Effects of Tree Production Method and Transplanting on Root Hydraulic Conductance[1]

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Abstract

The objective of this study was to investigate the post-transplant, root specific hydraulic conductance (K_S) of two oak species (*Quercus bicolor* Willd. and *Quercus rubra* L.). *Q. bicolor* and *Q. rubra* trees responded differently to transplanting across the differing types of production methods. Overall, higher post-transplant fine root K_S resulted in a larger leaf area after transplanting. Container-grown (CG) trees had the highest root K_S immediately after transplanting compared to balled-and-burlapped (BNB), in-ground fabric (IGF), and bare-root (BR) trees, but K_S in CG trees was largely reduced at the end of the first growing season after transplanting. Post-transplant variations of fine root K_S also differed between the two tree species. Fine root K_S remained similar in BNB and IGF *Q. bicolor* trees after transplanting, but increased with time after transplanting in *Q. rubra* trees. The increase in K_S was especially greater in BNB and BR *Q. rubra* trees than IGF *Q. rubra*.

Index words: transplanting, root hydraulic conductance, tree production method, *Quercus bicolor*, *Quercus rubra*, oak

Species used in this study: Swamp white oak (*Quercus bicolor* Willd.); northern red oak (*Quercus rubra* L.)

Significance to the Horticulture Industry

This research investigated the effect of tree production methods on transplanting, specifically by measuring the specific hydraulic conductance (K_S) of tree roots after transplanting and subsequent shoot growth and leaf area. Choosing the best production method to ensure adequate growth post transplanting would be a significant advantage for landscape managers, especially for more difficult to transplant trees. Our results indicated that although newly-installed container-grown trees had the highest root K_S at transplanting, extra care may be required by stakeholders to maintain post-transplant water availability, possibly due to the interface between container media and the surrounding mineral soil. Meanwhile, considering the relatively lower post-transplant mortality rate and greater shoot growth compared to bare-root trees, BNB trees would be a good option for urban foresters tasked with planting trees that are known to be difficult to transplant.

Introduction

Urban environments pose many challenges to the successful establishment and growth of urban trees and community green spaces. With over 80% of the U.S. population living in urbanized settings (Mackun and Wilson 2010), it is in this built environment that most people may appreciate the attributes associated with urban greening efforts. The environmental and economic benefits of urban tree planting are widely described and include air quality improvement, stormwater reduction, ambient temperature regulation, property value enhancement and energy cost reduction (Nowak and Crane 2002, McPherson 2007, Nowak and Dwyer 2007, Oliveira et al. 2011). It is important to note, however, that although urban tree planting and greening efforts are widespread, the effect of planting in difficult urban conditions may result in both substantially reduced tree establishment rates (%) and overall tree life expectancy (years) (Ko et al. 2015, Roman and Scatena 2011), as well as increased costs associated with re-planting trees (Green et al. 2015). To fully realize the desired environmental and economic benefits of urban trees, they must transplant well and grow with a high success rate. Successful urban tree planting requires better understanding of factors that impact urban tree survival and development. Through the cooperation and participation with local stakeholders (Infante-Casella and Kline 2003, Keenan et al. 2007) who produce and handle locally sourced commodities like urban trees, we have the opportunity to improve urban tree establishment in a meaningful way.

Root loss during transplanting of trees results in a reduction of primary and secondary tree growth (Watson 1985, Andersen et al. 2000), and contribute to an overall state of plant stress, commonly called transplant shock. In an urban setting, roots may encounter compacted soil conditions (Alberty et al. 1984), nutrient deficiencies (Nowak et al. 1990) and potentially harmful agents like road salts (Jutras et al. 2010). Water, however, is typically the most important growth-limiting factor for newly-planted trees (Watson and Himelick 2013), and new root growth is critical in maximizing water uptake (Jacobs et al. 2004). The plant's water status is largely dependent on a tree's ability to conduct water through its root system (i.e., hydraulic conductance, K). Hydraulic conductance may be influenced by an array of factors including root size, form and structure (Yin et al. 2014).

The purpose of this study was to determine the impact of the nursery production system used on the post-transplant root ~~K_S~~ of two oak species (*Quercus bicolor* and *Quercus*

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rubra) that are known to differ in their ease of transplanting – *Q. bicolor* has been reported to be an easy-transplant tree (e.g. Bassuk 1990, Buckstrup and Bassuk 2000, Curtis 2000), while *Q. rubra* is considered a relatively difficult to transplant (e.g. Struve et al. 2000, Struve 2009). We also investigated the effect of tree production methods on post-transplant survival, in an effort to transfer the results to interested nursery growers. The tree species used in this study are commonly selected as part of urban re-greening efforts by urban foresters and shade tree committee volunteers throughout the U.S.

Materials and Methods

Plants. A total of 24 *Quercus bicolor* and 24 *Quercus rubra* trees were installed alongside Southeast Street, Amherst, MA (42°20′47” N; 72°30′15” W) in May 2014. At transplanting, soil pH was 5.9. Average total nitrogen, phosphorus and potassium contents in the soil were 0.23%, 0.50 ppm, and 43 ppm, respectively. The trees averaged 3.28 m (10.76 ft) in height and 5.33 cm (2.10 in) in caliper. The trees were supplied and installed, courtesy of local private (Amherst Nurseries, Amherst, MA) and public (Town of Amherst, Department of Public Works, Amherst, MA) commodity stakeholders. All trees were leafed out at transplanting. Twenty-four *Q. bicolor* trees were produced using one of the following production methods: balled and burlapped (BNB), in-ground fabric (IGF), and pot-in-pot container grown (CG). Similarly, 24 *Q. rubra* trees were harvested from BNB, IGF, or bare-root (BR) production methods, respectively. Tree height and caliper were similar among the production methods. Pot-in-pot *Q. bicolor* trees were grown in number 25 pots. The root ball diameter for BNB was 60 cm (24 in) and 71 cm (28 in) for *Q. bicolor* and *Q. rubra*, respectively. IGF root ball diameter was 45 cm (18 in) for both *Q. bicolor* and *Q. rubra*. Two types of fabric were used for IGF trees – a black flexible artificial cloth-like fabric (High Caliper; Smart Growing System, Root Control Inc., Oklahoma City, OK) and a green polymer-based, screen-like material (RootMaker, Huntsville, AL) were used for *Q. bicolor* and *Q. rubra* IGF trees, respectively. Each production method had eight replicates within each tree species. The trees were not fertilized or watered after transplanting. On the final day of transplanting (May 17, 2014), the amount of precipitation was 3.18 cm (1.25 in), and no other precipitation occurred for the following five days. The total amount of precipitation from the date of transplanting to the end of the growing season (September 30, 2014) was 45.62 cm (17.96 in). Total amount of precipitation in the growing season (from the beginning of May to the end of September) of 2015 and 2016 was 54.56 cm (21.48 in) and 30.61 cm (12.05 in), respectively.

Root hydraulic conductance measurement. Root hydraulic conductance (K) was measured on each tree during the months of May, July, and September in 2014 and again in 2015, using a hydraulic conductance flow meter [HCFM (Gen 3, Dynamax, Houston, TX)]. One fine root branch was randomly collected from each tree. Fine root branch length was approximately 20 cm (7.9 in), and diameter was approximately 1.5 to 2.0 mm (0.06 to 0.08 in). Immediately before measurement, the end of the branch was removed under water with a sharp blade resulting in the branch that was approximately15 cm long (6 in). Hydraulic conductance in fine root branches was measured with the transient measurement mode which rapidly increased the applied pressure and simultaneously measured the corresponding flow (Tyree et al. 1995). Degassed, deionized water was forced through the roots under increasing pressure until the pressure reached 500 kPa. The instantaneous flow and pressure were recorded every 2 seconds. Hydraulic conductance ($kg \cdot s^{-1} \cdot kPa^{-1}$) was calculated from the slope of linear regression between the pressure and flow. The root diameter was determined using a digital caliper to calculate specific hydraulic conductance (K_S, $kg \cdot s^{-1} \cdot m^{-2} \cdot kPa^{-1}$), K divided by cross-sectional area of the root.

Leaf area measurement. Six mature leaves growing in the sun on the upper half of the tree were randomly collected from each tree in September 2015. Leaf area was measured with a leaf area meter (LI-3100; LI-COR, Lincoln, NE) to determine the average leaf area of each tree.

Shoot growth measurement. Shoot growth was determined at the end of the growing season of the year by measuring the extension length of new shoots that were exposed to the sun since some shoots were in shade. The length was measured on five new shoots of each tree in late September or early October of 2014, 2015, and 2016, respectively, using a measuring tape.

Data analysis. Although each production method had a minimum of eight replicates, some trees demonstrated symptoms consistent with severe transplant shock in the first year, with some specimens dying altogether. Data was only collected from living trees. The means of K_S and increase in K_S from the first to the second year after transplanting were compared among the differing types of production methods using Steel-Dwass' test. Differences were considered significant if $P < 0.05$. The correlation between K_S and average leaf area across both species and all the production methods was evaluated using Pearson's product-moment correlation. When the correlation was significant, reduced major axis (RMA) regression was performed to model the relationship between two variables. Statistical analyses were performed in JMP Pro 11 (SAS Institute Inc., Cary, NC, USA).

Results and Discussion

Post-transplant mortality rate differed between the two tree species, as well as among the differing production methods. Overall, *Q. bicolor* trees survived transplanting better than *Q. rubra* (Table 1). This result is consistent with the observations in the previous studies (Buckstrup and Bassuk 2000, Struve 2009). One IGF *Q. bicolor* tree died four months after transplanting, while all of the other *Q. bicolor* trees survived. All *Q. rubra* trees that were produced IGF survived transplanting, while two BNB and six BR trees died by the end of the first growing season. The high mortality rate of the BR *Q. rubra* trees was likely

Table 1. **Mortality rate (%) four months after transplanting for *Quercus bicolor* and *Quercus rubra* trees grown by different production methods.**

Species	Production Method	Mortality Rate (%)
Q. bicolor	Balled-and-burlapped	0
	In-ground fabric	12.5
	Container-grown	0
Q. rubra	Balled-and-burlapped	25
	In-ground fabric	0
	Bare-root	75

caused by severe loss in root biomass associated with root-pruning and exposure to dry conditions at the time of transplanting, resulting in severe water stress.

Shoot extension varied among the different types of production methods. For *Q. bicolor*, CG and IGF trees exhibited longer shoot extension in the first year post-transplanting compared to BNB trees (Fig. 1a). But in the third year, the mean shoot extension in BNB *Q. bicolor* trees was 1.5 times longer than that in IGF trees, and slightly longer than CG trees. Compared to CG and IGF trees, BNB trees dug by the tree spade lose a much higher percentage of the root system at harvest. Thus, regeneration of a new root system might be more essential than shoot extension for the establishment of a newly transplanted BNB trees, especially within the first two years following transplanting. For *Q. rubra*, the mean shoot extension in the first year after transplanting was greater in BNB and IGF trees than BR trees, by 307% and 253%, respectively (Fig. 1b). BR *Q. rubra* trees had the shortest shoot extension in all of the three years after transplanting compared to the trees produced from the other two production methods.

Immediately following the first year of transplanting, mean fine root K_S across all the production methods in *Q. bicolor* trees was almost two-times higher than that in *Q. rubra* trees. Specifically, CG *Q. bicolor* trees had the highest K_S immediately after transplanting, followed by BNB and IGF *Q. bicolor* trees (Fig. 2a). One of the largest advantages of container production is that the entire root system of a tree remains intact during transplanting. If given proper growing conditions, the roots can take up water quickly evidenced by a higher immediate post-transplant root K_S. *Q. rubra* trees of three production methods (BNB, CG, BR) had similar post-transplant fine root K_S, indicating that tree production system did not affect fine root K_S in *Q. rubra* trees immediately after transplanting (Fig. 2b). On the following sampling dates, CG *Q. bicolor* trees still had higher K_S compared to BNB and IGF *Q. bicolor* trees, especially BNB ones (Fig. 2a). For *Q. rubra* trees, despite the high tree mortality rate associated with the BR method, fine root K_S of living trees was similar among three production methods on any sampling date (Fig. 2b).

Post-transplant variations of fine root K_S differed between two species, as well as among three types of production methods. Although CG *Q. bicolor* trees had the highest root K_S after transplanting compared to BNB and IGF *Q. bicolor*, its K_S was reduced by about 100% at the end of the first growing season after transplanting, and remained at a similar value until the end of the second growing season. On each of the sampling dates of year 2, fine root K_S in CG *Q. bicolor* trees was lower than the first year by 48% and 76% for May and July respectively, and similar in September (Fig. 3a). CG trees' entire root system remained intact during shipping and retail storage, which can help maintain root K_S immediately after transplanting. Over-time, however, reduction in root K_S of CG trees may have occurred as a result of circling-root problems (Allen et al. 2017), in which roots circle around the rootball or base of the trunk instead of growing straight away from the trunk, thus reducing a tree's vigor by compromising the flow of water and nutrients. The reduction in root K_S of CG trees after transplanting may also have been caused by the differences in growing media before and after transplanting. Soilless media of CG trees provides good drainage and water retention, which may facilitate higher root K_S. The interface between growing media and ambient mineral soil after transplanting can alter water movement in the root zone resulting in changes in root hydraulic properties (Hillel 1998). BNB and IGF *Q. bicolor* trees maintained

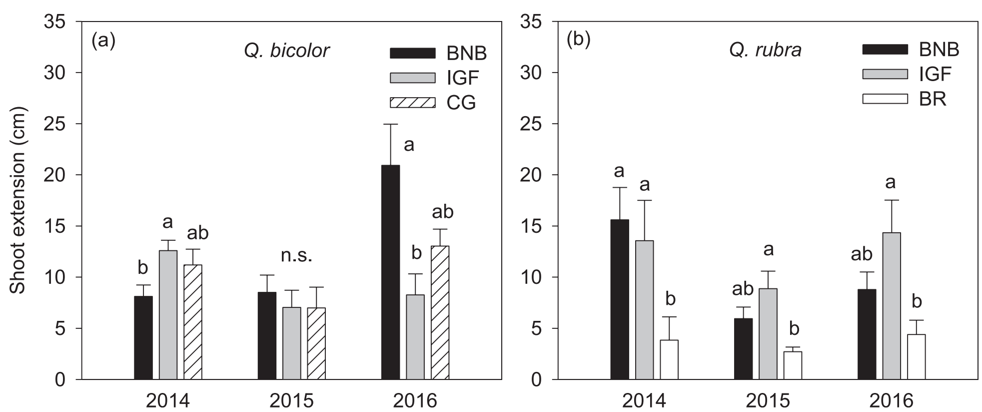

Fig. 1. **The shoot extension length (cm) after transplanting for *Quercus bicolor* and *Quercus rubra* trees grown by different production methods. Measurements were taken in late September of 2014, and early October of 2015 and 2016, respectively. Black bars represent K_S measured from balled and burlapped (BNB) trees; grey bars represent K_S measured from in-ground fabric (IGF) trees; hatched bars represent K_S measured from container-grown (CG) trees; and open bars represent K_S measured from bare-rooted (BR) trees.**

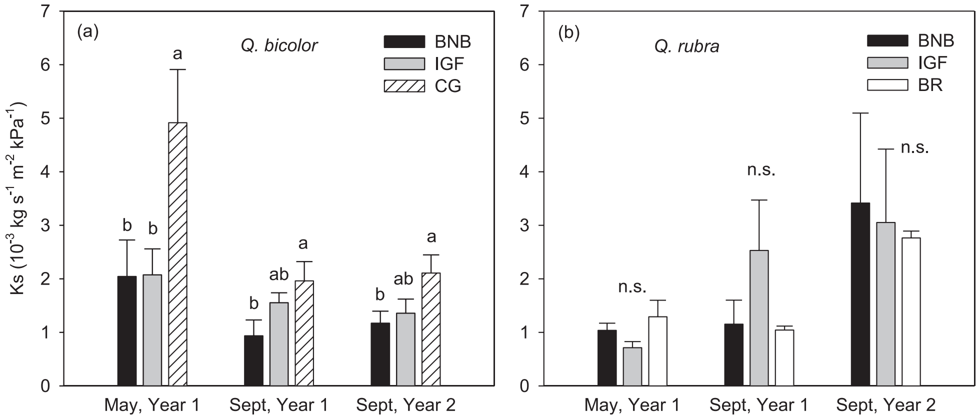

Fig. 2. The means of fine root specific hydraulic conductance (K_S) after transplanting for *Quercus bicolor* and *Quercus rubra* trees grown by different production methods. Measurements were taken in May of the first year after transplanting, and in September of the first and second year after transplanting. Black bars represent *Ks* measured from balled and burlapped (BNB) trees; grey bars represent K_S measured from in-ground fabric (IGF) trees; hatched bars represent *Ks* measured from container-grown (CG) trees; and open bars represent K_S measured from bare-rooted (BR) trees.

similar fine root K_S throughout the two growing seasons after transplanting.

Although *Q. rubra* trees had greater post-transplant mortality rates, fine root K_S in living *Q. rubra* trees increased with time after transplanting, unlike *Q. bicolor* trees. Overall, fine root K_S in living *Q. rubra* was higher in year 2 than year 1, regardless of production method (Fig. 3b). The increase in K_S from year 1 to year 2 was especially greater in BNB and BR *Q. rubra* trees than IGF *Q. rubra*. Compared to IGF production, more of the root system was pruned during BNB and BR production; root pruning can stimulate new root growth (Castle 1983), which may assist root K_S recovery after transplanting.

Across all species and production methods, trees with higher fine root K_S after transplanting tended to have larger average leaf area (Fig. 4). Higher K_S in fine roots implies faster water movement from roots to leaves, which increases turgor pressure and allows stomata to open (Trifilò et al. 2004), therefore increasing the rate of carbon gain and promoting faster post-transplant growth and recovery.

In conclusion, *Q. bicolor* and *Q. rubra* trees responded differently to transplanting across the differing types of production methods. Overall, higher post-transplant fine root K_S resulted in better shoot growth after transplanting. As a result of the intact root systems during transplanting, CG trees had the highest root K_S immediately after transplanting compared to BNB, IGF and BR trees. However, extra care may be required to maintain post-transplant water availability in the root zone of newly-installed CG trees, to prevent a large reduction in root K_S. Post-transplant variations of fine root K_S also differed between the two tree species. Fine root K_S remained similar in BNB and IGF *Q. bicolor* trees after transplanting, but increased with time after transplanting in living *Q. rubra* trees. The increase in K_S was especially greater in BNB and BR *Q. rubra* trees than IGF *Q. rubra*, probably due to greater root regeneration stimulated by large root pruning during BNB and BR production.

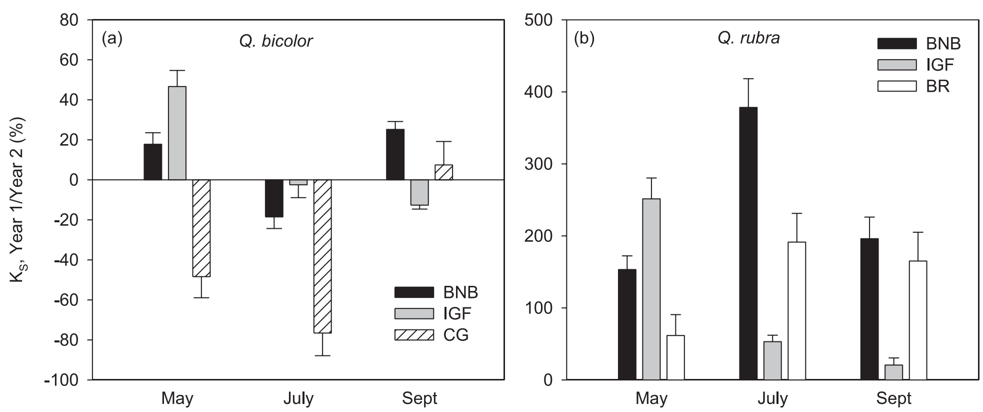

Fig. 3. Increase in fine root specific hydraulic conductance (K_S) of *Quercus bicolor* and *Quercus rubra* trees from the first year to the second year after transplanting, calculated in May, July, and September of the first and second year after transplanting, respectively. Black bars represent ~~*Ks* measured from~~ balled and burlapped (BNB) trees; grey bars represent ~~K_S measured from~~ in-ground fabric (IGF) trees; hatched bars represent ~~*Ks* measured from~~ container-grown (CG) trees; and open bars represent ~~K_S measured from~~ bare-rooted (BR) trees.

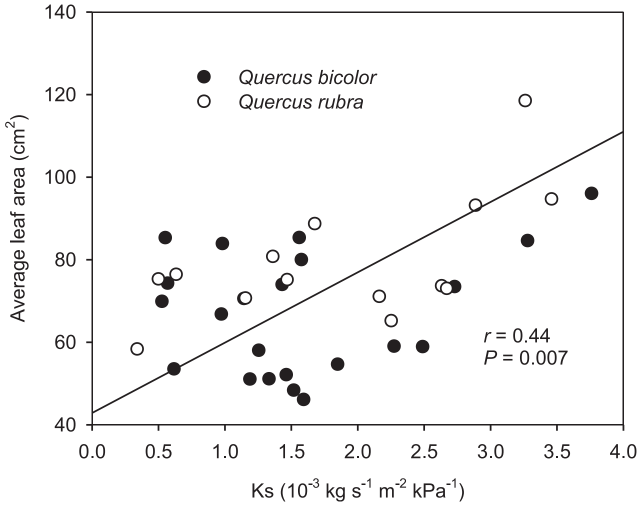

Fig. 4. Relationship between specific hydraulic conductance (K_S) in fine roots and average leaf area after transplanting for *Quercus bicolor* and *Quercus rubra* trees produced by different production methods. Both K_S and leaf area measurements were taken in September of the second year after transplanting. Solid dots represent *Q. bicolor* trees, and open dots represent *Q. rubra* trees.

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