Arboriculture & Urban Forestry 2011. 37(5): 247–253

The Effects of Planting Depth on Windthrow, Stability, and Growth for Four Tree Species in Containers

Chad P. Giblin, Jeffrey H. Gillman, Gary R. Johnson, David Hanson, and Patrick J. Weicherding

Abstract. Establishing the effects of planting depth on tree stability and growth is critical in understanding the role nursery production plays in planting depth issues at the landscape level. In this study, bare root Whitespire birch (*Betula platyphylla* var. *japonica* 'Whitespire'), green ash (*Fraxinus pennsylvanica*), Snowdrift crabapple (*Malus* × 'Snowdrift'), and bicolor oak (*Quercus bicolor*) were grown for 17 weeks in a container production setting with four levels of substrate over the first main-order root: 0, 5, 10, and 15 cm. Birch demonstrated the greatest instability of all species, leaning significantly more when planted at 0 cm than at 15 cm. In ash and crabapple, there were no significant differences in either the number of trees leaning or the amount of lean in all treatments throughout the study. Oak stems bent excessively, invalidating lean measurements. Stem caliper increase was significantly greater in ash planted 0 and 5 cm deep than 10 and 15 cm deep. There was no significant difference in stem caliper increase between planting depths in other species. Birch planted 0 and 5 cm deep had greater root volume increase than those planted 10 and 15 cm deep. Root volume increase in ash, crabapple, and oak did not differ significantly between treatments. Infrequent windthrow events were observed, but appeared random and apparently unrelated to planting depth. The perceived benefit of planting trees deep in containers to improve stability was observed in only one species (birch) at one depth (15 cm) and was at the expense of significantly reduced root volume increase.

Key Words. *Betula platyphylla* var. *japonica* 'Whitespire'; *Fraxinus pennsylvanica*; *Malus* × 'Snowdrift'; *Quercus bicolor*; Stem-encircling Root; Stem-girdling Root.

Container production of nursery stock is increasing in the United States. It is currently the dominant nursery production system, comprising about 50% of total nursery sales (USDA 2007). While offering production and merchandising advantages to the nursery grower, producing trees in containers has many challenges, including planting depth issues, plant stability, root deformities, root circling, stem-encircling roots (SERs), and stem-girdling roots (SGRs) (Harrington et al. 1989; Watson et al. 1990; Appleton 1993; Appleton 1995; Johnson and Hauer 2000).

Several studies have examined tree stability and SGRs in field and landscape settings. Much of the early work focused on investigations into poorly anchored or windthrown fruit trees. Lyons and Yoder (1981) found that deeply planted peach trees were generally smaller and more prone to instability and failure in wind loading events, even three to five years after planting, than trees with a first main-order root nearer the soil surface. They cautioned that the root system – not the graft union – should determine planting depth of nursery stock. Subsequent work (Lyons et al. 1982; Lyons et al. 1983; Arnold et al. 2005; Arnold et al. 2007) examined the effects of burying the first main-order root too deep on overall tree performance. This work showed, in many cases, how growth rate, stability, winter hardiness, and general vigor were improved if trees were planted with the first main-order root within 5 cm of the soil surface. Furthermore, Wells et al. (2006) reported a 50% mortality rate in deeply planted Yoshino cherry trees while all the control trees (planted at grade) survived.

Stability of newly planted or juvenile trees seems to be the driving force that compels growers to plant trees deeply (Arnold et al. 2005). Staking trees has been shown to have negative effects on tree growth rate and stem taper (Eckstein and Gilman 2008), so alternative stabilizing methods are desirable. Consequently, it is not surprising that improved stability and reduced windthrow (without mechanical support) is a common rationale for planting trees deeply (Lyons et al. 1983; Arnold et al. 2007). However, not all researchers have had deep planting result in the positive effects desired by producers. Lyons et al. (1987) found that the influence of deep planting had exactly the opposite effect. Apple trees with first main-order roots planted at shallower depths (approximately 5 cm) did not lean significantly more than those planted deeper (approximately 15 to 25 cm). Their research concluded that fruit growers would receive no benefit in tree stability by planting deeply. Lyons et al. (1987) recommended that producers of fruit tree nursery stock, when propagating, should place buds no more than 15.2 cm above the first main-order root, thus reducing temptation for the end-user to plant deeply.

Soil oxygen levels may play a role in the development of SERs and SGRs. Partyka (1982) suggests that decreased soil oxygen concentration, especially when associated with poor or disturbed soils in urban areas, can result in root death and tree decline. Wells et al. (2006) speculated that roots growing vertically in deeply planted red maples may grow close to buried stems because of increased oxygen levels found there, creating growth patterns that favor SERs and SGRs. Santoso (1987) also reports that mycorrhizal development was significantly reduced with increasing planting depth, further reducing chances of successful tree establishment and long-term survival.

However, some research has shown that planting trees deep is beneficial. During wind loading events, Parry (1974) found that apple trees planted with 15.24 cm of soil over the first main-order root were more stable than trees planted at the same depth as the production nursery. In traditional forestry applications, Stroempl (1990) found that deeply planting some pines and spruce protected tender stems from heat-induced mortality.

Currently, there are specific ANSI specifications (U.S.) for planting depth in field-grown nursery stock, including balled-and-burlapped (B&B) stock, in the current *American Standard for Nursery Stock* (ANLA 2004), "[d]epth of the ball is measured from the top of the ball, which in all cases shall begin at the root flare... Soil above the root flare...shall not be included in ball depth measurement, and should be removed."

In contrast to the large volume of research examining planting depth in nursery field production and landscape settings, little research has examined the effects of planting depth in nursery-grown container stock. Recently, Bryan et al. (2010) studied the effects of planting depth on growth in container-grown *Ulmus parvifolia*. They observed significant growth benefits when planting roots at grade or above grade in the first stage of container production. Gilman and Harchick (2008) examined the effects of deep planting in container-grown Cathedral Oak® (*Quercus virginiana*), noting that both extremely shallow and deep planting of rooted cuttings in containers can have adverse growth effects in this species. Fare (2005) also examined the effects of four different planting depths on five common containerized landscape trees, finding that planting depth had no significant effect on growth in four of the five species tested.

With regard to nursery container stock, the ANLA standard (U.S.) simply states, "[a]ll container grown nursery stock shall be healthy, vigorous, well rooted, and established in the container in which it is growing. Container grown nursery stock shall have a well-established root system reaching the sides of the container to maintain a firm ball when the container is removed, but shall not have excessive root growth encircling the inside of the container." There is no mention of planting depth in this standard.

A study was initiated in 2002 to examine the effects of planting depth in containerized nursery production on four tree species containerized at various depths in containers as they related to tree growth, lean, and windthrow.

MATERIALS AND METHODS

Four trees species were selected for use in this study: Whitespire birch (*Betula platyphylla* var. *japonica* 'Whitespire'), green ash (*Fraxinus pennsylvanica*), Snowdrift crabapple (*Malus* × 'Snowdrift'), and bicolor oak (*Quercus bicolor*). All trees were harvested as field-grown, bare root nursery stock. The birch and oak were 2 to 3 cm in stem caliper, 1.8 m in height, and were graded as "branched" by nursery production standards. Crabapples were also 2 to 3 cm in stem caliper but were 1.5 m in height and were graded as "heavy-branched." Ash varied from 1.5 to 2.5 cm in stem caliper, were 2.1 m in height, and were graded as "unbranched whips."

From June 6 to June 8, 2002, trees were root pruned to fit into Grip Lip GL4000 containers (#10 trade size: top diameter 36.2 cm, height 36.2 cm, bottom diameter 33 cm, volume 34L) and to remove any turned or broken roots (as per standard practice for finishing nursery stock) in containers at Bailey Nurseries (Hastings, Minnesota, U.S.). After root pruning, root volume was measured by water displacement (Young and Werner 1984), and stem caliper was measured 15 cm above the first main-order root attachment for each tree. Each species was then subjected to four different planting depth treatments, with 0, 5, 10, or 15 cm of additional substrate placed over the first main-order root. The container substrate consisted of sphagnum peat (40% by volume), pine bark (30% by volume), compost (20% by volume), sand (10% by volume), and also incorporated (2.9 kg/m^3) slow-release fertilizer (Polyon 19-4-8, Harrell's LLC, Lakeland, Florida, U.S.).

The research plot was located at a Bailey Nurseries pot-in-pot production facility. The experimental design was a completely randomized block design with three subsamples of each species and depth combination randomly placed in five different blocks. Weekly data included frequency of windthrow and the frequency and extent of lean. A windthrow event was defined as an event that resulted in more than 50% of the plant's roots being tipped out of the container substrate. Lean was recorded as centimeters off plumb, measured using a plumb bob held at the stem 30.5 cm above a meter stick placed on top of the container. During the first four weeks of the study, all trees were straightened after the lean data were recorded. From weeks 5 to 17, the extent of lean was recorded, but trees were not straightened, as per standard practice at Bailey Nurseries (Timothy Bailey, pers. comm.). Trees were watered using automatic micro-irrigation via individual spray stakes in each container. In general, standard nursery practices were followed except that trees were not staked to correct or prevent lean and/or windthrow. Air temperature, wind speed, and wind direction were measured using a WatchDog Model 525 weather station and data logger (Spectrum Technologies, Inc., Plainfield, Illinois, U.S.).

On October 4, 2002, final stem caliper and shoot new growth measurements (using three randomly selected branches) were made on each tree, and the study was terminated. Root systems were then cleaned of container substrate using compressed air and water. This technique was tested on several trees to ensure that roots were not lost in the cleaning process. After cleaning, final root volumes were measured using water displacement as previously described.

Descriptive statistics and univariate Analysis of Variance for stem caliper increase, root volume increase, and shoot new growth between treatments were determined using the general linear model and Tukey's HSD post hoc ($P < 0.05$) functions of SPSS 16.0. The effects of time after planting and planting depth on lean frequency and average lean were examined using repeated measures analysis of variance in the GLM function of PASW (SPSS) 17.0. In cases in which the assumption of sphericity was violated, the Greenhouse-Geisser correction was used to adjust degrees of freedom and calculate a valid F-statistic for repeated measures Analysis of Variance. Post hoc tests were computed using the Bonferroni correction ($P < 0.05$).

RESULTS & DISCUSSION

Windthrow

Windthrow was not a major problem for any of the species or treatments (data not shown). Three oak and one birch tree chronically windthrew. Other windthrow events occurred during the study but were infrequent and random. There was no statistically significant reduction in the occurrence of windthrow when these tree species were planted with their first main-order roots deeper in nursery containers. Reduction of windthrow frequency in nursery container production is more likely a result of staking practices than planting depth.

Lean Frequency

There were no significant ($P < 0.05$) effects of planting depth on lean frequency in any of the three species measured (Table 1). In birch, there was a significant ($P < 0.05$) interaction between planting depth and time after planting, implying that, while the effect of planting depth on lean frequency was not statistically significant, time after planting had varying effects on trees planted at different depths (Figure 1A). In ash and crabapple, there were no significant ($P < 0.05$) interactions between planting depth and time after planting for lean frequency (Figure 1B; Figure 1C). Lean measurements on the bicolor oaks were terminated early in the study due to excessive stem bending, which made accurate and objective measurements impossible.

Average Lean

There were no significant ($P < 0.05$) interactions between depth and time after planting for any of the species measured. The overall effect of depth was significant ($P < 0.05$) in birch, with trees planted at 0 cm leaning significantly more than those planted 15 cm deep (Table 1). At its greatest, the significant difference in lean resulted in a tree that is straighter by 4.7 degrees (Figure 2A). In ash and crabapple, there was no significant ($P < 0.05$) effect of planting depth on average lean (Figure 2B; Figure 2C).

While the total number of trees leaning is important in a production setting, the amount that each tree leans (centimeters off plumb) is also critical in proper management of nursery stock and the production of a marketable product. These results show that planting depth had no significant effect on the number of trees leaning, and that the angle of lean is significantly reduced by planting 15 cm deep only in birch trees.

Tolerance of deep planting in hypoxia-tolerant or floodplain tree species, like some species of birch and ash, has been suggested by Arnold et al. (2005) and Gilman and Harchick (2008); however, the Whitespire birch used in this study is considered to be relatively flood-intolerant, especially when compared to a common floodplain species like green ash. These results in birch are difficult to explain. One possible explanation might be found in the amount of wind resistance of different tree species. Larger trees, and those with a denser canopy, may also offer more wind resistance and thus have more potential for lean in container production. Further research in this area would be very beneficial, as tree stability is usually considered to be a function of root development. Additionally, a survey into perceptions of acceptable lean in containerized nursery stock would quantify the needs and desires of both the grower and consumer of containerized nursery stock.

Growth Rate

Tree caliper differed significantly only in ash, where caliper increase was reduced in deeply planted trees (Figure 3). There were no significant caliper increase differences in birch, crabapple, or oak.

There was no significant difference in root volume increase in ash, crabapple, or oak (Figure 4). In birch treat-

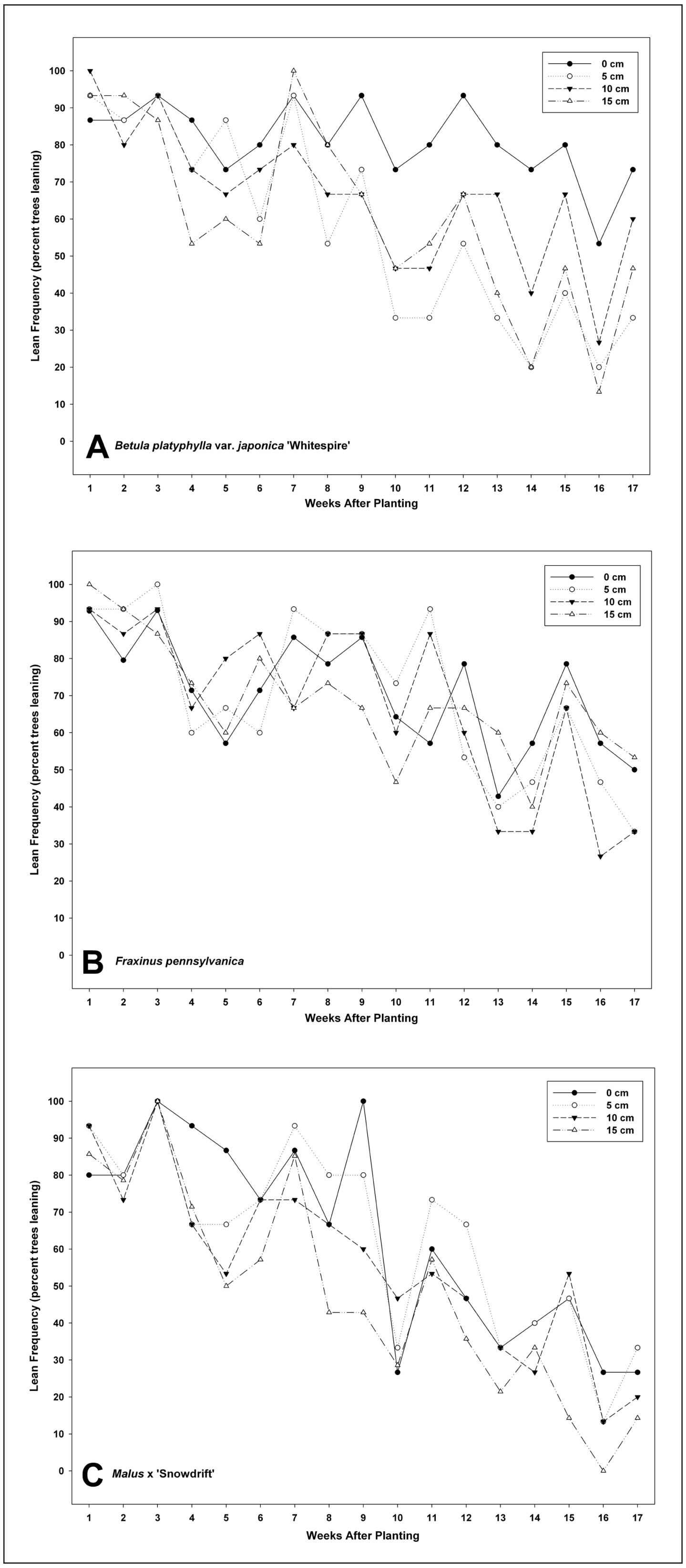

Figure 1. Lean frequency (percent leaning) observed in three tree species: Whitespire birch (*Betula platyphylla* var. *japonica* 'Whitespire'), green ash (*Fraxinus pennsylvanica*), and Snowdrift crabapple (*Malus* × 'Snowdrift'), planted at four depths in nursery containers over the course of 17 weeks (n = 5).

ments, however, trees planted at 0 and 5 cm depths had significantly greater root volume increase than those planted 10 and 15 cm deep. Annual shoot new growth did not differ significantly among any species or treatment (data not shown).

While some research has noted how planting deeper in the field can increase stability and tree survival (Parry 1974; Strohempl 1990), this generally results in decreased stem caliper and root growth (Lyons and Yoder 1981; Lyons et al. 1983; Lyons et al. 1987; Arnold et al. 2005; Arnold et al. 2007). The data generated from this study showed a significant reduction in stem caliper increase in ash when trees were planted with any amount of soil over the first main-order root. Bryan et al. (2010) observed a similar, statistically significant reduction in stem growth (dry mass) in container-grown *Ulmus parvifolia* when root systems were planted 5 cm too deep in 10.8 L nursery containers. In contrast, Gilman and Harchick (2008) found that container-grown Cathedral live oak (*Quercus virginiana* 'SLDN') showed a significant decrease in stem caliper growth at the most shallow planting depth treatment. It is important to note that these works (Bryan et al. 2010; Gilman and Harchick 2008) focused on container-grown nursery stock, whereas the present study was based on finishing field-grown, bare-root stock in a container during a single growing season. The establishment, stability, and growth rate of different trees grown in different production systems may vary greatly.

The significant reduction in root volume increase in birch, with more than 5 cm over the first main-order root, suggests that planting trees deeply in containers may reduce vigor and growth rate of the root system. Furthermore, lower root volume increases may indicate slower establishment and poor anchoring in the container. These trends in data are consistent with data presented from a nine-year study planted at the University of Minnesota (U.S.) examining the effect of deep planting on field-grown nursery stock (Giblin et al. 2005).

The reduction in lean, which was observed in this study in one tree species (birch), does not provide a justification for planting all trees deeply. However, the potential for reduced stem caliper and/or root growth in deeply planted trees, as well as the increased potential for SGRs to develop, does support a shallower planting.

One step to reduce the probability of trees being buried too deeply in the landscape and the associated development of abnormal and/or dysfunctional root systems would be to remove the deeply planted nursery stock from the retail and wholesale market. The only reasonable way to accomplish this involves inclusion of a planting depth component in the ANLA standard for trees produced in containers.

If planting deeply is perceived to reduce or avoid windthrow or lean in the nursery (Arnold et al. 2005) and becomes the common practice, then to follow the example of ANLA standard for preparation of B&B stock, growers of containerized stock would be required to remove all excess soil over the first main-order root in the root ball. Because nursery stock production is dominated by containerized and container-grown stock, the root depth in those finished products must be constructed to be consistent with an existing ANLA standard for field-grown nursery stock.

One of factors currently inhibiting the implementation of planting depth guidelines in production of containerized nursery stock is the ability of nursery growers to identify first main-order roots. In some fields, such as forest ecology, researchers are challenged to define, or even identify, what is commonly called the "root collar" (Gutsell and Johnson 2002). Gutsell and

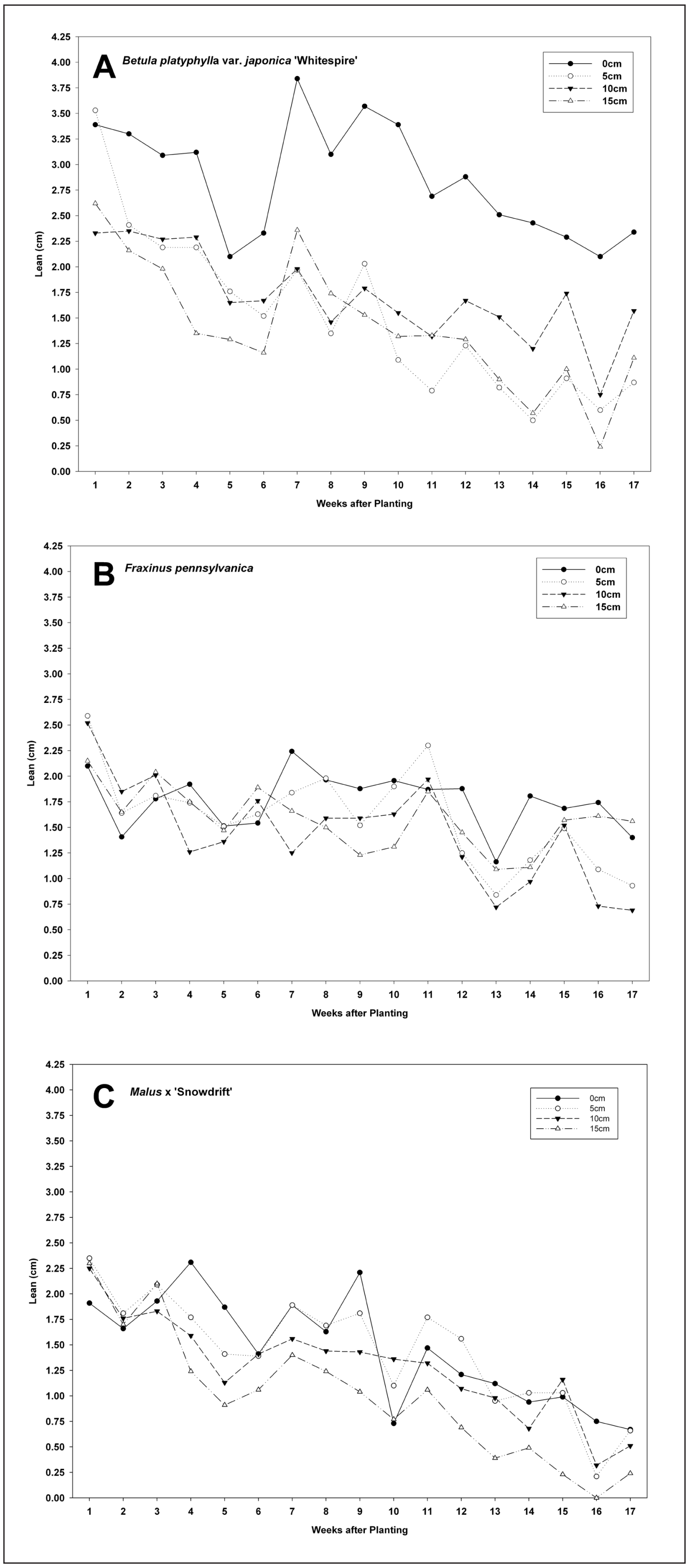

Figure 2. Average lean in centimeters off plumb for three tree species: Whitespire birch (*Betula platyphylla* var. *japonica* 'Whitespire'), green ash (*Fraxinus pennsylvanica*), and Snowdrift crabapple (*Malus* × 'Snowdrift'), planted at four depths in nursery containers over the course of 17 weeks (n = 5).

Table 1. Lean frequency (percent leaning) and average lean (centimeters off plumb) observed in three tree species: Whitespire birch (*Betula platyphylla* var. *japonica* 'Whitespire'), green ash (*Fraxinus pennsylvanica*), and Snowdrift crabapple (*Malus* × 'Snowdrift'), planted at four depths in nursery containers over the course of 17 weeks.

	Betula platyphylla var. *japonica* 'Whitespire'		*Fraxinus pennsylvanica*		*Malus* × 'Snowdrift'	
Planting depth	Lean frequency (%)	Average lean (cm)	Lean frequency (%)	Average lean (cm)	Lean frequency (%)	Average lean (cm)
0 cm	81.2a[zy]	2.8a	69.2a	1.7a	63.1a	1.4a
5 cm	57.6a	1.5ab	70.2a	1.6a	63.1a	1.4a
10 cm	65.9a	1.7ab	67.5a	1.4a	56.1a	1.3a
15 cm	65.1a	1.4b	68.6a	1.6a	46.1a	0.9a

[z] Within species values with the same letter are not significantly different ($P < 0.05$).
[y] Values are a mean of three subsamples and five replicates measured weekly over the course of 17 weeks (n = 5).

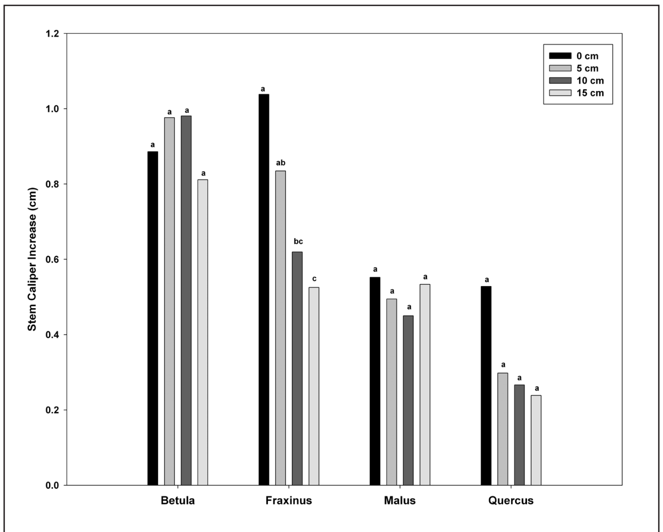

Figure 3. Mean stem caliper increase in centimeters in four tree species planted at four depths in nursery containers. Note: Within species, bars with the same letter are not significantly different at *P* < 0.05.

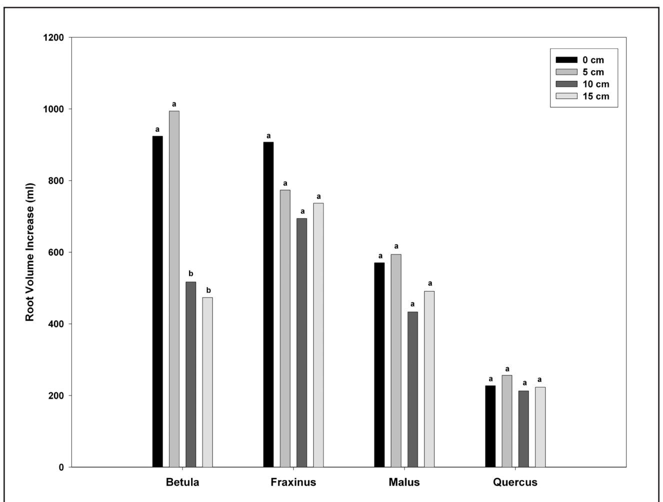

Figure 4. Mean root volume increase measured by water displacement in milliliters in four tree species planted at four depths in nursery containers. Note: Within species, bars with the same letter are not significantly different at *P* < 0.05.

Johnson (2002) and Fahn (1990) both define the root collar as the point at which root tissue transitions to stem tissue. This is, specifically, "the shift in the central pith, from undifferentiated parenchyma cells in the stem, to a vascular cylinder in the root" (Gutsell and Johnson 2002). Precise, laboratory methods of identifying the root collar have been elucidated; however, destruction of the tree is required for positive identification. Further work must continue to better define these structures morphologically, allowing easy and consistent identification outside the lab.

Container size, substrate composition, and the physical characteristics of different tree species may affect windthrow and tree stability in the production of containerized nursery stock. This research, however, focuses on commonly used tree species, container size, and container substrate at Bailey Nurseries, a nationally (U.S.) recognized wholesale production nursery. Additional research examining different tree species grown in different sized containers and with different substrates will add to this growing body of work. This work should further address the issues of tree stability, planting depth, and equitable ANLA nursery stock standards.

Acknowledgments. We would like to thank Bailey Nurseries, Inc., especially Eric Nordlie, Samuel Drahn, and John Fisk for their extensive support of this work. Partial funding for this work was provided by the TREE Fund. We would also like to dedicate this work to the memory of our friend and co-author, Patrick J. Weicherding. His faithful service as a University of Minnesota extension educator and countless hours of hands-on support of our teaching, research, and outreach projects will be greatly missed.

TREE FUND
Tree Research & Education Endowment Fund

LITERATURE CITED

American Nursery & Landscape Association. 2004. American Standard for Nursery Stock ANSI Z60.1-2004. ANLA, Washington, D.C. 113 pp.

Appleton, B.L. 1993. Nursery production alternatives for reduction of elimination of circling tree roots. Journal of Arboriculture 19(6): 383–388.

Appleton, B.L. 1995. New nursery production methods lead to tree root circling reduction or elimination. Arboricultural Journal 19(2): 161–174.

Arnold, M.A, G.V. McDonald, D.L. Bryan, G.C. Denny, W.T. Watson, and L. Lombardini. 2007. Below-grade planting adversely affects survival and growth of tree species from five different families. Arboriculture & Urban Forestry 33(1):64–69.

Arnold, M.A, G.V. McDonald, and D.L. Bryan. 2005. Planting depth and mulch thickness affect establishment of green ash (*Fraxinus pennsylvanica*) and bougainvillea goldenraintree (*Koelreuteria bipinnata*). Journal of Arboriculture 31(4):163–170.

Bryan, D.L., M.A. Arnold, A. Volder, T.W. Watson, L. Lombardini, J.J. Sloan, L.A. Valdez-Aguilar, and A.D. Cartmill. 2010. Planting depth during container production and landscape establishment affects growth of *Ulmus parvifolia*. HortScience 45:54–60.

Eckstein, R., and E.F. Gilman. 2008. Evaluation of landscape tree stabilization systems. Arboriculture & Urban Forestry 34(4):216–221.

Fahn, A. 1990. Plant Anatomy, 4th edition. Butterworth Henemann, Bath, Great Britain. 588 pp.

Fare, D.C. 2005. Should potting depth be a concern with container-grown trees? Proc. Trees and Planting: Getting the Roots Right Conference. Morton Arboretum, Lisle, IL. Nov. 10, 2005.

Giblin, C.P, J.H. Gillman, D.L. Hanson, G.R. Johnson, and P.J. Weicherding. 2005. The effects of soil depth on the long-term health and frequency of storm damage to trees in the Upper Midwest. Proc. Trees and Planting: Getting the Roots Right Conference. Morton Arboretum, Lisle, IL. Nov. 10, 2005:33–39. Retrieved March 18, 2011. <www.mortonarb.org/deeptreeroots/pdf/GRR_Proceedings.pdf>

Gilman, E.F, and C. Harchick. 2008. Planting depth in containers affects root form and tree quality. Journal of Environmental Horticulture 26(3):129–134.

Gutsell, S.L., and E.A. Johnson. 2002. Accurately ageing trees and examining their height-growth rates: implications for interpreting forest dynamics. Journal of Ecology 90:153–166.

Harrington, C.A., J.C. Brissette, and W.C. Carlson. 1989. Root system structure in planted and seeded loblolly and shortleaf pine. Forest Science 35(2):469–480.

Johnson, G.R., and R.J. Hauer. 2000. A practitioner's guide to stem girdling roots of trees: impacts on trees, symptomology, and prevention. University of Minnesota Extension Service, Saint Paul, MN. Retrieved March 18, 2011. <www.extension.umn.edu/distribution/naturalresources/DD7501.html>

Lyons, C.G., Jr., and K.S. Yoder. 1981. Poor anchorage of deeply planted peach trees. HortScience 16(1):48–49.

Lyons, D.G., Jr., K.S. Yoder, and R.E. Byers. 1982. Poor anchorage and growth of spur 'Red Delicious' apple trees with deep crown roots. Scientia Horticulturae 18:45-47.

Lyons, C.G., Jr., R.E. Byers, and K.S. Yoder. 1983. Influence of planting depth on growth and anchorage of young 'Delicious' apple trees. HortScience 18(6):923–924.

Lyons, C.G., Jr., R.E. Byers, and K.S. Yoder. 1987. Influence of planting depth on growth of young apple trees. Journal of Environmental Horticulture 5(4):163–164.

Parry, M.S. 1974. Depth of planting and anchorage of apple trees. Journal of Horticultural Science 49(4):349–354.

Partyka, R.E. 1982. The ways we kill a plant. Journal of Arboriculture 8(3):57–66.

Santoso, E. 1987. Correlation between root length of Dipterocarpaceae with class of mycorrhizal fungus infection on roots of Dipterocarp seedlings in Bukit Suligi protection forest, Riau, Sumatra. Buletin-Penelitian-Hutan - Pusat-Penelitian-dan-Pengembangan-Hutan 488: 18–27.

Stroempl, G. 1990. Deeper planting of seedlings and transplants increases plantation survival. Tree-Planters' Notes 41(4):17–21.

USDA National Agricultural Statistics Services. 2007. Nursery Crops 2006 Summary, September 2007. Sp Cr 6-3 (07). Retrieved November 24, 2009. <http://usda.mannlib.cornell.edu/usda/current/NursProd/NursProd-09-26-2007.pdf>

Watson, G.W., S. Clark, and K. Johnson. 1990. Formation of girdling roots. Journal of Arboriculture 16(8):197–202.

Wells, C., K. Townsend, J. Caldwell, D. Ham, E.T. Smiley, and M. Sherwood. 2006. Effects of planting depth on landscape tree survival and girdling root formation. Arboriculture & Urban Forestry 32(6): 305–311.

Young, E., and D.J. Werner. 1984. A nondestructive method for measuring shoot and root fresh weights. HortScience 19(4):554–555.

Chad P. Giblin (corresponding author)
University of Minnesota
Department of Horticultural Science
St. Paul, MN, U.S.

Jeffrey H. Gillman
University of Minnesota
Department of Horticultural Science
St. Paul, MN, U.S.

Gary R. Johnson
University of Minnesota
Department of Forestry Resources
St. Paul, MN, U.S.

David Hanson
University of Minnesota
Department of Forestry Resources
St. Paul, MN, U.S.

Patrick J. Weicherding
University of Minnesota
Minnesota Extension Service
St. Paul, MN, U.S.

Résumé. Déterminer les effets de la profondeur de plantation sur la stabilité et la croissance des arbres s'avère critique pour comprendre le rôle que la production en pépinière joue sur les conséquences de la profondeur de plantation à l'étape de l'aménagement paysager. Dans cette étude, des bouleaux de Mandchourie Whitespire (*Betula platyphylla* var. *japonica* 'Whitespire'), des frênes de Pennsylvanie (*Fraxinus pennsylvanica*), des pommetiers Snowdrift (*Malus* × 'Snowdrift') et des chênes bicolores (*Quercus bicolor*) à racines nues ont été placés en production dans des pots durant 17 semaines avec quatre niveau de plantation dans le substrat par rapport à la première racine principale: 0, 5, 10 et 15 cm. Le bouleau a démontré la plus grande instabilité parmi toutes les espèces en s'inclinant plus lorsque planté à 0 cm par rapport à ceux plantés à 15 cm. Chez le frêne et le pommetier, il n'y avait pas de différence significative tant au niveau du nombre d'arbres inclinés ou du degré d'inclinaison, et ce parmi les divers traitements tout au long de l'étude. Les tiges de chênes s'inclinaient excessivement, ce qui a invalidé les mesures d'inclinaison. L'augmentation en calibre de tronc du frêne était plus importante à 0 et 5 cm de profondeur qu'à 10 ou 15 cm de profondeur. Il n'y avait pas de différence significative dans l'augmentation en calibre du tronc entre les différentes profondeurs de plantation avec les autres espèces. Les bouleaux plantés à 0 et 5 cm de profondeur avaient un accroissement du volume de racines plus important que ceux plantés à 10 ou 15 cm de profondeur. L'accroissement en volume de racines chez le frêne, le pommetier et le chêne ne différait pas de manière significative entre les divers traitements. Des renversements occasionnels par le vents ont été observés, mais ils apparaissaient être aléatoires et étaient apparemment non reliés à la profondeur de plantation. Le bénéfice perçu de planter les arbres plus profondément dans les pots pour améliorer la stabilité a été observé avec une seule espèce (le bouleau) à une seule profondeur (15 cm) et cela au prix de diminuer significativement l'accroissement en volume du système racinaire.

Zusammenfassung. Ein Verständnisder Auswirkungen der Pflanztiefe auf die Baumstabilität und Wachstum ist ein kritischer Punkt im Verständnis der Rolle der Baumschulproduktion bei der Pflanztiefe in der Landschaft. In dieser Studie wurde Wurzelware von (*Betula platyphylla* var. *japonica* 'Whitespireen'), (*Fraxinus pennsylvanica*), (*Malus* x 'Snowdrift'), und (*Quercus bicolor*) für 17 Wochen in der Containerproduktion in 4 verschiedenen Pflanztiefen gezogen: 0, 5, 10 15 cm Substrat über der obersten Hauptwurzel. Die Birke zeigte die größte Instabilität von allen getesteten Arten und kippte deutlich mehr bei 0 cm als bei 15 cm. Bei der Esche und dem Apfel gab es keine so deutlichen Unterschiede in der Anzahl der gekippten Bäume oder der Neigung innerhalb aller Experimente dieser Studie. Die Eiche beugte sich deutlich zu ungunsten der Neigungsmessung. Die Stammdurchmesserzunahme war bei der Esche bei 0 und 5 cm deutlich größer als bei 10 und 15 cm Tiefe. Es gab keinen signifikanten Unterschied im Zuwachs bei anderen Arten. Die Birke, gepflanzt bei 0 und 5 cm, hatte ein größeres Wurzelvolumen als bei 10 und 15 cm. Der Wurzelvolumen-Zuwachs bei Esche, Apfel und Eiche differierte innerhalb der verschiedenen Versuche nicht. Unregelmässige Winde und Sturmereignisse wurden beobachtet, aber sie tauchen nur am Rande auf und standen in keiner Beziehung zur Pflanztiefe. Der Vorteil von Strassenbaumpflanzung in Containern zur Stabilitätsverbesserung wurde nur in einer Art (Birke) in einer Tiefe (15 cm) beobachtet und stand im Zusammenhang mit deutlich reduziertem Wurzelvolumenzuwachs.

Resumen. Los efectos de la profundidad de plantación en el establecimiento, estabilidad y crecimiento de los árboles son críticos en el entendimiento del papel que la producción de los viveros juega en los temas de profundidad de plantación a nivel del paisaje. En este estudio, abedul Whitespire (*Betula platyphylla* var. *japonica* 'Whitespire'), fresno verde (*Fraxinus pennsylvanica*), manzano Snowdrift (*Malus* x 'Snowdrift') y encino bicolor (*Quercus bicolor*), plantados a raìz desnuda, crecieron por 17 semanas en un contenedor con cuatro niveles de profundidad de sustrato sobre la raíz principal: 0, 5, 10, y 15 cm. Abedul demostró la mayor inestabilidad entre todas las especies, inclinàndose significativamente cuando se plantò a 0 cm que a 15 cm. En fresno y manzano no hubo diferencias significativas entre las especies. Los tallos de encino se inclinaron excesivamente invalidando las mediciones. El incremento del calibre de los tallos fue significativamente mayor en fresnos plantados a 0 y 5 cm que a 10 y 15 cm de profundidad. El volumen de raíces incrementó en fresno, manzano, y en encino no difiriò significativamente entre tratamientos. Fueron observados eventos infrecuentes de vientos, pero fueron esporàdicos y aparentemente no relacionados con la profundidad de plantaciòn. El beneficio percibido de las profundidades de plantaciòn en contenedores para mejorar la estabilidad fue observado en solamente las especies de abedul a una profundidad (15 cm) y fue a costa de un reducido incremento en el volumen de raìces.