Magnolias as urban trees – a preliminary evaluation of drought tolerance in seven magnolia species

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ABSTRACT

Tree selection must ensure that trees are capable of thriving in the environment in which they are placed. Inappropriate species or trees of poor quality will never develop any substantial capacity for delivering ecosystem services. The aim of this study is to evaluate seven species of *Magnolia* for their drought tolerance by estimating their water potential at leaf turgor loss to help provide quantitative data for their capacity to tolerate dry urban sites. According to the results, *Magnolia virginiana* is ranked as the most drought-tolerant, while *Magnolia x loebneri* "Leonard Messel" is the most sensitive to drought. However, in comparison with other plant groups previously studied, magnolias have to be treated as drought sensitive. Consequently, magnolias used in this study should be used in garden and park environments, as their potential for use along streets can be limited by their vulnerability to drought. The turgor loss point methodology used in the study provides an efficient alternative to decades of observation, especially when new genotypes or underutilised trees are being evaluated. It is now possible to show the group's general sensitivity to drought as well as quantifying individual species sensitivity to drought.

KEYWORDS

Urban trees; urban forestry; tree selection; diversification

Introduction

The *Magnolia* genus consists of 224 species, including deciduous and evergreen trees and shrubs (Grimshaw & Bayton, 2009). Magnolia species are predominantly found in moist and rich forest habitats in eastern Asia as well as in North and South America. The majority of species that are hardy for the northern hemisphere are endowed with spectacular spring flowering as well as appealing leaf textures and autumn colours that qualify them as one of the most remarkable trees for amenity planting.

Published inventories (e.g. Cowett & Bassuk, 2014; Raupp, Buckelew-Cumming, & Raupp, 2006; Sjöman, Östberg, & Bühler, 2012) indicate that magnolias are rare as public urban trees across the temperate world. However, in Sweden, sales of magnolias for public use have increased significantly over the past decade. This sale is limited to a few

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species, especially the Japanese magnolia (*Magnolia kobus*). Experience of other species in the genera is very limited. Furthermore, at Bruns Nursery in Germany, one of the largest tree nurseries in Europe, the number of species and genotypes of magnolias have increased from only nine species and genotypes presented in their 1999 catalogue to fourteen species and genotypes in 2013. Yet, without experience of the different species and cultivars, their capacity to tolerate different growing habitats is difficult to anticipate, making robust recommendations for their use challenging. Today, much of the information from dendrological and horticultural literature concerning magnolias focuses on the species' aesthetic characteristics such as flowers, leaf textures, autumn colours and height. Information relating to their tolerance of different site conditions is rare, and the information that is presented is notable for its brevity and vague conclusions (Table 1).

In urban environments, relatively small soil volumes, high levels of soil compaction, impermeable surfaces and warm microclimates mean that water deficits are a fundamental constraint to tree development (Sieghardt et al., 2005). Drought stress is likely to increase under future climate scenarios (Allen et al., 2010) so the quantitative drought tolerance of a species, or genotype, should be a fundamental consideration in tree selection for urban environments – information that is not currently available for magnolias.

The aim of this study is to evaluate well-known species and genotypes of magnolias for their drought tolerance by estimating their water potential at turgor loss (Ψ_{P0}) to help provide quantitative data for their capacity to tolerate dry urban sites. The data from the study will also be compared with habitat information of the magnolia species in the literature as well contrasted with representative species of *Acer* previously assessed, thus allowing magnolias to be considered in relation to other important genera of amenity trees.

Materials and method

The water potential at turgor loss (Ψ_{P0}) provides a robust measure of plant drought *tolerance* since a more negative Ψ_{P0} allows the leaf to maintain physiological function over an increased range of leaf water potentials (Sack, Cowan, Jaikumar, & Holbrook, 2003; Lenz, Wright, & Westoby, 2006). Plant genotypes that have a more negative Ψ_{P0} tend to maintain leaf gas exchange, hydraulic conductance and growth at lower soil water potentials (Ψ_{soil}), and so are at a competitive advantage where soil water deficits occur during the growth season (Blackman, Brodribb, & Jordan, 2010; Mitchell, Veneklaas, Lambers, & Burgess, 2008). The Ψ_{P0} also provides a surrogate for the Ψ_{soil} below which the plant cannot recover from wilting (Bartlett, Scoffoni, & Sack, 2012). Consequently, Ψ_{P0} is a highly instructive plant trait to measure when actual tolerance of water deficits is required.

Traditionally, the Ψ_{P0} is assessed using pressure–volume curves (Turner, 1988; Tyree & Hammel, 1972; Tyree & Richter, 1982) but these are highly time-consuming, particularly if a large data-set is to be produced. Meta-analysis of pressure–volume curve data (Bartlett, Scoffoni, & Sack, 2012) has demonstrated that the osmotic potential at full turgor ($\Psi_{\pi100}$) is a key variable driving Ψ_{P0} across species and, as a result, can be used to predict physiological drought tolerance in plants. A major advantage of assessing $\Psi_{\pi100}$ is that it can be determined using techniques that are much more rapid than pressure–volume curves (Bartlett, Scoffoni,

Table 1. Compilation of site-related information of seven species/genotypes of magnolias with regards to information concerning perceived drought tolerance. Sources include recent publications and standard literature within the field of urban forestry and urban tree selection.

Species	Number of trees included in the study	Site related information
Magnolia acuminata	6	• Prefers moist to average soil moisture (Hightshoe, 1988) • Should be planted into loamy, deep, moist, well-drained soil – does not tolerate extreme drought and wetness (Dirr, 2009) • Quite hardy park tree (Krüssmann, 1986) • Consistently moist and well-drained (Trowbridge & Bassuk, 2004) • Ability to grow in a wide range of soils, but is not tolerant of drought (Gardiner, 2000) • Moist and well-drained soil (Leopold, 2005) • Prefer moist soil conditions (Flint, 1983) • Grows in deciduous woodlands with deep, rich soils on moist slopes along river banks (Nelson, Earle, Spellenberg, Huges, & More, 2014) • Prefer moist, well-drained soil (Stoecklein, 2001)
Magnolia kobus	4	• Excellent for all types of soils, including limestone (Dirr, 2009) • It does not do well in thin dry soils, presumably because its home is in moisture-retentive, humus-rich sites in Japan (Gardiner, 2000) • Prefers moist, well-drained soil (Stoecklein, 2001)
Magnolia x loebnerii "Leonard Messel"	3	• Remarkably tolerant of a wide range of soil type – From light sand to moisture-retentive (but not waterlogged) clay (Gardiner, 2000) • Prefer moist soil conditions (Flint, 1983) • Prefer moist, well-drained soil (Stoecklein, 2001)
Magnolia salicifolia	2	• Native in rocky granite soil by the side of forest streams (Dirr, 2009) • Prefer moisture-retentive soil (Gardiner, 2000) • Prefer moist soil conditions (Flint, 1983)
Magnolia sieboldii	3	• Not suitable for chalky soils (Bean, 1980) • Prefers moisture-retentive soil (Gardiner, 2000)
Magnolia tripetala	4	• Grows in deep, moist woodsy soils along streams and swamp margins (Dirr, 2009) • Prefers humus-rich and moisture-retentive soil (Gardiner, 2000) • Moist and well-drained soil (Leopold, 2005) • Grows in rich woods, ravine slopes, margins of mountain streams (Nelson et al., 2014) • It grows naturally in deep rich forests. It occurs in moist soils high in humus in protected ravines, along streams (Elias, 1989) • Prefer moist, well-drained soil (Stoecklein, 2001)

(Continued)

Table 1. (*Continued*).

Species	Number of trees included in the study	Site related information
Magnolia virginiana	2	• Prefer moist to wet (Hightshoe, 1988) • Does well in wet and even swampy soils (Dirr, 2009) • Needs deep soil that does not dry out in summer (Bean, 1980) • Wet to consistently moist and well-drained (Trowbridge & Bassuk, 2004) • Prefers moisture-retentive soil – not hot and dry soils (Gardiner, 2000) • Prefers moist and wet soil (Leopold, 2005) • Prefers moist to wet soil conditions (Flint, 1983) • Grows naturally in swamps, low woods, margins of wet savannas (Nelson et al., 2014) • Grows naturally in wet, often acid soils along streams, swamps and bottom lands (Elias, 1989) • Prefer moist, well-drained soil (Stoecklein, 2001)

Ardy, et al., 2012) facilitating the collection of larger data-sets. Consequently, it is now possible to efficiently screen traditional and novel tree species for a drought tolerance trait that is highly relevant for the urban environment. This study presents an evaluation of turgor loss points for seven magnolia species.

The seven species and genotypes of magnolia were all found at the F.R. Newman Arboretum at Cornell University, New York State (42°27′0 N, 76°28′19W) and at the surrounding north campus of Cornell University (Table 1). The mean annual temperature of the case study area is 8.1 °C with the highest mean monthly temperature is in July with 21 °C while the lowest mean monthly temperature is in January with −5.6 °C recorded. The study area is categorised as zone 6a according to USDA Plant hardiness Zone Map. The trees used in the study were all well-established trees growing as solitary trees in park environments (which include mixed plantations with shrubs or in cut grass lawns) with unconstrained rooting space.

Following the approach of Bartlett, Scoffoni, Ardy, et al. (2012), sun-exposed branches, three to five metres above ground and <20 mm in diameter, with no symptoms of abiotic or biotic damage (such as leaf fungal pathogens, leaf defoliation or leaf chlorosis), were selected from each species/genotype. Depending on the availability of trees within the collection, leaf material was collected from two to six individual trees between 18:00 and 20:00 h. Excised branches were immediately placed in a humid bag and taken to the laboratory within 20 min. At the laboratory, branches were recut under water at least two nodes distal to the original cut and placed in a tube of water without exposing the cut surface to the air, to avoid embolisation. Branches were rehydrated overnight in a dark, humid chamber. The following day, leaf discs (one per leaf) were taken from fully expanded leaves using a 7 mm cork-borer from the mid-lamina region between the mid-rib and leaf margin. To minimise potential sources of error, no leaf discs were taken from lamina regions with first and second order veins. All discs were tightly wrapped in foil to limit condensation or frost after freezing. Foil-wrapped leaf discs were then submerged in liquid nitrogen for 2 min to fracture the cell membrane and walls. The time from harvesting the fully hydrated leaf discs to submergence in liquid nitrogen was less than 40 s. Upon removal from the liquid nitrogen, leaf discs were punctured 10–15 times with sharp tipped forceps to facilitate evaporation through the cuticle and to decrease equilibration time (Kikuta & Richter, 1992) before sealing the leaf disc in the vapour pressure osmometer (Vapro 5600, Westcor, Logan, UT, USA) using a standard 10 µl chamber. Initial solute concentration (c_s (in mmol kg^{-1})) readings were taken after 10 min equilibration time, c_s was recorded when repeat readings at two-minute intervals was <5 mmol kg^{-1}. Solute concentration was converted to an osmotic potential (Ψ_π) using Van't Hoff's relation (Equation (1)):

$$\Psi_\pi = -RTc_s \tag{1}$$

where R is a gas constant, T is temperature in Kelvin and c_s is the solute concentration. Eight leaf discs were analysed per species during late spring (collected 19th–30th May 2014: spring data-set) and mid-summer (collected 1st–10th August 2014: summer data-set), except for *Magnolia virginiana*, which is only represented by a summer reading.

Although Bartlett, Scoffoni, & Sack (2012) published an equation allowing the prediction of Ψ_{P0} from $\Psi_{\pi100}$, this was based on a global data-set that included data from tropical biomes. Since the current study is limited to the temperate biome, a subset (i.e. woody temperate,

Mediterranean/temperate-dry and temperate conifer species) of the Supplementary data published by Bartlett, Scoffoni, & Sack (2012) was used to generate a new equation for deriving Ψ_{P0} from $\Psi_{\pi100}$ in temperate tree species (Equation (2), Sjöman, Hirons, & Bassuk, 2015). This equation was used as it provided a higher coefficient of determination (R^2 .91 *vs.* .86) so provided a more reliable means of calculating Ψ_{P0}.

$$\Psi_{P0} = -.2554 + 1.1243 \times \Psi_{\pi100} \tag{2}$$

Osmotic adjustment ($\Delta\Psi_{\pi100}$) was calculated as the difference between the $\Psi_{\pi100}$ of the spring and summer data-sets.

Statistical analysis was conducted using Minitab v17 (Minitab Ltd., Coventry, UK). A paired *t*-test was used to evaluate the change in a single variable between spring and summer. One-way analysis of variance (ANOVA) was used when comparing differences across a single level. A Tukey's *post hoc* analysis was then applied to determine where these differences occurred, as indicated by letters of homogeneity. All data were plotted using SigmaPlot v13 (Systat Software Inc. San Jose, California, USA).

Results

These magnolia species only showed a mean $\Psi_{\pi100}$ of −1.48 (±.04) MPa with a rather narrow range of .25 MPa during spring. No significant differences were found in the $\Psi_{\pi100}$ across the magnolia species in the spring data-set. However, in the summer data-set, significant seasonal osmotic adjustment was demonstrated in *Magnolia acuminata, M. salicifolia, M. sieboldii* and *M. tripetala* (Table 2). Unfortunately, evaluation of the seasonal osmotic adjustment was not available for *M. virginiana* as no spring data were available. In summer, highly significant ($p < .001$) differences in $\Psi_{\pi100}$ were found across species (Table 2). The mean value across species was −1.86 (±.07) MPa, the range increased to .49 MPa with the highest $\Psi_{\pi100}$ (least osmotic adjustment) observed in *Magnolia × loebneri* "Leonard Messel" and the lowest (highest osmotic adjustment) in *Magnolia virginiana*.

By summer, highly significant differences in the predicted Ψ_{P0} existed across species. The mean value was −2.34 (±.08) MPa and ranged .55 MPa from the most drought sensitive *Magnolia* x *loebneri* "Leonard Messel" with a Ψ_{P0} of −2.07 MPa to the most drought tolerant *Magnolia virginiana* with a Ψ_{P0} of −2.61 MPa (Figure 1).

Table 2. Osmotic potential at full turgor ($\Psi_{\pi100}$ (±SE)) for magnolia species and seasonal osmotic adjustment ($\Delta\Psi_{\pi100}$).

Species	Spring $\Psi_{\pi100}$ (MPa)	Summer $\Psi_{\pi100}$ (MPa)	$\Delta\Psi_{\pi100}$ (MPa)
Magnolia acuminata	−1.60 (±.09)	−2.00 (±.03)[BC]	.40**
Magnolia kobus	−1.45 (±.12)	−1.71 (±.02)[A]	.26
Magnolia x *loebnerii* "Leonard Messel"	−1.42 (±.04)	−1.61 (±.07)[A]	.19
Magnolia salicifolia	−1.44 (±.06)	−1.79 (±.05)[AB]	.35**
Magnolia sieboldii	−1.36 (±.06)	−1.75 (±.02)[A]	.39***
Magnolia tripetala	−1.56 (±.08)	−2.02 (±.08)[C]	.47**
Magnolia virginiana	−	−2.10 (±.05)[C]	−

Notes: No significant differences were found across species in spring but highly significant differences were found in summer. Letters of heterogeneity indicate where significant differences occur determined by a one-way ANOVA ($p < .001$).
*s indicates a significant difference between the spring and summer data determined by a paired *T*-test.; **$p \leq .01$.; ***$p \leq .001$.
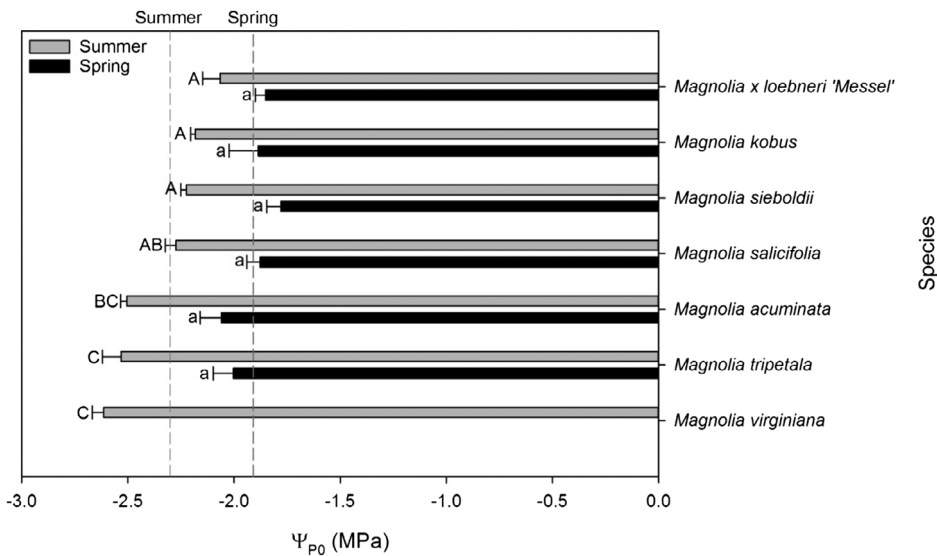
Figure 1. Predicted leaf turgor loss point in spring and summer of seven magnolia species.
Notes: Bars represent the SE of the mean; lowercase and uppercase letters indicate where significant differences ($p < .001$) occurred within spring and summer, respectively, as indicated by a one-way ANOVA. Vertical dashed lines indicate the season mean across all species.

Discussion

When planting or establishing a created urban forest, diversity is likely to be important in helping ensure its resilience to changing biotic and abiotic conditions over time (Alvey, 2006; Hooper et al., 2005). As such, the strategic goal of urban forest diversification must be to plant species with long-term viability and not to simply to plant a wider range of species. Forcing species into conditions to which they are inherently poorly adapted will result in increased maintenance costs and compromise the provision of future ecosystem services.

According to the results of this study, *Magnolia virginiana* is ranked as the most drought tolerant, while *M. loebneri* "Leonard Messel" is the most sensitive (Figure 2). However, in comparison with other plant groups previously studied, magnolias in the study have to be treated as drought sensitive (Figure 2). For example, when compared to a data-set of twenty-seven maples (Sjöman et al., 2015), *M. virginiana* shows similar Ψ_{P0} to *Acer pseudoplatanus* which is proven to be drought sensitive (e.g. Köcher, Gebauer, Horna, & Leuschner, 2009; Scherrer, Bader, & Körner, 2011). Although significant seasonal osmotic adjustment was found in a number of magnolia species in this study (Table 2) and in *M. virginiana* by Nash and Graves (1993), the comparison with maples suggests that the magnolias in this study only have the capacity to perform well in moist conditions with a good water supply: their ability to cope with dry environments appears very limited (Figure 2). However, a species such as *M. grandiflora*, not included in this study, is used in North America as well as in Europe in street environments with successful development and performance which indicates that it is possible to find magnolias even for areas with greater water deficits. Consequently, magnolias used in this study should be used in garden and park environments as their potential for use in street environments is limited by their vulnerability to drought. It is notable that these findings are consistent with site-related information from dendrological literature
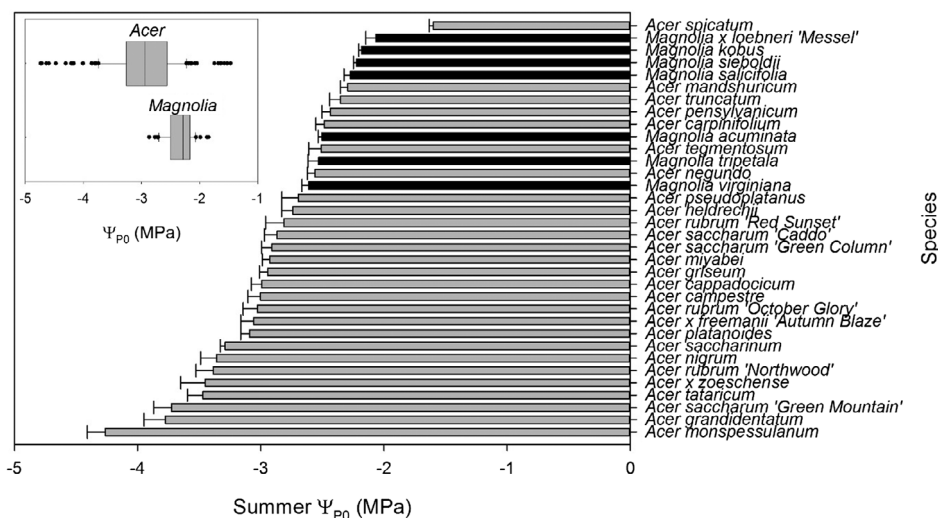
Figure 2. Comparison between representative species from *Magnolia* (black) and *Acer* (grey).
Notes: Bars indicate SE of the mean. *Inset:* Box plot of the combined species data for Magnolia and Acer showing the narrower range and tendency for a higher turgor loss point in *Magnolia* spp. Within the boxplot the vertical line indicates the median, the grey shaded box indicates 25th–75th percentile range; the error bars define the 10th and 90th percentile range; the (•) indicate extreme values.

presented in Table 1, which was derived from long periods of field observations by the authors rather than scientific experiments. The turgor loss point methodology provides a more efficient alternative to decades of observation, especially when new genotypes or underutilised and rare plants are being evaluated. From Table 1, it is also apparent that site-related information is considerably more extensive for *M. acuminata, M. tripetala* and *M. virginiana*, all native in the USA, compared to the other species and genotypes. This clearly shows the need for a fast and efficient way to also screen for tolerance and hence potential, species that are not traditionally in use for urban forest planting. It is now possible to show the group's general sensitivity to drought as well as quantifying individual species sensitivity to drought. In the context of other data-sets, these data are highly instructive as they facilitate comparison with other plant groups allowing the user to position species' within a broader scale of drought tolerance derived from species with diverse habitat preferences.

It is important to bear in mind that the data-set presented in this study represents just a limited number of trees, except for *M. acuminata* which included six individual samples (trees). A clear limitation in the process of evaluating unusual or unconventional tree species is that they are rarely found in collections in quantities suitable for statistical analysis. Therefore, this study should be considered preliminary, but nonetheless useful for those requiring guidance on the sensitivity of magnolias to drought. However, the methodology used describes a framework for the evaluation of a plant trait that is of inherent interest to those specifying or growing trees for the urban environment.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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Henrik Sjöman is a senior researcher and teacher at the Swedish University of Agricultural Science and Scientific Curator at Gothenburg Botanical Garden. His research profile includes plant selection for urban environments with focus towards understanding different species capacity delivering important ecosystem services and tolerating urban environments with focus on untraditional plant material resilient to future urban challenges.

Andrew D. Hirons is a Senior Lecturer in Arboriculture at University Centre Myerscough, UK. He teaches full-time and online higher education courses, delivering modules relating to tree biology and tree management. His current research activity is motivated by the need to create resilience in our urban forests, and is focused on using plant traits to inform species selection for urban environments.

Nina L. Bassuk is professor and program leader of the Urban Horticulture Institute at Cornell University. Her research interest is improving the quality of urban life by enhancing the functions of plants within the urban ecosystem, integrating plant stress physiology, horticultural science and plant ecology and soil science.

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