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Transplant Season, Irrigation, and Planting Depth Effects on Landscape Establishment of Baldcypress and Sycamore

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Abstract. Tree transplanting practices influence plant survival, establishment, and subsequent landscape value. The inability to adequately quantify effects of transplanting practices threatens long-term sustainability of landscape trees. Planting depth [i.e., location of the root collar relative to soil grade (soil surface)], is of particular concern for tree growth, development, and landscape performance. The authors of this study investigated the effects of planting depth and transplant season on landscape establishment of baldcypress [*Taxodium distichum* (L.) Rich.] and effects of planting depth and irrigation practices on landscape establishment of sycamore (*Platanus occidentalis* L.). Baldcypress planted above grade had reduced relative growth rate in height and diameter compared to those planted at or below grade during the first growing season, regardless of transplant season. Sycamore trees planted below grade had increased mortality and decreased growth compared to trees planted at grade or above grade, regardless of irrigation treatment. Even though trees of both species were grown under similar conditions, baldcypress was much more tolerant to belowgrade planting than sycamore. We suggest that this is related to the native habitat of both species, where baldcypress is frequently exposed to hypoxic conditions while sycamore is more prevalent on well-drained soils. Thus, it may be important to consider the native habitat of a species when evaluating the effect of planting depth.

Key Words. Cultural Practices; Landscape Installation; *Platanus occidentalis*; Relative Growth Rate; *Taxodium distichum*.

Variability in tree planting and transplanting practices is of particular concern as optimum planting depth may vary among species and ecotypes, and success may be dependent on environmental conditions and subsequent cultural practices (Drilias et al. 1982; Pirone et al. 1988; Browne and Tilt 1992; Ball 1999; Gilman and Grabosky 2004; Arnold et al. 2005; Arnold et al. 2007). Intentional belowgrade planting of trees is typically attributed to one of four reasons: 1) to attain uniform height [e.g., palms (Broschat et al. 2009)], 2) to reduce the need for staking during establishment (Day et al. 1995), 3) to improve access to soil moisture (South 2005), and 4) to avoid root growth conflicts with components of man-made infrastructures in urban landscapes (McPherson et al. 2001).

Planting trees too deep may cause significant reductions in tree growth. Arnold et al. (2005) showed that planting the root collar deep (7.6 cm) in dense sandy loam soil resulted in poor growth, possibly as a result of decreased soil moisture and/or oxygen in the rhizosphere. Wells et al. (2006) reported that when balled-and-burlapped Yoshino cherry (*Prunus* × *yedoensis* Matsum.) trees were planted with root flares at 15 cm or 31 cm below grade, 50% of the trees died within two years of transplanting, while all trees planted with root flares at grade survived. This was likely due to reduced water infiltration to the root ball and insufficient access to shallow mineral nutrient pools (Wells et al. 2006). Similarly, transplanting container-grown sycamore (*Platanus occidentalis* L.) trees into field conditions (Boonville fine sandy loam) with the root collars 7.6 cm below grade adversely affected survival and growth (Arnold et al. 2007). Planting trees with root collars above grade may cause significant reductions in tree growth possibly due to a wicking effect of moisture and nutrients from the exposed root ball. However, this may be dependent on other environmental factors such as soil conditions, as planting above grade may be beneficial to tree growth when soils are prone to anoxic conditions. For example, Arnold et al. (2007) reported that sycamore trees transplanted 7.6 cm above grade had a significantly greater height and trunk diameter after three growing seasons when compared to trees transplanted at grade in a heavy (underlain by a hard clay pan at 15 to 30 cm depth) sandy loam soil.

Successful landscape establishment of trees is also dependent on numerous cultural practices including transplant season and irrigation. The season in which trees are transplanted may affect plant growth, survival, and landscape establishment. In temperate climates, transplanting usually takes place during autumn and spring, when soil moisture content is generally high (Richardson-Calfee and Harris 2005). Transplanting in autumn, while the tree is dormant, may allow for root establishment if winter soil temperatures remain high enough (Richardson-Calfee and Harris 2005). However, transplanting in autumn could also result in low survival as a result of low physiological potential for root regeneration and growth when soil temperatures are low (Jenkinson 1980; Larson 1984). Spring planting would ensure soil temperatures are high enough for root growth; however, transplanting in spring when trees are approaching budbreak may result in excessive carbohydrate drain from the roots (Dumbroff and Webb 1978).

During tree transplant establishment, soil water content is a determining factor for plant growth and survival (Kozlowski and Davies 1975; Gilman 1990). Establishment, growth, and survival of live oak (*Quercus virginiana* L.) was enhanced when root zones were maintained at a steady water content, compared to high soil water content fluctuations when grown in a sandy soil (Gilman et al. 1998). In addition, when live oaks were frequently irrigated after field transplanting into sandy soil, they grew twice as much (diameter and height) in the first growing season as trees which were infrequently irrigated (Gilman 2004). However, positive effects of irrigation on live oak growth rates disappeared in the second season, possibly as a result of tree establishment (Gilman 2004) or possibly due to low fertility (no fertilizer applied during study) as a result of nutrients leaching out of the root zone. Similarly, red maple (*Acer rubrum* L.) subjected to frequent irrigation after transplanting had greater trunk diameter, increased root number, root diameter, and uniform root distribution, than trees irrigated less frequently (Gilman et al. 2003). Results from the above-mentioned research indicate that irrigation frequency is important to tree growth and survival after transplanting.

What remains unclear is the effect of planting depth and potential interactions with either transplant season or irrigation on plant growth and survival. Therefore, it is important to determine the effects of planting practices on tree survival at transplant, and to assess the effects of these practices on subsequent landscape performance. Baldcypress [*Taxodium distichum* (L.) Rich.] and sycamore (*Platanus occidentalis* L.) are majestic trees of considerable ornamental value in urban and riparian environments (Bailey and Bailey 1976; Simpson 1988; Liu et al. 2007). Baldcypress is known to tolerate a wide range of soil moisture conditions, ranging from periodic flooding to mild drought (Elcan and Pezeshki 2002). Sycamore is flood tolerant (Kozlowski and Pallardy 2002), and is known to have the ability to adjust its osmotic potential in response to drought (Tschaplinski et al. 1995). The broad objectives of the present experiments were to explore the effect of planting depth and transplant season on baldcypress growth and establishment, and the effect of planting depth and irrigation rate on sycamore growth and landscape establishment.

MATERIALS AND METHODS

Experiment 1: Effect of Planting Depth and Transplant Season on Growth and Landscape Establishment of Baldcypress

Cultural Conditions

Baldcypress seeds were collected in Poteet, Texas (29°2’23.11”N, 98°34’27.45”W), and stored under ambient conditions until required (approximately two months). Seeds were immersed in a heated [43°C (109°F)] water bath (180 Series Water Bath, Precision Scientific Inc., Chicago, IL) and left to soak for approximately 24 hours in cooling water [to 23°C (73°F)]. Seeds were then removed and rinsed in reverse osmosis (RO) treated water. This procedure was repeated five times. Seeds were then stratified in a cold room at 1.7°C (35°F) for 90 days in moist peat (Premier® Pro Moss® TBK Professional, Premier Horticulture Inc., Red Hill, PA), and then planted in 10 cm × 36 cm × 51 cm (height x width x length) (18.4-L) black plastic flats (Dyna-flat™, Kadon Corp., Dayton, OH) containing vermiculite (Sunshine® Strong-Lite® Medium Vermiculite Premium Grade, SUN GRO™ Horticulture, Pine Bluff, AR), and placed in a greenhouse at Texas A&M University Horticultural Gardens, College Station, TX (30°36’5”N, 96°18’52”W). Emerging seedlings were irrigated with RO water as required.

After approximately 100 days, uniform seedlings, approximately 11 cm in height, were transplanted into 0.85 L black plastic containers (Kinney Bonded Warehouse, Inc., Donna, TX) with their root collars at substrate surface (grade) (Metro-Mix® 700 Series, SUNGRO®, Bellevue, WA). Root collars were defined as the area between the stem and the root system. Transplanted seedlings were maintained under shade (55% light exclusion) in a graveled nursery at Texas A&M University Horticultural Gardens. Plants were fertigated (0.27 L·min^{-1} flow rate), as required with 50 mg·L^{-1} (50 ppm) N from a water soluble fertilizer (Peters Professional® Acid Special water soluble fertilizer, 21N-3.1P-5.8K, Scott’s Company, Marysville, OH). Irrigation water was injected with concentrated sulfuric acid to lower pH to a target of 6.5.

Young trees (liners) were transplanted, after approximately 80 days, into 2.6 L (#1) black plastic containers (C-300S Classic, Nursery Supplies, Inc., Chambersburg, PA) with their root collars at substrate (composted pine bark mulch; Landscapers Pride®, New Waverly, TX) surface (grade). Container substrate was amended with the following: 7 kg·m^{-3} 15N-3.9P-9.9K controlled release fertilizer (Scotts Osmocote®Plus 15-9-12, Scotts-Sierra Horticultural Products Co., Marysville, OH), 4 kg·m^{-3} dolomitic limestone (Austin White Lime Company, Austin, TX), 2 kg·m^{-3} gypsum (Hoedown™ Standard Gypsum LP, Fredericksburg, TX), and 1 kg·m^{-3} micronutrients (Scotts Micromax® micronutrients, Scotts-Sierra Horticultural Products Co., Marysville, OH). Liners were maintained in the nursery under shade and fertigated as previously described.

Trees were transplanted, after approximately 225 days, into 10.8 L (#3) (28 cm top diameter; 24 cm height) black plastic containers (1200C Classic, Nursery Supplies, Inc., Chambersburg, PA), with the substrate (composted pine bark mulch; Earth’s Finest Black Diamond Mulch, The LetCo Group, Dallas, TX) surface maintained at grade. Container substrate was amended as described previously. Trees were maintained in the nursery under shade and fertigated as previously described. Trees were staked (1.2 m bamboo stakes) and tied to maintain a central leader.

Trees were transplanted into field conditions at the Texas A&M University Horticulture Farm, after approximately 210 days (November 19, 2005) for the autumn transplant, and 320 days (March 12, 2006) for the spring transplant. Trees were transplanted at various depths in relation to the root collar, at grade (at soil surface), 7.6 cm below grade, or 7.6 cm above grade. Trees were drip-irrigated (T-Tape®, T-Systems Intl. Inc., San Diego, CA) as required. Field soil had a textural analysis of 74% sand, 16% silt, and 10% clay (sandy loam), contained 2.73% organic matter (OM), pH 6.4, electrical conductivity (EC) 0.201 dS·m^{-1}, and nutrient levels with the following μg·g^{-1} (ppm): 11 NO_3-N, 47 P, 70 K, 490 Ca, 47 Mg, 17 S, 294 Na, 87.4 Fe, 0.87 Zn, 8.69 Mn, 0.28 Cu, and 0.15 B (Soil, Water, and Forage Testing Laboratory, Texas A&M University, College Station, TX).

Daily precipitation events during the active growing season (March to September) at nearby Easterwood Airport (Office of the Texas State Climatologist, Department of Atmospheric Sciences, Texas A&M University, College Station, TX) in 2006 and 2007 are presented in Figure 1.

Assessment of Plant Growth

Tree height, from soil line to apical tip, and trunk diameter (15 cm above soil) were measured in March and November 2006, and again in March and November 2007. Relative growth rates were calculated (Hoffmann and Poorter

2002), for the height and diameter growth from March 2006 to November 2006, and from March 2007 to November 2007.

Statistical Design

The experiment was a randomized complete block design with three transplant depths × two transplant seasons × ten blocks. There was one tree per treatment combination per block. Data was analyzed using analysis of variance (ANOVA) in the JMP system for Windows, Release 7.02 (SAS Institute Inc., Cary, NC).

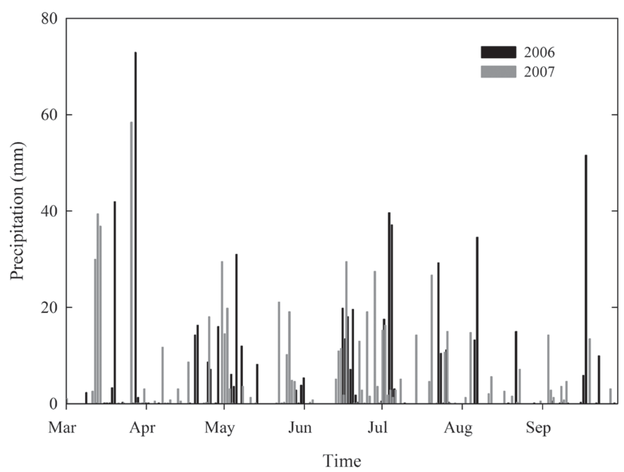

Figure 1. Reported daily precipitation events during the active growing season (March to September) in 2006 and 2007 (Office of the Texas State Climatologist, Department of Atmospheric Sciences, Texas A&M University, College Station, TX).

Experiment 2: Effect of Planting Depth and Irrigation on Growth and Landscape Establishment of Sycamore

Cultural Conditions

Sycamore cuttings were collected in September 2004 from stock plants (group of clones from open pollinated siblings) and grown under shade (55% light exclusion) in a graveled nursery at Texas A&M University Horticultural Gardens. Cuttings included the shoot apex and were approximately 9 cm in length. The basal 1 cm of each cutting was dipped in a commercial rooting powder (0.3% indole-3-butryic acid, Hormex No. 3, Brooker Chemical Corp., Chatsworth, CA) and inserted (to approximately 1 cm depth) in 10 cm × 36 cm × 51 cm (18.4 L) black, plastic flats (Kadon, Corp., Dayton, OH) containing perlite (Coarse Perlite Premium Grade, Sungro™ Horticulture, Pine Bluff, AR). Cuttings were placed in a greenhouse under intermittent mist (four seconds every 10 minutes from dawn to dusk).

Uniform rooted cuttings were transplanted, after approximately 20 days, into 0.946 L, black, plastic containers (Dillen Products, Middlefield, OH), with their root collars at the substrate (Metro-Mix® 700 Series, SUNGRO®, Bellevue, WA) surface (grade). Root collars were defined as the area where the topmost adventitious roots formed. Transplanted cuttings were transferred to the nursery and maintained as previously described for baldcypress trees.

Young trees (liners) approximately 30 cm in height were transplanted after 250 days, into 2.6 L (#1) black plastic containers (C-300S Classic, Nursery Supplies, Inc., Chambersburg, PA) and grown for approximately 70 days, after which the trees were transplanted into 6.2 L (#2) black plastic containers (Poly-Tainer™ 2, Nursery Supplies, Inc., Chambersburg, PA). Trees were transplanted with substrate (composted pine bark mulch; Earth's Finest Black Diamond Mulch, The LetCo Group, Dallas, TX) surface maintained at grade. Container substrate was amended and trees were maintained as previously described for baldcypress trees.

Trees (mean height 120.0±0.9 cm, mean trunk diameter 9.5±0.1 mm were transplanted, after approximately 40 days (September 2005), into field conditions at the Horticulture Farm. Trees were transplanted at various depths in relation to their root collars (at grade, 7.6 cm below grade, or 7.6 cm above grade), and watered as required. Trees were staked [1.8 m bamboo stakes] and tied for support. Approximately two weeks after transplanting, trees were irrigated with 0, 1, 2, or 4 spray stakes (SS-AG160LGN-100, Lt. Green Low Flow 160 Spray Pattern, Aboveground Spot-Spitter®, Roberts Irrigation, San Marcos, CA) per tree at an approximate flow rate of 0 $L \cdot min^{-1}$, 0.42 $L \cdot min^{-1}$ (1/2× recommended rate, according to manufacturer label), 0.84 $L \cdot min^{-1}$ (0.22 $gal \cdot min^{-1}$ = 1× recommended rate), and 1.68 $L \cdot min^{-1}$ (0.44 $gal \cdot min^{-1}$ = 2× recommended rate), respectively. Trees were pulse-irrigated for 10 minutes when soil water potential in the 1× treatment reached approximately -15 kPa (Model 2725, Jet-Fill Tensiometers, Soil Moisture Equipment Corp., Santa Barbara, CA). The soil had a textural analysis of 74% sand, 16% silt, and 10% clay (a sandy loam), contained 2.13% OM, pH 5.0, EC 0.099 $dS \cdot m^{-1}$, and had nutrient levels with the following $\mu g \cdot g^{-1}$ (ppm): 12 NO_3-N, 40 P, 54 K, 277 Ca, 30 Mg, 14 S, 196 Na, 102.3 Fe, 0.51 Zn, 6.19 Mn, 0.28 Cu, and 0.08 B (Soil, Water, and Forage Testing Laboratory, Texas A&M University, College Station, TX). The reported (Office of the Texas State Climatologist) daily precipitation events during the active growing season (March to September) in 2006 and 2007 are presented in Figure 1.

Plant Growth Parameters

Tree height (soil line to apical tip), and trunk diameter [approximately 15 cm above soil/substrate line] were measured every six months from start (September 2005) to end of the experiment (September 2007) with a digital caliper (Max-Cal "Blade" caliper, Fred V. Fowler Co. Inc., Newton, MA). Tree survival was recorded one year after transplant. Relative growth rate was calculated as described by Hoffmann and Poorter (2002) for height and trunk diameter.

Statistical Design

The experiment was a randomized complete block design with four irrigation treatments × three transplant depths × ten blocks containing single plant replications per treatment combination. Effects of irrigation and transplant depth on survival, tree height, and trunk diameter were analyzed using the ANOVA procedure in the JMP system for Windows, Release 7.0.2 (SAS Institute Inc.) with dead trees treated as missing data points.

RESULTS

Experiment 1. Effect of Planting Depth and Transplant Season on Landscape Establishment of Baldcypress

Planting depth and year that trees were measured significantly ($P \leq 0.001$) affected relative growth rate in height (RGR_{height}) and diameter ($RGR_{diameter}$) (Table 1). There was a significant ($P = 0.005$, $P \leq 0.001$) year × depth interaction for RGR_{height} and $RGR_{diameter}$, respectively. Planting season did not significantly ($P = 0.363$, $P = 0.365$) affect RGR_{height} or $RGR_{diameter}$, respectively. Survival was 100% across treatments (data not shown).

The RGR_{height} was greater in the first year's growing season (March to November 2006) than the second year's growing season (March to November 2007) regardless of transplant season (Figure 2a). On average during the first year's growing season, planting trees with root collars at grade or 7.6 cm below grade increased (23% or 32%, respectively) RGR_{height} when compared to planting trees with root collars 7.6 cm above soil grade. No significant difference was detected in RGR_{height} during the second year's growing season.

The $RGR_{diameter}$ was greater in the first year's growing season (March to November 2006) than the second year's growing season (March to November 2007) regardless of transplant season (Figure 2b). On average planting trees with root collars at grade or 7.6 cm below grade increased $RGR_{diameter}$ (24% or 32%, respectively) when compared to planting trees with root collars 7.6 cm above soil grade during the first year's growing season. No significant difference was detected in $RGR_{diameter}$ during the second year's growing season.

Main effects of planting depth and transplant season were not significant ($P = 0.081$, $P = 0.468$, respectively), for final tree height, and there was no significant planting depth × transplant season interaction ($P = 0.213$, data not shown). Planting depth significantly ($P \leq 0.001$) affected final trunk diameter, but transplant season did not significantly ($P = 0.461$) affect trunk diameter and there was no significant ($P = 0.827$) planting depth × transplant season interaction (data not shown). Trees planted with root collars below grade or at grade had a greater final trunk diameter (53.5±1.3 mm or 51.7±1.9 mm), respectively when compared to planting trees with root collars above grade (41.5±1.8 mm).

Table 1. Significance of relative growth rate for height and trunk diameter (RGR_{height} and $RGR_{diameter}$) of baldcypress (*Taxodium distichum* (L.) Rich.) using the analysis of variance (ANOVA) method.

Fixed effects test	RGR_{height} [z]	$RGR_{diameter}$ [y]
Depth[x]	<0.001[w]	<0.001
Transplant season (TS)[v]	0.363	0.365
Depth × TS	0.882	0.361
Year[u]	<0.001	<0.001
Year × Depth	0.005	<0.001
Year × TS	0.454	0.340
Year × Depth × TS	0.288	0.213

[z] Relative growth rate (RGR) calculated according to Hoffman and Poorter (2002). Height measured from soil line to apex of tree.
[y] Trunk diameter measured 15 cm above soil line.
[x] Root balls planted 7.6 cm above soil grade (Above), at grade (Grade), or 7.6 cm below grade (Below).
[w] P-values.
[v] Trees were either transplanted in the autumn 2005 or the spring 2006.
[u] Year represents growth of trees from March to November 2006 and March to November 2007.

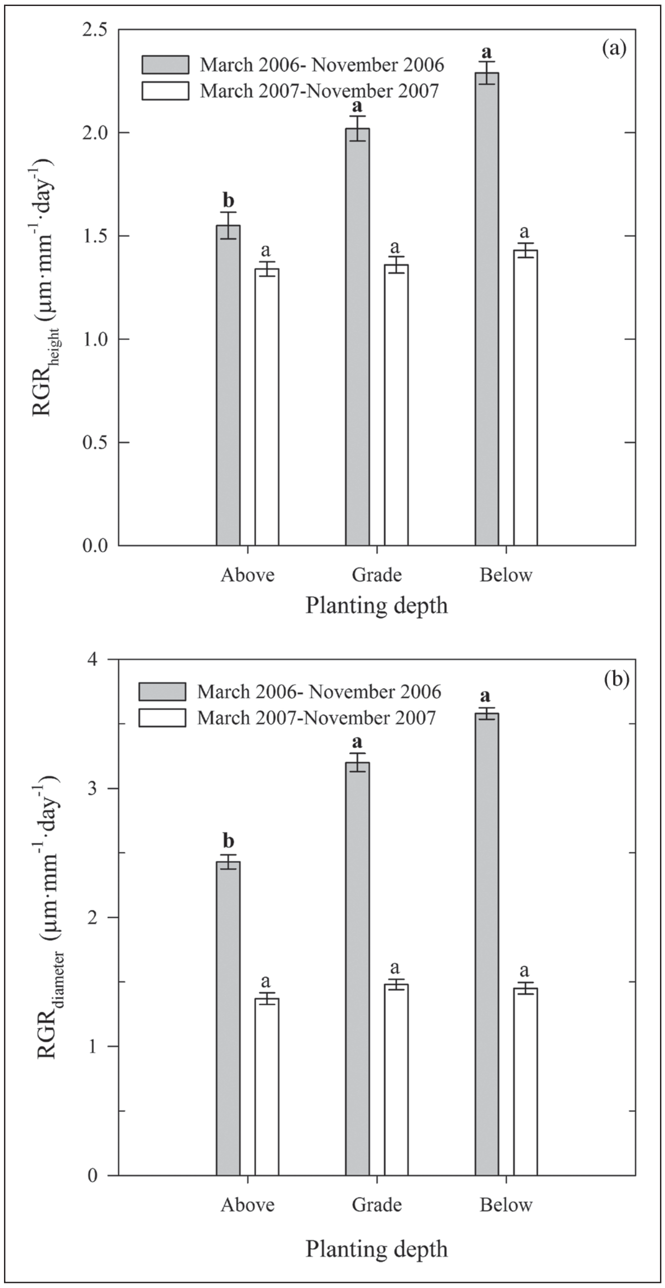

Figure 2. Interactions among planting depths and year on relative growth rate for (a) height (RGR_{height}), and (b) trunk diameter ($RGR_{diameter}$) of baldcypress [*Taxodium distichum* (L.) Rich.] across transplant seasons. Root balls planted 7.6 cm above soil grade (Above), at grade (Grade), or 7.6 cm below grade (Below). Relative growth rate (RGR) calculated according to Hoffmann and Poorter (2002). Height measured from soil line to apex of tree. Trunk diameter measured 15 cm above soil line. Means ± standard error (n = 10). Planting depth within the same year with the same letters are not significantly different according to Least Squares Means Student's t-test, $\alpha = 0.05$.

Experiment 2. Effect of Planting Depth and Irrigation on Landscape Establishment of Sycamore

Tree survival was significantly ($P \leq 0.001$) affected by planting depth, but not irrigation treatment ($P = 0.965$, data not shown). There was no significant planting depth × irrigation treatment interaction ($P = 0.997$). Planting the root collar 7.6 cm below soil grade resulted in reduced survival (47%), compared to planting at grade (100% survival) or planting 7.6 cm above grade (100% survival).

Planting depth and year of measurement had a significant ($P \leq 0.001$) effect on relative growth rate for height (RGR_{height}) and diameter ($RGR_{diameter}$) of surviving trees (Table 2). There was a significant ($P \leq 0.001$) planting depth × year interaction for both height and diameter relative growth rates. Irrigation treatments did not significantly affect RGR_{height} or $RGR_{diameter}$.

Averaged across planting depth and irrigation treatment, RGR_{height} was greater from March 2006 to September 2006 than from March 2007 to September 2007 (Figure 3a). On average across years, planting trees with root collars 7.6 cm below soil grade reduced RGR_{height} (46% or 33%) when compared to planting trees with root collars at grade or 7.6 cm above grade, respectively.

Averaged across planting depth and irrigation treatment, $RGR_{diameter}$ was greater from March 2006 to September 2006 than from March 2007 to September 2007 (Figure 3b). On average across years, planting trees with root collars 7.6 cm below soil grade reduced $RGR_{diameter}$ (49% or 41%) when compared to planting trees with root collars at grade or 7.6 cm above grade, respectively.

Final tree height was not significantly affected by planting depth ($P = 0.072$) or irrigation ($P = 0.895$), and there was no significant ($P = 0.654$) planting depth × irrigation interaction (data not shown). Final trunk diameter was significantly ($P = 0.003$) affected by planting depth, but not by irrigation treatment ($P = 0.348$), and there was no significant ($P = 0.725$) interaction between planting depth and irrigation for final trunk diameter. Across irrigation treatments, planting trees with root collars at grade significantly increased final trunk diameters (72.1±1.9 mm) when compared to planting trees with root collars above grade (65.3±1.4 mm) or below grade (62.3±3.2 mm).

Table 2. Significance of relative growth rate for height and trunk diameter (RGR_{height} and $RGR_{diameter}$) of sycamore (*Platanus occidentalis* L.) using the analysis of variance (ANOVA) method.

Fixed effects test	RGR_{height} [z]	$RGR_{diameter}$ [y]
Depth[x]	<0.001[w]	<0.001
Irrigation[v]	0.953	0.996
Depth × Irrigation	0.945	0.941
Year[u]	<0.001	<0.001
Year × Depth	<0.001	<0.001
Year × Irrigation	0.970	0.700
Year × Depth × Irrigation	0.380	0.907

[z] Relative growth rate (RGR) calculated according to Hoffmann and Poorter (2002). Height measured from soil line to apex of tree.
[y] Trunk diameter measured 15 cm above soil line.
[x] Root balls planted 7.6 cm above soil grade (Above), at grade (Grade), or 7.6 cm below grade (Below).
[w] Significance according to ANOVA. P-values presented.
[v] Trees were pulse irrigated with spray stakes (0, 1, 2, or 4 spray stakes per tree delivering 0.42 $L \cdot min^{-1}$ per stake for 10 minutes when soil water potential reached approximately -15 kPa).
[u] Year represents growth of trees from March to September 2006 and from March to September 2007.

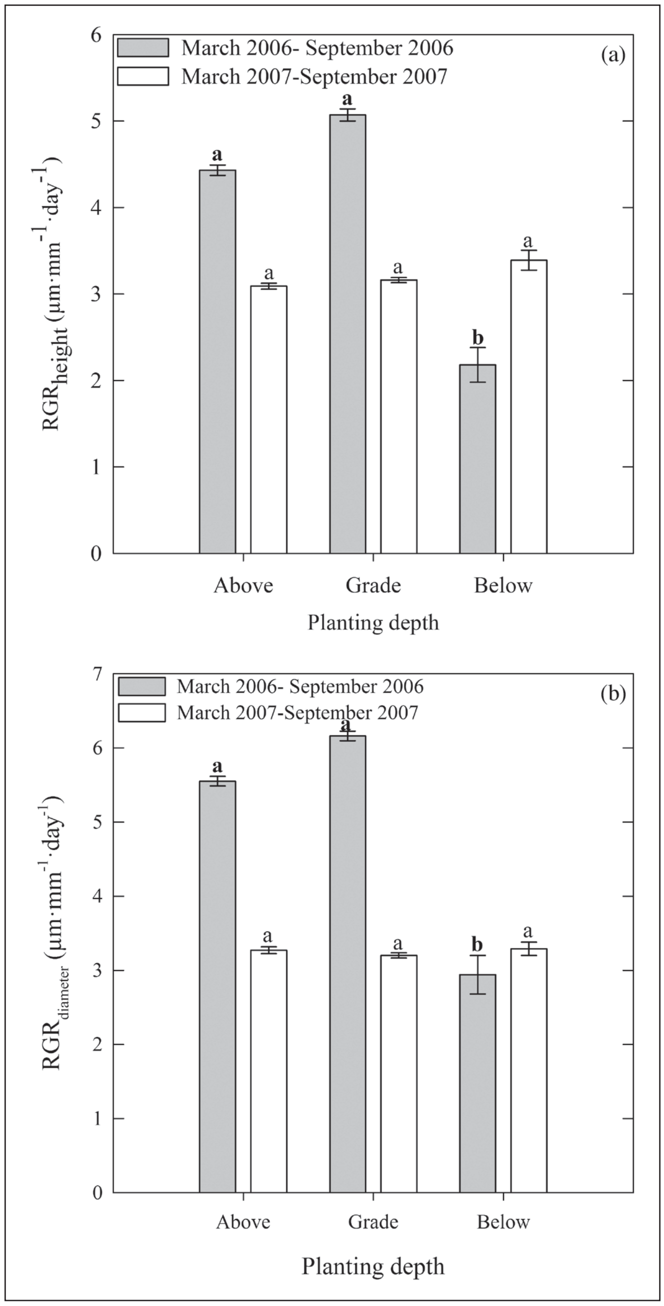

Figure 3. Effect of planting depth and year on relative growth rate for (a) tree height (RGR_{height}), and (b) trunk diameter ($RGR_{diameter}$) of surviving sycamore (*Platanus occidentalis* L.). Data were averaged across irrigation treatments. Root collars were planted 7.6 cm above soil grade (Above), at grade (Grade), or 7.6 cm below grade (Below). Relative Growth Rate (RGR) calculated according to Hoffmann and Poorter (2002). Height measured from soil line to apex of tree. Trunk diameter measured 15 cm above soil line. Means ± standard error (n = 10, excluding dead trees). Levels with the same letter within the same year are not significantly different according to least squares means student's t-test, $\alpha = 0.05$.

DISCUSSION

Planting depth significantly affected RGR_{height} and $RGR_{diameter}$ in baldcypress and sycamore, and survival in sycamore. Baldcypress performed better when planted with their root collars at grade or below grade. Planting sycamore root collars below grade resulted in increased mortality and also reduced height and trunk diameter when compared to planting root collars at grade or 7.6 cm above grade. Arnold et al. (2007) reported that planting with the root collar 7.6 cm below grade adversely affected the growth of crapemyrtle (*Lagerstroemia indica* L. × *Lagerstroemia fauriei* Koehne. 'Basham's Party Pink'), green ash (*Fraxinus pennsylvanica* Marsh.), oleander (*Nerium oleander* L. 'Cranberry Cooler'), sycamore (*P. occidentalis*), and vitex (*Vitex agnus-castus* L. 'LeCompte'), although the severity varied depending on species. Planting above grade was beneficial for sycamore when compared to planting at or below soil surface grade (Arnold et al. 2007). Arnold et al. (2007) reported that various ornamental trees planted at grade or above grade outperformed trees planted below grade, however in this study baldcypress performed better when planted with their root collars at grade or below grade. Baldcypress is reported to be tolerant to low oxygen/anaerobic soil conditions (Kozlowski and Davies 1975) and may also form adventitious roots in response to continuously saturated soils (Davidson et al. 2006). This may explain why baldcypress was not negatively affected by planting the root collars below grade. Planting baldcypress with root collars above grade in the present study was detrimental to overall growth, perhaps due to a wicking effect on the exposed portion of the root ball which may have decreased root ball moisture content.

Wells et al. (2006) suggested that when Yoshino cherry (*Prunus* × *yedoensis* Matsum.) trees were planted with their root collars below grade they may have experienced reduced water infiltration or insufficient access to shallow mineral nutrient pools, causing nutrient deficiencies and increasing tree mortality. Arnold et al. (2005) suggested that in denser soil, planting the root collar deep may result in poor growth, possibly as a result of decreased soil moisture and/or oxygen. Planting deeply in heavy soils can cause the roots to experience prolonged flooding conditions after a period of heavy rainfall, resulting in hypoxic conditions. During drought periods, tree roots planted deeply in heavy soils may have a reduced ability to extract water as stronger adhesive forces of smaller pore spaces decrease the soil water potential, thus reducing the amount of plant available water compared to less heavy soils. Kozlowski and Pallardy (1997) reported that stomata in sycamore readily close under anoxic soil conditions resulting in reduced respiration and growth. However, Tang and Kozlowski (1982) and Tsukahara and Kozlowski (1985) observed the formation of swollen lenticels on stems of sycamore seedlings in response to anoxic conditions, which may enhance absorption and translocation of oxygen to the roots. Thus, sycamore trees may be able to adapt to periodically flooded soils. Arnold et al. (2007) reported that planting sycamore with root collars 7.6 cm below grade resulted in 50% mortality when planted in a fine sandy loam underlain at a depth of 15 to 30 cm by a hard clay pan. In the present study, planting young sycamore trees with their root collars below grade may have caused the roots to suffer periods of hypoxic conditions interspersed with periods of drought while the root system was not developed yet, resulting in 53% mortality within 12 months, even in the well-drained sandy loam at this study site.

Transplanting season did not affect baldcypress RGR_{height} or $RGR_{diameter}$. The study authors suggest this may have been a result of an unusually wet spring/summer in 2006 (24 mm above the 30 year average from March to September, Office of the Texas State Climatologist), and that winters are fairly mild in the southern United States. Richardson-Calfee et al. (2007) reported that with proper maintenance of soil moisture, autumn and spring transplanting resulted in similar root regeneration as summer planting/transplanting of sugar maple (*Acer saccharum* Marsh.) (Virginia site). In addition, Harris et al. (2001) reported that, with proper irrigation, autumn or spring planting/transplanting resulted in similar growth (height and diameter) and rate of root length accumulation in Turkish hazelnut (*Corylus colurna* L.) (Virginia site). In contrast, Shoemake and Arnold (1997) reported that autumn transplanting resulted in better growth and survival of sycamore than spring transplanting, which in turn was better than summer transplanting (Central Texas site). Low survival of autumn-transplanted seedlings was related to a low physiological potential for root regeneration at that time of year (Larson 1984, Ohio site) and the inability of new transplants to grow roots in cold soils (Jenkinson 1980, Western Sierra Nevada site). However, these varied and contrasting results may depend on plant species/ecotype and/or geographic factors, including climate.

In this study, sycamore growth was not significantly affected by irrigation treatment. This could be due to wetter than normal conditions during the growing season (2006), as temperature did not deviate much from the normal averages. Average RGR_{height} and $RGR_{diameter}$ were greater for the 2006 growing season than for the 2007 growing season. It is unlikely that excessive temperatures would explain the difference in growth between years. Temperature-wise, the 2006 and 2007 growing seasons (March to September) were not unusual, and were on average only 0.8°C (1.5°F) and 0.06°C (0.7°F), respectively, warmer than average (Office of the Texas State Climatologist, Department of Atmospheric Sciences, Texas A&M University, College Station, TX). The trees experienced wetter than normal conditions during June (2007) and July (2006, 2007), when drought conditions would normally be likely to occur. Total precipitation during the growing season (March–September) was 24 mm above average in 2006, and 77 mm above average in 2007 (Office of the Texas State Climatologist, Department of Atmospheric Sciences, Texas A&M University, College Station, TX). From May to mid July 2006, there were large rainfall events followed by prolonged drought, while in 2007, individual rainfall events were smaller, but distributed evenly during the summer season (Figure 1). It is possible that excessive amounts of water during the growing season in 2007 periodically reduced oxygen availability to the roots and produced hypoxic conditions that slowed down plant growth, but it did not stop plant growth altogether. Alternatively, trees could have been established by the second year, or in a growth lag phase. Given the general lack of an irrigation effect in this study, the growth responses of sycamore to planting depth during the first year were likely due to factors other than soil moisture.

CONCLUSION

Relative growth rate of height and trunk diameter of baldcypress was significantly affected by planting depth, but not by transplant season. Planting trees with root collars at soil grade or slightly below soil grade (7.6 cm) in a sandy loam soil produced taller trees with greater stem diameters than planting root collars slightly above soil grade (7.6 cm). The difference between the findings published here and other literature may be a result of differing propagation methods, nursery production, and/or species variation. Currently the study authors are unable to definitively explain the variability in planting depth response for different tree species. Trees propagated vegetatively may respond differently than trees grown from seed due to inherent physiological differences. In addition, how trees are produced/transplanted (e.g., container production versus ball and burlap versus bare root), may also influence the final response to planting depth (Watson and Himelick 2005; Day et al. 2009). Furthermore, plant species and cultivars within species can differ markedly in their response to environmental/cultural stresses. Each tree species originating from a specific environment may represent an ecotype adapted to that particular environment (Fitter and May 2002). Therefore, tree survival and performance may depend on the difference between the environment from which the tree was obtained and the experimental system/landscape site into which it was introduced. Baldcypress is naturally found on sites that frequently flood and thus may be less affected by hypoxia or anoxia than other species, perhaps explaining its tolerance to belowgrade planting on this sandy soil.

Sycamore survival and growth was significantly affected by planting depth, but not by irrigation treatment. Planting the root collars 7.6 cm below grade resulted in 53% tree mortality by the end of the first year, while all trees planted with root collars at grade or 7.6 cm above grade survived. Planting the trees with root collars at grade or above grade in a sandy loam soil produced taller trees with larger trunk diameters compared to trees planted below grade. A lack of interaction for growth and survival among planting depths and irrigation levels suggests that planting depth responses in sycamore were due to factors other than soil moisture.

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Résumé. Les pratiques de transplantation exercent une influence sur la survie de la plante, son développement et sur sa valeur paysagère subséquente. L'impossibilité de quantifier adéquatement les effets des pratiques de transplantation affecte le maintien à long terme des arbres ornementaux. La profondeur de plantation, c'est-à-dire la localisation du collet racinaire par rapport au niveau du sol (surface du sol), a un effet particulier sur la croissance de l'arbre, son développement et sa performance paysagère. Nous avons examiné l'effet de la profondeur de plantation ainsi que de la saison de transplantation sur la reprise de cyprès chauves (*Taxodium distichum* (L.) Rich.) ornementaux et aussi ceux de la profondeur de plantation et des pratiques d'irrigation sur la reprise de platanes occidentaux (*Platanus occidentalis* L.). Les cyprès chauves plantés au-dessus du sol avaient un taux de croissance relativement plus faible, tant en hauteur qu'en diamètre, comparativement à ceux plantés au même niveau ou sous le niveau du sol environnant durant la première saison de croissance, peu importe la saison de transplantation. Les platanes occidentaux plantés sous le niveau du sol avaient un taux de mortalité accru et une croissance plus réduite comparativement aux arbres plantés au même niveau ou au-dessus du niveau du sol, et ce peu importe le régime d'irrigation. Même si les arbres des deux espèces poussaient dans des conditions similaires de croissance, le cyprès chauve était plus tolérant à la plantation sous le niveau du sol que le platane occidental. Nous croyons que cela est relié à l'habitat naturel propre à chacune de ces espèces car le cyprès chauve est fréquemment exposé à des conditions hypoxiques tandis que le platane occidental est plus présent dans les sols bien drainés. De ce fait, il peut être important de prendre en considération l'habitat naturel d'une espèce lorsqu'on évalue les effets de la profondeur de plantation.

Zusammenfassung. Der Vorgang des Baumverpflanzens beeinflusst das Überleben der Pflanzen, das Anwachsen und subsequent auch den landschaftsgestalterischen Wert. Die Unfähigkeit, die Auswirkungen der Verpflanzungstechnik adäquat zu quantifizieren, beeinflusst langfristig die Nachhaltigkeit von Landschaftsbäumen. Die Pflanztiefe (im besonderen die Position des Wurzelkragens in Beziehung zur Bodenoberfläche) ist von besonderer Bedeutung für das Wachstum, die Entwicklung und die Performance des Baumes. Die Autoren dieser Studie untersuchten die Einflüsse der Pflanztiefe und des Pflanzzeitpunkts bei der Pflanzung von Sumpfzypressen und die Effekte der Pflanztiefe und Bewässerungsregime bei der Pflanzung von Platanen. Die Sumpfzypressen, die gerade oberhalb der Bodenlinie gepflanzt wurden, hatten in der ersten Wachstumsphase, unabhängig vom Pflanzzeitpunkt, reduzierte, relative Wachstumsraten in der Höhe und dem Stammdurchmesser, verglichen mit den Pflanzen, die mit dem Wurzelkragen auf der Bodenlinie oder darunter gepflanzt wurden. Die Platanen, die unterhalb der Linie gepflanzt wurden, hatten, verglichen mit den anderen Pflanzarten, eine größere Sterblichkeit und geringeres Wachstum, unabhängig von der Bewässerungstechnik. Obwohl beide Baumarten unter vergleichbaren Bedingungen gepflanzt wurden, war die Sumpfzypresse viel toleranter als die Platane gegenüber einer tieferen Pflanzung. Wir vermuten, daß das in Beziehung zu dem natürlichen Vorkommen der beiden Arten zu sehen ist, wo die Sumpfzypresse an ihrem Standort gelegentlich auch sauerstoffarmen Bedingungen ausgesetzt ist, während die Platane mehr auf gut drainierten Böden gedeiht. Daher könnte es wichtig sein, bei der Bewertung des Einflusses der Pflanztiefe, auch das natürliche Habitat der Art zu berücksichtigen.

Resumen. Las prácticas de trasplante de árboles influyen en la supervivencia de las plantas, el establecimiento y el subsecuente valor del paisaje. La incapacidad de cuantificar adecuadamente los efectos de las prácticas de trasplante pone en riesgo la sustentabilidad a largo plazo de los árboles. La profundidad de plantación [por ej. Ubicación de la corona de raíces relativa al nivel del suelo (superficie del suelo)] es de particular preocupación para el crecimiento del árbol, desarrollo y función en el paisaje. Los autores de este estudio investigaron los efectos de la profundidad de plantación y estación de trasplante en el establecimiento de ahuehuetes [*Taxodium distichum* (L.) Rich.] y los efectos de la profundidad de plantación y prácticas de riego en el establecimiento del sicomoro (*Platanus occidentalis* L.). El ahuehuete plantado arriba del nivel del suelo redujo relativamente las tasas de crecimiento en altura y diámetro comparado a los plantados en o abajo el nivel durante la primera estación de crecimiento, sin importar la estación de trasplante. Los árboles de sicomoro plantados debajo del nivel tuvieron aumento de la mortalidad y disminución del crecimiento, comparado con los plantados a nivel o abajo del mismo, sin importar el tratamiento de riego. Aunque los árboles de las dos especies crecieron bajo condiciones similares, el ahuehuete fue mucho más tolerante a plantación abajo del nivel que el sicomoro. Se sugiere que esto está relacionado al hábitat nativo relativo de ambas especies, donde el ahuehuete está frecuentemente expuesto a condiciones hipóxicas mientras que el sicomoro lo es a suelos bien drenados. Por tanto, puede ser importante considerar el hábitat nativo de una especie cuanto se evalúe el efecto de la profundidad de plantación.