUSSION

Evaluating Watering Device Performances

All watering devices were easy to install. The geometry of multi-stemmed trees made installation of the upright bags somewhat difficult, but this would not present a challenge for single-stemmed trees. Watering device empty weights ranged from 0.36 kg (0.79 lb) for the upright bags to 1.36 kg (2.9 lb) for the Bioplex tub (Table 1). Depending on water holding capacity, each watering device was filled with 38 liters (10 gal) of water and was able to drain most of it (details in Materials and Methods). In terms of cost per liter of water, devices ranged from \$0.31 to \$0.91 (Table 1), with ring bags and tubs being the least and most expensive, respectively. A lower cost is desirable if watering devices have similar performance, especially when purchasing many watering devices for a large-scale urban tree planting program.

Drainage times varied substantially among watering devices ranging from 2 minutes to 9.5 hours (Table 1). With the exception of ArborRain ring bags, which drained completely during the drainage test, all other devices had residual water, which could not drain from a device due to the configuration of drainage holes or the device itself. Significant volumes of water remained in almost all devices, with ring bags and tubs having the least (1.0 liter) and the ArborRain upright bag having the most (3.3 liters) residual water (Table 1). While this study was not designed to investigate the cause of this drainage variability, water-filled upright bags tend to collapse onto drain holes and block them, thereby reducing water release. The drain holes in the upright bags are located several inches above the base of the bag. Incomplete drainage in devices with small drain holes could also be associated with reduced water pressure resulting from reduced water weight and also from water tension. For the devices with larger drain holes, such as Tree I.V. tubs, although drainage was faster, complete drainage was likely prevented by the lip around the "soil injector" placed in the bottom of the tub. Finally, differences in drainage times among devices are associated with the total number and size of drainage holes (water entry points), which ranged from 2 to 22 holes across all devices, with the Bioplex tub having the most water entry points into the root zone (22 holes, total drain hole area 3.3 cm^2).

Overall, this study demonstrates that indirect watering devices offer logistic advantages in many aspects such as ease of installing and handling (associated with light weights) as well as filling of water. We expect that these logistic benefits would render slow-release indirect watering devices favorable over fast-release direct watering devices such as hoses, which may not be readily available at the site and may be difficult to install and time-consuming to handle for watering newly transplanted trees. Our results also indicate that when choosing slow-release watering devices for an urban tree planting program, ring bags should be favored over other devices due to their lower cost and ability to drain water more completely. Ring bags, because they are enclosed, also have the advantage of avoiding the accumulation of tree debris (leaves, seeds, etc.) that may clog the drain holes and prevent water release, as happened with the open tubs (personal observation). However, from the water distribution viewpoint, Bioplex tubs have the advantage of more uniform water distribution ability over the root zone through six water entry points surrounding the tree stem. Whichever devices are used, frequent deep watering is important for the successful establishment of new trees (Clark and Kjelgren 1990).

Evaluating Watering Device Benefits to Trees

There were no statistically significant differences among tree growth and leaf rating variables across watering treatments ($P > 0.05$; Figure 2A-D), indicating that the impacts of watering devices employed in this study on the growth of young urban trees were similar to each other and provided no benefit to the trees compared to direct watering. We used compost and containers to provide the most uniform drainage conditions across treatments as possible while accommodating the need to work in a greenhouse environment in order to maintain complete control of water additions during our experiment without interference from precipitation. As such, we cannot rule out the possibility that the devices may benefit trees in other soil types with different drainage properties.

Given the large variability observed within treatments, the limited sample size (3 replicates of 7 treatments) might have obscured possibly real differences between treatments.

To address this concern, we conducted a power analysis to determine the ability of our study to detect a difference. Specifically, we strived to detect a "small" effect of 3 replicates of each watering treatment with a significance of 0.05 based on conventional effect size from Cohen (1982). This analysis demonstrated that, given our sample size, our data generated a power of 0.12, meaning a 12% probability to detect a difference with $\alpha = 0.05$ (results not given). This analysis also showed that we needed a larger sample size in each treatment ($n = 30$) in order to achieve a power of 0.8 (recommended).

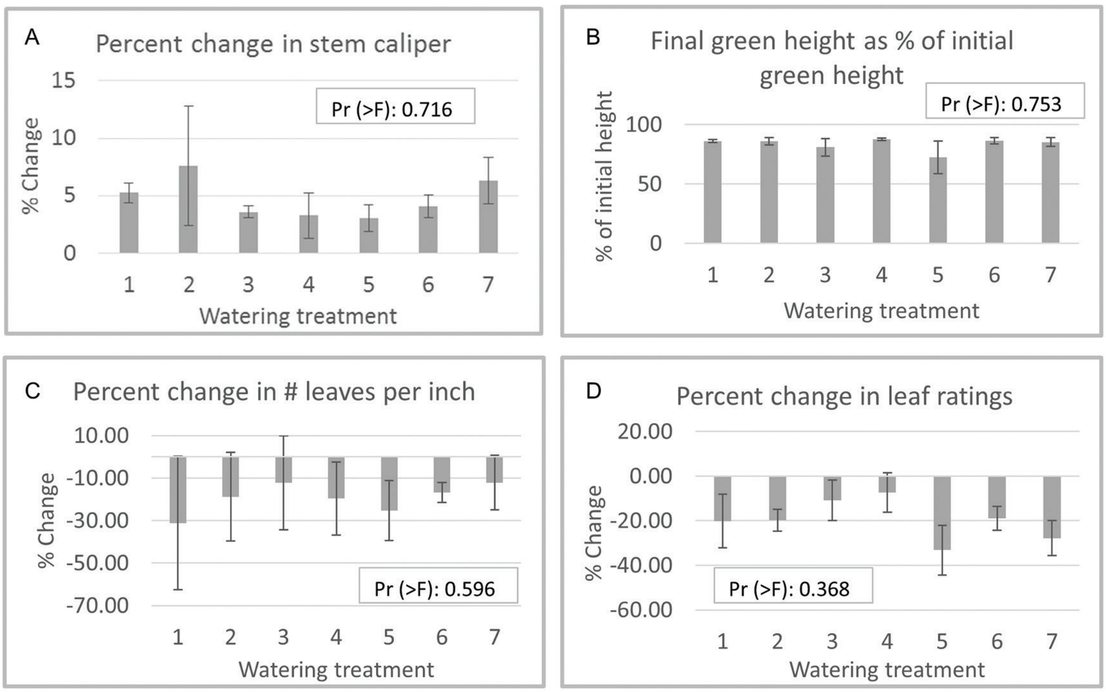

Figure 2. Growth and leaf condition of river birch trees with different watering device treatments. Percent change (initial versus final) in average stem caliper for each treatment (A). Average final green stem heights for each treatment were compared to initial green stem heights (B). Percent change (initial versus final) in average number of leaves per inch on four randomly selected side branches per tree (C). The percent change (initial versus final) in green leaf (versus brown leaves or bare branches) coverage for each stem (D). Treatments are numbered as in Figure 1: 1) Treegator® upright bag; 2) ArborRain® upright bag; 3) Treegator® Jr. Pro ring bag; 4) ArborRain® ring bag; 5) Tree I.V.® tub; 6) Bioplex® Tree Ring Jr. tub; and 7) Control. Bars indicate standard errors.

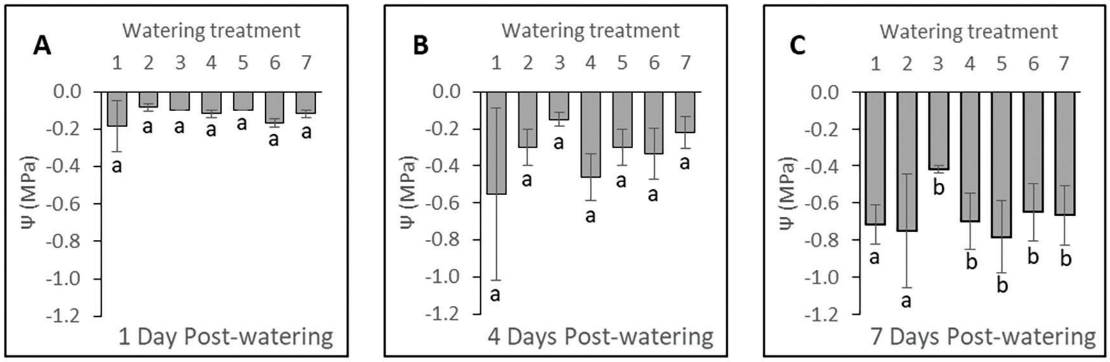

Figure 3. Leaf pre-dawn water potential (MPa) was measured for each tree on three different days, i.e., 1 day post-watering (A), 4 days post-watering (B), and 7 days post-watering (C) during Week 11 of the 12 week study. Treatments are numbered as above. Bars indicate standard errors. Different letters on a treatment between days represent significant difference at *P* < 0.05.

Leaf pre-dawn water potential (MPa) decreased from 1 day post watering to 7 days post watering (-0.12 MPa to -0.67 MPa) across all treatments, indicating reduced water availability for planted trees over time (Figure 3 A-C).

In a previous study, well-watered river birches had pre-dawn water potentials around -0.1 MPa, whereas -0.6 MPa indicated a moderate water stress accompanied by decreased stomatal conductance and photosynthesis (Ranney et al. 1991). Ranney et al. (1991) reported turgor loss at -1.3 MPa, while Gu et al. (2007) induced water potentials as low as -2.1 MPa in river birch. Thus, our river birch trees mostly experienced a moderate stress weekly by the time more water was added. This declining water potential is expected as water is lost by drainage out of containers, evaporation from the soil surface, and transpiration through the leaves. ANOVA testing the influence of water devices on leaf water potential detected a marginally non-significant effect ($P = 0.06$; results not shown), which appeared to be associated with a nominally higher water potential observed under treatment 3 (Treegator ring bag; Figure 3 A-C), suggesting that trees under this treatment may have been the least water-stressed. The ring bag tended to cover most of the soil surface in the pot (personal observation), which may have reduced evaporative losses directly from the soil surface. A further ANOVA between water potential values of treatment 3 revealed that there was a significant ($P < 0.05$) difference between the 1 day and 7 day potentials and between the 4 day and 7 day potentials (Figure 3 A-C). Trees under most treatments, including the control, experienced an increasing water stress in between weekly watering events associated with a progressive decline in water potential, particularly between 4 day and 7 day potentials (Figure 3). This indicates that trees in these treatments need more water during the week to avoid being stressed, which could be detrimental to growth.

Weekly minimum water potentials (at 7 days post-watering) correlated positively with both percent change in number of leaves per cm and leaf ratings when all treatments were pooled ($P = 0.04$; $R^2 = 0.16$ and $P = 0.01$; $R^2 = 0.32$ in Figure 4 A and B, respectively), indicating a negative impact of water stress on leaf retention and consequently on tree growth.

Previous studies have also reported water-stress related declines in tree growth (Kozlowski 1983; Kramer 1983). These studies have commonly attributed reduction in growth to disturbance of physiological processes, i.e., photosynthesis. For example, as water becomes limited, stomatal closure occurs in the leaves (Sperry et al. 2002), which limits CO_2 availability to the chloroplasts causing reduced carbon assimilation and hence reduced growth (Ryan et al. 2006). River birches may have premature leaf abscission when water availability is low (Gu et al. 2007; Wendler and Millard 1996), which may explain the reduced number of leaves observed in this study (Figure 2C). Reduced leaf area by abscission would also be expected to reduce growth, since leaves are required for carbon assimilation.

An indirect impact of water stress is the loss of turgor pressure associated with reduced water potential (Ranney et al. 1991). Trees are able to maintain turgor pressure for cell expansion when water is available (Lockhart 1965). However, as water becomes limited,

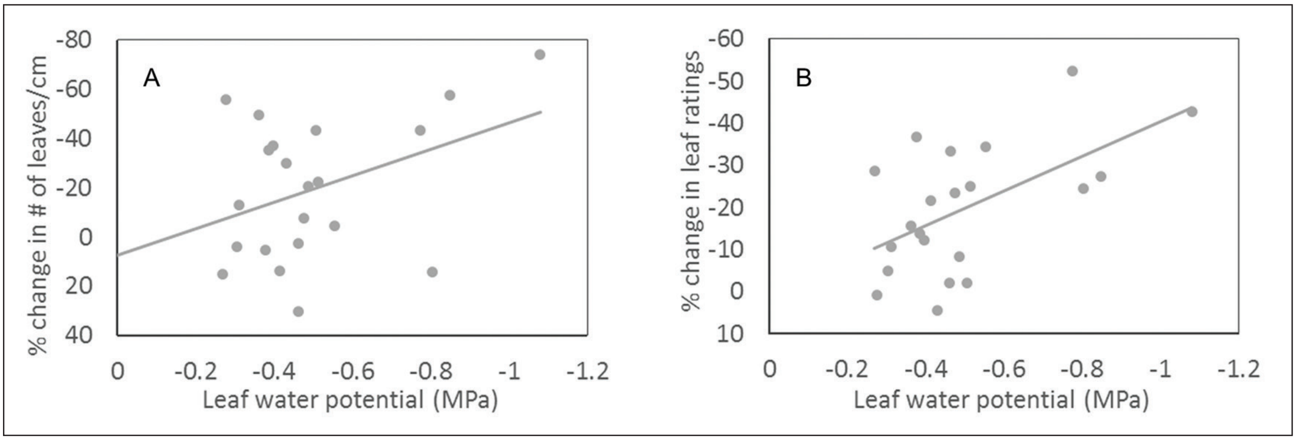

Figure 4. Leaf water potential (MPa) at 7 days post-watering in relation to (A) percent change in the number of leaves per inch (P = 0.04; R^2 = 0.16) and (B) percent change in leaf ratings (P = 0.01; R^2 = 0.32).

turgor pressure declines, reducing cell enlargement, which ultimately results in decreased growth (Kramer 1987). The first visible effect of water stress in plants may be leaf curling, then wilting, followed by leaf browning and defoliation if adequate water is not restored in time to prevent tissue death. Such injuries may be more vivid in species such as river birch that are adapted to mesic sites (Dirr 1983). Even under mild stress, river birch shows the lowest capacities for maintaining turgor among other birch species (Ranney et al. 1991). Although we do not have data to examine the effect of loss of turgor on tree growth, most of this study's river birch trees had shown brown terminals and foliage ten weeks after transplanting and six weeks after initiation of the watering treatment (personal observation; note that trees were allowed four weeks to acclimate to the larger containers in the greenhouse). This might be the result of water stress, high temperatures in the top of the greenhouse (tree tops extended into the greenhouse trusses, where temperatures were difficult to control), or possibly the combination of both high temperatures and water stress. Depending on planting practices, water stress may occur for several weeks or much longer due to transplant shock, which could have reduced the rate of uptake of available water in this study. Limited soil water abundance could have also contributed to water stress. Water potentials at mid-tree height were moderately low by the end of the week, and were likely even lower at the tree tops. In our study conditions, a slight increase in the frequency of water additions may have been optimal for tree establishment, but may have made little difference if water uptake capacity of roots in the weeks immediately following transplanting was more limiting than soil water abundance per se. In practice, more than 38 liters of water could be added via the upright and ring bags due to their larger capacities, which might allow less frequent watering, depending on the field capacity of the soil.

While the watering devices provided no greater benefits to trees than direct watering in our study, we cannot dismiss the possibility that the devices may provide benefits to trees transplanted into a field setting. The devices are intended to increase the proportion of water delivered to the soil immediately surrounding the tree by reducing losses to runoff. Our study did not account for runoff, because the use of pots in our study forced all of the water through the root ball, but on natural soils, water flows in both vertical and horizontal directions. Slow watering may also facilitate deeper water infiltration, particularly where infiltration is limited (e.g., compacted soils), which should encourage deeper rooting. Urban soils are often compacted and may have inherent drainage problems (Kopinga 1991). In turn, trees with deeper roots are adapted to a water-limited environment and their survivorship should be enhanced particularly during dry spells (Clark and Kjelgren 1990). Future research should compare the proportion of water lost as runoff by direct watering and by indirect watering devices on a variety of soil types and slopes. Regardless of whether water is applied directly from a hose or through an indirect watering device, since the texture and drainage of urban soils varies considerably, planting sites must be prepared properly to allow sufficient drainage. Also, watering volume and frequency will need to be adjusted to suit the site-specific soil characteristics, tree-specific water usage, and weather conditions.

CONCLUSIONS

There is a dearth of information in the literature on the benefits of watering devices for newly planted urban trees. This study was designed to determine if there are any differences in performance and benefits of several different types of indirect watering devices to newly transplanted river birch trees by conducting a watering experiment on container-grown trees in a controlled greenhouse environment. We strived to use methods of watering in our experiment that are practical for city workers to apply in a different environmental setting, including urban landscapes, where spigots may not be easily accessible. Some of our indirect watering devices had some performance and logistical advantages (e.g., ease of installing, handling, and filling of water), and had slower release of water than a hose, but the devices did not benefit transplanted trees more than watering with a hose (e.g., growth). Future studies should assess whether indirect watering devices reduce loss of water due to runoff in a natural field setting, which would imply greater infiltration. If the devices reduce runoff, their use could conserve water compared to direct watering. Future studies should also test for benefits to trees on soils with different drainage properties. However, variations in soil types and microsites, and in natural precipitation, would be more difficult to control in a natural setting. Our results also indicated that the increasing watering frequency (once per week) may have been beneficial to the trees in our study, but the volume and frequency will need to be adjusted to suit the site-specific conditions.

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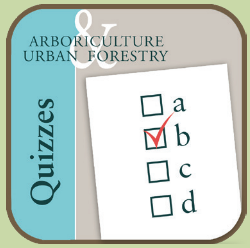
Résumé. Trois types de dispositifs d'arrosage indirect furent comparés afin d'évaluer leur performance et déterminer leurs avantages pour des bouleaux noirs (*Betula nigra*) récemment transplantés, cultivés en conteneurs avec un compost bien drainé dans une serre à température contrôlée. Pour cette étude, deux échantillons de chacun des dispositifs furent utilisés pour irriguer les arbres: des poches verticales, des poches en anneau et des bacs ouverts. Les caractéristiques des dispositifs d'arrosage, dont le coût d'acquisition, le poids, la capacité et la durée de l'irrigation, furent mesurées préalablement à leur installation autour des arbres. La hauteur et le calibre des tiges, ainsi que la couverture foliaire et le potentiel hydrique des feuilles furent mesurés afin d'identifier toute différence de croissance ou de stress hydrique associée aux dispositifs d'arrosage. Des variations substantielles au niveau des coûts et de la durée d'irrigation furent constatées parmi les dispositifs, les poches en anneau étant les moins onéreuses et toute leur eau fut entièrement drainée lors des essais. Cependant, en comparaison avec l'arrosage direct, aucune preuve d'un bénéfice quelconque sur le plan de la croissance, du feuillage ou du stress hydrique ne fut constatée, sauf la possible exception de la poche en anneau Treegator, qui semble avoir légèrement réduit le stress hydrique. Bien que l'eau provenant des dispositifs d'arrosage indirect soit libérée beaucoup plus lentement que l'irrigation directe, l'apport d'eau de tous les dispositifs était achevé à l'intérieur d'une période de 10 heures, ce qui est trop rapide pour avoir un impact sur la fréquence d'arrosage dans le cadre de cette étude. Les principaux avantages de ces dispositifs sont la libération plus lente de l'eau vers le sol, nécessitant une main d'œuvre moindre, et davantage d'infiltration dans le sol et la zone des racines, ce qui permet d'éviter le ruissellement en surface constaté lors de l'arrosage direct avec un boyau.

Zusammenfassung. Es wurden drei Typen von indirekter Bewässerung verglichen, um ihre Leistung zu vergleichen und ihre Vorteile im Einsatz bei neu verpflanzten Birken in Containern mit wasserdurchlässigem Kompost in einem Gewächshausprojekt zu bestimmen. Zwei Beispiele von jedem Typ wurden verwendet, um die Bäume in dieser Studie zu wässern: aufrechte Beutel, Ringbeutel und offene Schläuche. Die Charakteristika der Bewässerungshilfen einschließlich der Anschaffungskosten, Kapazität und Drainagezeit wurden vor der Installation der Hilfen um den Baum gemessen. Baumstammhöhe und Umfang, sowie Blattmasse und Blattwasserpotential wurden gemessen, um ein Wachstum oder Wasserstresspotential in Verbindung mit der Bewässerung zu messen. Es gab zwischen den Bewässerungshilfen substantielle Variationen bei den Kosten und Drainagezeiten, wobei die Ringbeutel am wenigsten teuer waren und das Wasser während des Drainagetests komplett durchließen. Dennoch gab es keinen Nachweis, dass die Bewässerungshilfen das Baumwachstum, die Blattbewertung oder den Wasserstress im Vergleich zu direkter Bewässerung begünstigten; mit einer möglichen Ausnahme der Treegator-Ringbeutel, welche den Wasserstress etwas milderten. Obwohl die Wasserabgabe von einigen dieser indirekten Bewässerungshilfen viel langsamer war als eine direkte Bewässerung, war die Wasserabgabe auf allen getesteten Hilfen innerhalb von zehn Stunden abgeschlossen, was viel zu schnell war, um die Frequenz der Bewässerung in unserem Experiment zu reduzieren. Der Hauptvorteil dieser Bewässerungshilfen besteht in der langsamen Wasserabgabe an den Boden, mit reduziertem Arbeitskrafteinsatz und mehr Infiltration in den Boden und die Wurzelzone, was ein Ablaufen von Wasser bei schneller Bewässerung durch den Schlauch vermeidet.

Resumen. En un experimento de invernadero controlado, se compararon tres tipos de dispositivos de riego indirecto para evaluar su rendimiento y determinar los beneficios para árboles de abedul (*Betula nigra*), recién trasplantados, que crecen en contenedores con compost bien drenado. Se usaron dos muestras de cada tipo de dispositivo para regar árboles en este estudio: bolsas verticales, bolsas de anillos y tubos abiertos. Las características del dispositivo de riego, incluido el costo de compra, el peso, la capacidad y los tiempos de drenaje, se midieron antes de instalar los dispositivos alrededor de los árboles. Se midió la altura del tallo de los árboles y el diámetro, junto con la cobertura foliar y el potencial hídrico de las hojas, para determinar las diferencias de crecimiento o estrés hídrico asociadas con los tratamientos de riego. Hubo una variación sustancial en los costos y tiempos de drenaje entre los dispositivos de riego, con las bolsas de anillo que son las menos costosas y el drenaje de agua por completo durante la prueba de drenaje. Sin embargo, no hubo evidencia de que los dispositivos de riego beneficiaran el crecimiento del árbol, la calidad de las hojas o el estrés hídrico en comparación con el riego directo, con la posible excepción de las bolsas de anillo Treegator, que pueden haber reducido el estrés hídrico marginalmente. Aunque la liberación de agua de algunos de los dispositivos de riego indirecto fue mucho más lenta que el riego directo, la liberación de agua de todos los dispositivos se completó en diez horas, lo cual es demasiado rápido para reducir la frecuencia de riego en nuestro experimento. Los principales beneficios de estos

dispositivos son una liberación más lenta de agua al suelo, con un tiempo de operación reducido y una mayor infiltración en el suelo y la zona de la raíz, lo que evita la escorrentía superficial causada por el riego rápido (directo) con manguera.

Arboriculture & Urban Forestry Quiz Questions



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