



Impacts of Artificial Soil Drought on Aboveground Biomass of Some Bangkok Street Tree Species: Comparisons Between Irrigated and Non-irrigated Potted Trees

Pantana Tor-ngern

Department of Environmental Science, Faculty of Science, Chulalongkorn University, Bangkok 10330 Thailand

Corresponding author. E-mail address: Pantana.T@chula.ac.th

Received: 12 May 2016; Accepted: 10 August 2016

Abstract

Numerous research revealed that urban trees can play an important role in mitigation of rising atmospheric carbon dioxide in cities. To achieve sustainable urban greening management, selective tree planting is recommended, especially in an environment with projected intensified drought events. This study presents the assessment of changes in aboveground dry mass of potted trees of *Pterocarpus indicus* (*Pi*), *Swietenia macrophylla* (*Sm*) and *Lagerstroemia speciosa* (*Ls*), species commonly found in Bangkok, Thailand, under artificial soil drought during a one-week treatment. For each species, ten potted trees were used in the experiment: five trees were irrigated every day throughout the one-week period whereas the other five trees were withheld from water. Comparisons between the two tree groups in each species showed that soil drought induced leaf loss, resulting in significant reductions in transpirational surface (i.e., leaf area) and photosynthetic machinery (i.e., leaf mass) in all species, with the greatest decrease in *Ls*. The insignificant changes of woody dry mass under soil drought in these species indicated carbon allocation from leaf to root, with the greatest degree in *Ls*. Consequently, it may be implied that, for the same treatment period, *Ls* is the most sensitive to soil drought, exhibiting the greatest reduction in leaf area and leaf dry mass, and possibly increase in water absorbance capacity through enhanced root surface. Based on these findings, *Pi* and *Sm* may be recommended for planting in urban areas due to their slower responses and therefore higher tolerance to soil water deficit.

Keywords: urban trees, soil drought, aboveground biomass, urban greening

Introduction

Increasing green space in cities has become one of the strategies to cope with adverse environmental effects from urbanization, such as pollution, rising greenhouse gas emission, and urban heat island (Deloya, 1993). Many kinds of vegetation are planted in various places in urban areas, including street-side, parks, balconies and rooftops of buildings. Of particular interest are urban trees which contribute most to carbon sequestration from the atmosphere. Moreover, urban trees provide several ecosystem services, such as, clean and fresh air, shade and cooling effects, recreational and educational values (Deloya, 1993; Akbari, 2002). However, different species of trees, even under optimal conditions, may exhibit different water use

and growth characteristics and may use different strategies to survive under stress, such as drought. Drought stress may be exacerbated in urban areas because of the heat island effect (Pataki et al., 2006). Thus, due to projected intensified and more frequent drought events (Dierick & Hölscher, 2009), selective tree planting by choosing tree species that use water conservatively while still gaining sufficient carbon through photosynthesis should be considered for sustainable urban greening management.

Studying plant response to water deficit is important since most climate change scenarios indicate increasing drought in many areas around the globe (Petit et al., 1999). The drought stress, whether in soil or the atmosphere and combined with high temperature, constrains plant survival and



productivity. Furthermore, species-specific responses of plant water use and growth to soil water deficit are areas of uncertainty for estimating transpiration which is the main component of total water loss from forest ecosystems (Oren & Pataki, 2001). The degree of such uncertainty is higher in forests because it is hampered by difficult access to the canopy. Nevertheless, recent advances in measurement techniques, especially sap flux measurement of tree stems, allow tree- to canopy-level estimates of water use and stomatal conductance which correlate with photosynthesis and growth (Granier, 1985; Ewers, Oren, Phillips, Strömberg, & Linder, 2001). Evaluating the responses of stomatal conductance and growth of trees to soil drying conditions will improve the understanding of underlying mechanisms which could be integrated into ecosystem modelling.

Studies on tree response to water stress in Thailand are available but most of them focus on natural forests or agricultural plantations (Kume et al., 2007; Kunjet et al., 2013). Research on water use and growth of urban trees in Thailand is still lacking. Nevertheless, there are three studies that examined water relations in certain street tree species. One study investigated different water use strategies of three urban tree species in Bangkok, differing in leaf phenology, based on leaf hydraulic measurements (Puangchit, Sriladda, Kjelgren, & Someechai, 2014) while the other study measured daily tree water use of four urban species of potted trees using gravimetric method (Kjelgren, Puangchit, Sriladda, & Someechai, 2008). Although gravimetric method offers direct measurement of tree water use, it is inconvenient to perform measurements at fine temporal resolution, such as in seconds or minutes. A recent study (Tor-ngern & Panha, 2016) applied a widely-used sap flux measurement technique (Granier, 1985) to study water relations under artificial soil drought at sub-daily timescale in

three common street tree species: *Pterocarpus indicus* (*Pi*), *Swietenia macrophylla* (*Sm*) and *Lagerstroemia speciosa* (*Ls*). This last study found that water deficit induced leaf drops which resulted in increased stomatal conductance of the small trees with different degrees of increases among the three species. The increasing stomatal conductance compensated for decreased leaf area in *Pi* and *Sm*, resulting in unaffected tree water use, while the compensatory effect was incomplete in *Ls*, resulting in significant decrease in water use of *Ls*.

The current study will extend the findings from Tor-ngern and Panha (2016) and add more results implying growth response to the soil drying condition. In particular, I will analyze the aboveground dry mass of plant materials harvested from *Pi*, *Sm* and *Ls* potted trees by comparing the values between irrigated (wet) and non-irrigated (dry) groups. The main research questions were (1) How did previous findings in Tor-ngern and Panha (2016) contribute to growth response as indicated by changes in leaf dry mass? (2) Combining answers from (1) and the previous results, do *Pi* and *Sm* still exhibit more tolerant characteristics to soil drought and better suited for urban tree planting than *Ls*?

Methods and Materials

Experimental settings

This study was performed on the balcony of the 4th floor of Department of Environmental Science building in Chulalongkorn University, Bangkok, Thailand (13 °N 100 °E). Thirty tree saplings of *Pterocarpus indicus* (*Pi*), *Swietenia macrophylla* (*Sm*) and *Lagerstroemia speciosa* (*Ls*) were purchased from a nursery and transported to the study site. These trees were originally grown in the same local field, harvested and potted into 20L containers with mixed soil growing medium. The potted trees



were irrigated with ~3L of water twice a day for five weeks to allow establishment of the trees prior to data collection. Nevertheless, one *Pi* and one *Ls* trees died before the experiment commenced. Table 1 summarizes characteristics of the trees used in this study. Starting on December 19, 2015, each species was divided into two groups: one with continued irrigation with the same amount and frequency (referred to as wet group) while the other group was withheld from watering (referred to as dry group). To ensure that the wet groups were under well-watered condition, soil moisture level was measured using a soil tester (Takemura Japan test instruments) prior to each irrigation. Soil moisture level of above 5 (on the scale from 1 to 8) was maintained in the wet group. The study period lasted one week (December 19 – 25, 2015).

Calculations and measurements of studied variables

Thirty thermal dissipation probes (TDPs) for measuring sap flux density (J_s ; $\text{g cm}^{-2} \text{s}^{-1}$) were made. Details of the TDPs' function and construction are described in the previous work (Tor-ngern & Panha, 2016). One TDP was installed at 10 mm depth from inner bark of each tree. Assuming negligible non-conductive part of the stems due to small tree size, the whole-tree water use was estimated as

$$E_t = J_s \times A_s \quad (1)$$

where E_t represents whole-tree water use rate in g s^{-1} and A_s is the entire cross-sectional sapwood area of each tree in cm^2 . Vapor pressure deficit (D , kPa) refers to atmospheric demand and mostly contributes to stomatal changes in plants. Air temperature and relative humidity were measured by two portable temperature and humidity data loggers (OM-92, Omega Engineering, Stamford, CT, USA) and used to compute D (Monteith & Unsworth, 1990).

On the last day of the experiment, total leaves were harvested for leaf area (L , m^2) estimates. For each tree, ten leaves were sampled for varying sizes, scanned using a printer (LaserJet Pro MFP M125a) and analyzed the areas with ImageJ program (Schneider, Rasband, & Eliceiri, 2012). Total number of leaves was obtained and used to scale the scanned L to total L of each tree. Next, the whole-tree stomatal conductance (G_s , mm s^{-1}) was calculated using the above information and a simplified version of the Penman-Monteith equation (Pataki, Oren, & Phillips, 1998):

$$G_s = \frac{\gamma \lambda E_t}{\rho c_p D L} \quad (2)$$

where γ is the psychrometric constant (kPa K^{-1}), λ is the latent heat of vaporization (J kg^{-1}), ρ is the density of moist air (kg m^{-3}) and c_p is the heat capacity of moist air ($\text{J kg}^{-1} \text{K}^{-1}$).

On the last day of the experiment (December 25, 2015), all trees were harvested for biomass analysis. For each tree, leaves were separated from woody parts which included branches and stem. All plant materials were bagged and put in an oven which was set at 65 °C and left for 48 hours for drying. Then, the dried leaf samples, including those for scanned L , were weighed using a two-digit balance while the woody samples were weighed with a simple one-digit scale. Dry matter (DM) of leaves and woody parts of each tree was recorded in grams of biomass.

Comparisons and statistical analyses

Analyses of variables were based on their ratios between dry and wet groups, and referred to as dry-to-wet ratios. I concentrated on data on the last day which presumably reflects the most severe drought impact. The variables of interest included G_s , L and DM of leaf (DM_{leaf}) and woody parts



(i.e., stem and branches; DM_{wood}). Additionally, I analyzed the dry-to-wet ratios of specific leaf area (SLA) which defines as the ratio between leaf area and leaf dry mass (L/DM_{leaf}). One-sample t-test was performed to compare the ratios to one using SPSS Statistics (IBM Corp. Released 2013. IBM SPSS Statistics for Windows, Version 22.0. Armonk, New York, USA). Data visualization was conducted using SigmaPlot 12.0 (Systat Software, Inc., San Jose, California, USA).

Results and Discussion

Table 1 summarizes characteristics of the tree saplings used in this study. The average of stem diameters at ~1 m above ground ranged from 2.72 to 3.34 cm with coefficient of variation ranging from 9 to 22%. During the study period, vapor pressure deficit (D) at daily timescale ranged from 1.8 to 2.2 kPa, averaged 1.98 ± 0.18 kPa. The sunlight was mostly abundant during daytime with no rain observed during the one-week study period. Thus, weather conditions were similar throughout the study period and should not confound the comparisons between the wet and dry groups of trees.

A previous study examined water use rate of these trees and reported unaffected rate in *Pi* and *Sm* on the last day of drought treatment while water use of *Ls* was significantly reduced (Tor-ngern & Panha, 2016). The authors concluded that soil drought induced leaf drops which resulted in increased stomatal conductance in all three species but with different degrees of increases. Such response may indicate the compensation for the reduced leaf area, resulting in unaffected water use in *Pi* and *Sm* but incomplete compensation was found in *Ls*, leading to its reduced water use. Table 2 summarizes averaged values with one standard errors of the quantities used in the analysis. The compensatory effect of increased

G_s on decreased L was clearly demonstrated in all species ($p \leq 0.04$) with the smallest percentage of increase of G_s in *Ls* (58%; Figure 1, black bars). Lower L in the dry groups was observed in all species with 14–45 % reduction (Figure 1, light gray bars). In this study, I added the assessment of growth as implied by dry mass of the aboveground parts of the trees. For all species, DM_{leaf} (Figure 1, dark gray bars) values of the dry groups were 16 – 31 % lower than those of the wet ones with the largest difference in *Ls*. Considering the dry-to-wet ratios of L and DM_{leaf} , the ratios of specific leaf area (SLA) was computed and shown in Figure 1 (cross-patterned bars). The SLA ratios of *Pi* and *Sm* were not significantly different from one ($p \geq 0.93$), suggesting unchanged ratios of leaf area to leaf dry mass of these two species. The SLA ratio of *Ls* was significantly lower than one ($p = 0.04$), indicating a decrease in SLA of the dry *Ls* trees. Hypothetically, plants that experience soil drying should have lower SLA which implies conservative water use where physiological adjustments were achieved to minimize transpirational area (i.e., leaf area) while maximizing or maintaining photosynthesis as indicated by leaf dry mass (Marcelis, Heuvelink, & Goudriaan, 1998; Moroco, Pereira, & Chaves, 2000). In the case of *Pi* and *Sm* where SLA was not affected by soil drought, it may be implied that high increases in G_s allowed high photosynthetic rates and consequently less reductions in DM_{leaf} and slow physiological adjustment in response to drought. However, larger decrease of SLA in *Ls* agreed with the hypothetical adjustment to soil water deficit and may suggest faster response than the other two species, given the same treatment period.

Because increases of G_s in all species may indicate higher photosynthesis, one may expect higher DM_{leaf} instead of the reductions as presented in



Figure 1. The reductions of DM_{leaf} in all species may suggest carbon allocation from leaf to root. Higher allocation of carbon to roots is one of the physiological adjustments in plants under drought stress (Tschaplinski, Tuskan, & Gunderson, 1994; Dias, Araujo, Moraes, Barros, & DaMatta, 2007). Because some roots were cut in order to fit trees into pots, it will not be appropriate to assess changes in root dry mass using these trees. To determine whether increased carbon allocation to roots was possible, I evaluated DM_{wood} of branches and stems and compare the values between dry and wet groups (Figure 2). The result showed that DM_{wood} was unaffected by soil drought in all species ($p \geq 0.64$). Thus, it may imply that decreased DM_{leaf} , with unchanged DM_{wood} , resulted in higher carbon allocation to roots in all species with the highest allocation in *Ls* compared to the other two species. Plants increase carbon allocation to roots to enhance root water absorption in the soil. Thus, the greatest decrease of DM_{leaf} in *Ls* may imply the largest increase in root dry mass and, combined with the previous results of G_s and SLA, suggesting that *Ls* is the most sensitive to soil drought among the studied urban species.

Conclusion and Suggestion

This study examined the indications of growth response to a one-week soil drought treatment in *Pterocarpus indicus* (*Pi*), *Swietenia macrophylla* (*Sm*) and *Lagerstroemia speciosa* (*Ls*), three

common street tree species in Bangkok, Thailand. Higher increases of whole-tree stomatal conductance in *Pi* and *Sm* resulted in smaller reduction of leaf dry mass compared to in *Ls*, possibly due to higher photosynthetic rates. Considering changes of leaf area and leaf dry mass, or specific leaf area (SLA), between dry and wet trees, the dry-to-wet ratios of SLA were obtained. The SLA ratios of *Pi* and *Sm* were unaffected by soil drought while that of *Ls* significantly decreased, suggesting immediate response in *Ls* compared to the other species. Because woody dry mass was unchanged by soil drought, the observed reductions of leaf dry mass may contribute to carbon loss to roots in all species, with possibly the greatest amount in *Ls*. Such physiological changes are essential for plants to enhance water absorption in lieu of decreased water availability. Based on these results, *Pi* and *Sm* may be recommended for planting in urban areas because they are less sensitive and thus may be more tolerant to soil drought than *Ls*.

Acknowledgement

This study was partially supported by Grants for Development of New Faculty Staff, Ratchadapiseksomphot Endowment Fund, Chulalongkorn University. I would like to thank the Department of Environmental Science of Chulalongkorn University for providing space and facility to conduct this research. Also, I would like to express my sincere gratitude to P. & P. Tor-ngern for their field assistance.

Table 1 Summary of tree characteristics

Species	H (m)	d (cm)	A_s (cm ²)	n
<i>Pterocarpus indicus</i> (<i>Pi</i>)	2.86 ± 0.18	2.72 ± 0.59	6.04 ± 2.93	9
<i>Swietenia macrophylla</i> (<i>Sm</i>)	2.86 ± 0.22	3.34 ± 0.32	8.83 ± 1.67	10
<i>Lagerstroemia speciosa</i> (<i>Ls</i>)	2.77 ± 0.17	3.13 ± 0.39	7.80 ± 1.91	9

H represents tree height in m. d is the diameter measured at the sap flux sensor location (~1 m from the ground) in cm. A_s is the cross-sectional sapwood areas of the trees in cm². n is the number of potted trees used in the study.



Table 2 Summary of mean values of the quantities used in the analyses. Numbers in parentheses are one standard errors of the means

Species	G_s (mm s^{-1})		L (m^2)		DM_{leaf} (g)		DM_{wood} (g)	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
<i>Pterocarpus indicus</i> (Pi)	3.03 (0.25)	1.69 (0.18)	1.32 (0.2)	1.54 (0.14)	45.12 (4.55)	53.71 (3.88)	1230 (69.6)	1233 (17.74)
<i>Swietenia macrophylla</i> (Sm)	0.99 (0.09)	0.52 (0.07)	1.33 (0.14)	1.74 (0.13)	81.14 (7.66)	105.04 (2.12)	1650 (57.65)	1690 (48.84)
<i>Lagerstroemia speciosa</i> (Ls)	0.57 (0.05)	0.36 (0.02)	0.49 (0.02)	0.89 (0.15)	37.81 (2.76)	54.96 (7.93)	1431 (61.10)	1438 (86.61)

G_s is the whole-tree stomatal conductance in mm s^{-1} , determined using equation (2) in text. L represents total leaf area in m^2 of the trees. DM_{leaf} and DM_{wood} are dry mass for leaf and wood (branches and stem) of the trees, respectively, in g.

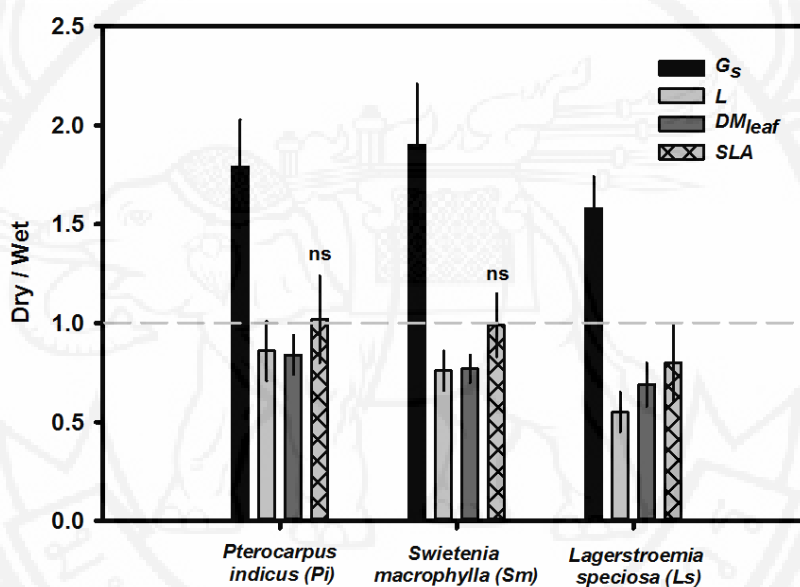


Figure 1 Dry-to-wet ratios of whole-tree stomatal conductance (G_s , black), leaf area (L , light gray), leaf dry mass (DM_{leaf} , dark gray) and specific leaf area (SLA, cross-patterned) for the three species. Error bars indicate one standard error of the ratios. The label 'ns' refers to insignificant difference of the ratio from one ($\alpha = 0.05$).

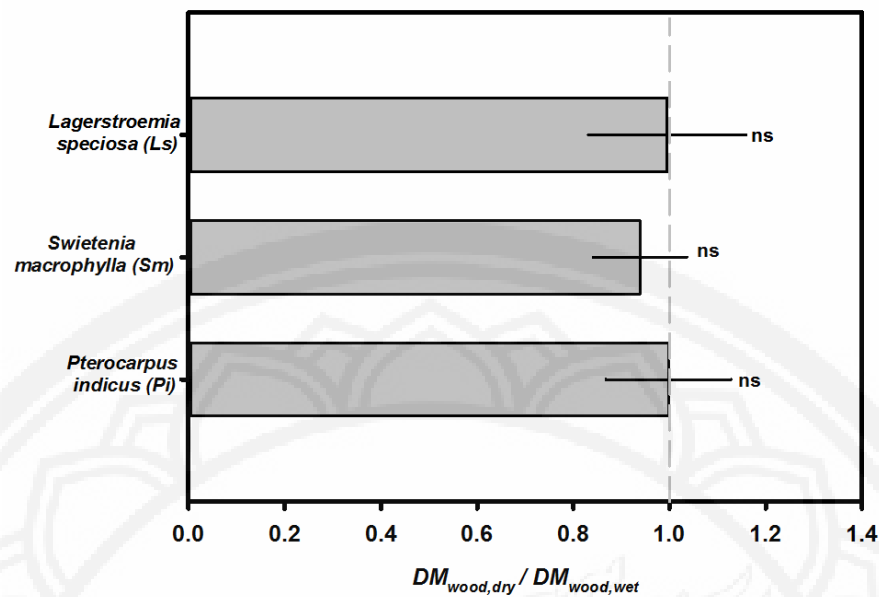


Figure 2 Dry-to-wet ratios of the wood dry mass of branches and stems. The label ‘ns’ refers to insignificant difference of the ratio from one ($\alpha = 0.05$).

References

- Akbari, H. (2002). Shade trees reduce building energy use and CO₂ emissions from power plants. *Environmental Pollution*, 116, S119–S216.
- Deloya, M. C. (1993). Urban forestry activities in Mexico. *Unasylva*, 173(44), 28–32.
- Dias, P. C., Araujo, W. L., Moraes, G. A. B. K., Barros, R. S., & DaMatta, F. M. (2007). Morphological and physiological responses of two coffee progenies to soil water availability. *Journal of Plant Physiology*, 164, 1639–1647.
- Dierick, D., & Hölscher, D. (2009). Species-specific tree water use characteristics in reforestation stands in the Philippines. *Agricultural and Forest Meteorology*, 149, 1317–1326.
- Ewers, B. E., Oren, R., Phillips, N., Strömgren, M., & Linder, S. (2001). Mean canopy stomatal conductance responses to water and nutrient availabilities in *Picea abies* and *Pinus taeda*. *Tree Physiology*, 21, 841–850.
- Granier, A. (1985). Une nouvelle méthode pour la mesure du flux de sève brute dans le tronc des arbres. *Annals of Forest Science*, 42, 193–200.
- Kjelgren, R., Puangchit, L., Sriladda, C., & Someechai, M. (2008). Water use of four street tree species in Bangkok, Thailand. *Acta Horticulture*, 792, 405–409.
- Kume, T., Takizawa, H., Yoshifuji, N., Tanaka, K., Tantisarin, C., Tanaka, N., & Suzuki, M. (2007). Impact of soil drought on sap flow and water status of evergreen trees in a tropical monsoon forest in northern Thailand. *Forest Ecology and Management*, 238, 220–230.



- Kunjet, S., Thaler, P., Gay, F., Chuntuma, P., Sangkhasila, K., & Kasemsap, P. (2013). Effects of drought and tapping for latex production on water relations of *Hevea brasiliensis* trees. *Kasetsart Journal (Natural Science)*, 47, 506–515.
- Marcelis, L. F. M., Heuvelink, E., & Goudriaan, J. (1998). Modelling biomass production and yield of horticultural crops: a review. *Scientia Horticulturae*, 74, 83–111.
- Monteith, J. L., & Unsworth, M. H. (1990). Principles of Environmental Physics. Retrieved from <http://denning.atmos.colostate.edu/readings/Monteith.and.Unsworth.4thEd.pdf>
- Moroco, J. P., Pereira, J. S., & Chaves, M. M. (2000). Growth, photosynthesis and water-use efficiency of two C_4 Sahelian grasses subjected to water deficits. *Journal of Arid Environments*, 45, 119–137.
- Oren, R. & Pataki, D. E. (2001). Transpiration in response to variation in microclimate and soil moisture in southeastern deciduous forests. *Oecologia*, 127, 549–559.
- Pataki, D. E., Oren, R., & Phillips, N. (1998). Responses of sap flux and stomatal conductance of *Pinus taeda* L. trees to stepwise reductions in leaf area. *Journal of Experimental Botany*, 49, 871–878.
- Pataki, D. E., Alig, R. J., Fung, A. S., Golubiewski, N. E., Kennedy, C. A., McPherson, E. G., ... Lankao, P. R. (2006). Urban ecosystems and the North American carbon cycle. *Global Change Biology*, 12, 2092–2101.
- Petit, J. R., Jouzel, J., Raynaud, D., Barkov, N. I., Barnola, J-M., Basile, I., ... Stievenard, M. (1999). Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica. *Nature*, 399, 429–436.
- Puangchit, L., Sriladda, C., Kjelgren, R., & Someechai, M. (2014). Water relations of three tree species growing in the streetside forest of Bangkok, Thailand during the monsoonal dry season. Retrieved from <http://digitalcommons.usu.edu/>
- Schneider, C. A., Rasband, W. S., & Eliceiri, K. W. (2012). NIH Image to ImageJ: 25 years of image analysis. *Nature Methods*, 9, 671–675.
- Tor-ngern, P. & Panha, S. (2016). Species-specific responses of water use by urban trees to artificial soil drought: results from a small-scaled study. *Applied Environmental Research*, 38(1), 53–60.
- Tschaplinski, T. J., Tuskan, G. A., & Gunderson, C. A. (1994). Water-stress tolerance of black and eastern cottonwood clones and four hybrid progeny. I. Growth, water relations and gas exchange. *Canadian Journal of Forest Research*, 24, 364–371.