# TRANSPLANTING SUCCESS OF BALLED-AND-BURLAPPED VERSUS BARE-ROOT TREES IN THE URBAN LANDSCAPE

**by Michelle J. Buckstrup[1] and Nina L. Bassuk[2]**

**Abstract.** In this study, 40-mm-caliper (1.5-in.) balled-and-burlapped (B&B) and bare-root (BR) hackberry (*Celtis occidentalis*), American hophornbeam (*Ostrya virginiana*), and swamp white oak (*Quercus bicolor*) were paired and planted on sites throughout the city of Ithaca, New York. Half of the trees were planted in fall, half in spring. BR trees received a hydrogel root dip at the nursery to prevent post-harvest root desiccation. Survival rates were excellent for all treatment combinations except spring-planted BR hophornbeam, which experienced 50% mortality. Growth measurements were taken in August of the first and second growing seasons. First-year results showed many significant differences between treatments. By the end of the second growing season, however, very few significant differences in growth responses between treatments persisted. During the first growing season, fall-planted BR hackberry grew better than fall-planted B&B hackberry. Growth on spring-planted hackberry was better on B&B trees. Fall-planted hop-hornbeam responded equally well B&B and BR, but spring-planted hophornbeam grew better B&B. Swamp white oak grew somewhat better B&B than BR, regardless of season. Both B&B and BR swamp white oak planted in fall grew somewhat better than their spring-planted counterparts. A separate study on swamp white oak looked at the impact of withholding irrigation on spring-planted, paired B&B and BR trees. B&B and BR swamp white oak trees performed equally well after two growing seasons characterized by drought.

**Key Words.** Transplanting; balled and burlapped; B&B; bare root; season; fall planting; spring planting; hackberry (*Celtis occidentalis*); American hophornbeam (*Ostrya virginiana*); swamp white oak (*Quercus bicolor*); hydrogel.

Bare-root (BR) transplanting historically has been considered by many in the landscape industry, including arborists, to be higher risk than B&B transplanting (Kozlowski and Davies 1975; Cool 1976; Pirone et al. 1988). Post-planting stress caused by desiccation of roots during post-harvest handling is thought to be the major cause of poor establishment for BR trees.

Few studies have been done to compare the impact of B&B and BR production methods on transplanting success in the urban environment. Heisler et al. (1982) planted B&B and BR red maple (*Acer rubrum* 'October Glory') and green ash (*Fraxinus pennsylvanica* 'Marshall Seedless') in parking-lot tree pits. After two growing seasons, the authors found that both BR red maples and green ashes generally grew better than their B&B counterparts.

The transplanting performance of trees dug and moved by tree spade is comparable to the transplanting performance of B&B trees (Gilman 1997). Thus, two urban studies comparing BR and tree spade transplanting are considered here. Cool (1976) found that over a ten-year period the average mortality for BR trees was 41% but less than 5% for tree spade trees. He determined that 2.5 surviving tree spade trees could be planted for the same expense as one surviving BR tree. Vanstone and Ronald (1981) compared BR and tree spade-harvested green ash (*Fraxinus pennsylvanica* 'Patmore'), black ash (*F. nigra* 'Fallgold'), hackberry (*Celtis occidentalis*), and Amur cherry (*Prunus maackii*). In the first growing season, all tree spade trees except Amur cherry showed significantly greater shoot extension and leaf area than their BR counterparts. After two seasons, however, differences in growth between BR and B&B trees of all four species were not significant.

Most studies comparing production methods took place in nonurban nursery and test field situations. Magley and Struve (1983) compared 7-to 15-cm-caliper (3- to 6-in.) BR and tree spade-dug pin oaks (*Quercus palustris*). Shoot extension and leaf expansion were significantly greater for trees transplanted by tree spade than for BR trees. A study by Hensley (1993) compared the impact of B&B, BR, and fabric-bag production methods on the height, caliper, and dry root weight of 2.5-cm-caliper (1-in.) green ash trees. The author found no significant difference among the three production methods in tree height, stem diameter, or dry root weight at any time during the four-year study.

Spring is advocated by Pirone et al. (1988) and others as the best time to transplant BR trees, without regard to species. Nurseries and authors of street tree manuals publish lists of fall transplanting hazards (Bailey Nurseries 1999; Northern Nurseries 1999; Princeton Nurseries 1999) or trees best planted in spring (Schein 1993; Watson and Himelick 1997). These recommendations frequently are based on anecdotal experience and do not distinguish between production methods. Several research studies have indicated transplanting success can actually be greater in fall, depending on species. In Ithaca, New York, BR green ash and tree lilac *(Syringa reticulata)* transplanted successfully in fall (Harris and Bassuk 1994). B&B fringetree *(Chionanthus virginicus)* planted in Blacksburg, Virginia, transplanted more successfully in fall than spring (Harris et al. 1996). A study of BR littleleaf linden *(Tilia cordata)* by Witherspoon and Lumis (1986) looked at root regeneration of three digging–planting time combinations in Ontario, Canada. The fall-dug, fall-planted trees had the greatest new root growth, which suggests that fall is the best time to transplant this species.

Some studies suggest that planting at other times of year is preferable, depending on species. For example, Watson et al. (1986) looked at eight species of shade trees transplanted by tree spade in Illinois in the months of March, May, July, or October. Shoot extension was measured for five years after transplanting. Based on their results, the authors could not make general recommendations about fall versus spring transplanting. For several of the species, July transplanting provided the best results when adequate soil moisture was maintained.

The purpose of our study was to compare fall and spring B&B and BR transplanting of three street tree species in the urban environment. Hackberry *(Celtis occidentalis)*, American hophornbeam *(Ostrya virginiana)*, and swamp white oak *(Quercus bicolor)* were selected for several reasons. Anecdotally, they are considered by the industry to be difficult to transplant (variably difficult in the case of hackberry), yet all had shown promise as street trees in Ithaca, New York. Furthermore, little research had been conducted with these species. It was hoped that these comparisons would lead to recommendations for the best season and production method for transplanting each species. A separate study, to test the validity of the commonly held opinion that B&B trees have an advantage over BR trees in coping with drought stress, would involve withholding irrigation from paired B&B and BR swamp white oak trees.

## MATERIALS AND METHODS

### Plant Material

Ten each of the following three species were harvested balled and burlapped (B&B) on October 23, 1997, from the Chenango gravelly loam of Schichtel's Nursery, Springville, New York, United States: hackberry, American hophornbeam, and swamp white oak. In addition to the B&B trees, ten each of the same species were harvested BR on October 29, 1997. In spring 1998, hackberry and hophornbeam were harvested in the same manner and in the same numbers, but an extra ten B&B and ten BR swamp white oak were dug for use in the related experiment comparing effects of drought stress on B&B and BR trees. Due to weather and work scheduling factors, the spring B&B hackberry trees were harvested at different times ranging from March 16 to April 3, 1998. All spring B&B hophornbeam were harvested on March 11, 1998, and all spring B&B swamp white oak were harvested on March 6, 1998. Spring BR trees were harvested on dates as follows: hackberry, April 13, 1998; hophornbeam, April 12, 1998; swamp white oak, April 11, 1998. All hophornbeam in the study were dug from the same nursery block, as were all swamp white oak. Among hackberry, all but seven spring B&B trees were dug from the same nursery block. All trees were dormant when dug, with the exception of spring hophornbeam that, due to unusually warm weather, started to break bud just prior to harvest.

Fall BR trees were dug, dipped, and transported on October 29, 1997. B&B trees were also transported on October 29. Due to unusually warm weather, spring BR trees were dug four to six days before they were dipped and picked up on April 17, 1999. During the holding period before pickup, they were stored in a cool, shaded garage and watered every other day. Spring B&B trees were delivered to the Ithaca municipal nursery on April 13, 1998.

Trees of 40 mm (1.5 in.) caliper were dug according to ANSI Z60.1-1996 standards (American Association of Nurserymen 1996). B&B trees were dug with a Vermeer tree spade, and root balls were put into wire baskets lined with natural burlap. Root-ball diameters met or exceeded the standard of 51 cm (20 in.) for a 40-mm-caliper (1.5 in.) tree. Hophornbeam and hackberry root balls were 51 cm (20 in.) in diameter and swamp white oak root balls were 61 cm (24 in.) in diameter. BR trees were dug with a U-blade and exceeded the ANSI minimum root spread of 56 cm (22 in.) for 40-mm-caliper trees. All trees conformed to ANSI standards for appropriate height-to-caliper relationship.

## Dipping Procedure for BR Trees

All BR trees were dipped in a hydrogel slurry at the nursery immediately prior to transport. Using a method modified from Haug (1996), approximately 15 oz (445 mL) of Soil Moist Fines™ (particles sized 700 µ or less) hydrogel was added for every 25 gal (95 L) of water, mixed in a 100-gal (380-L) plastic container, then left to hydrate for ten to fifteen minutes. Tree roots were dipped in the slurry and immediately slipped into large, pleated plastic bags. Bags were knotted around the trunk to hold in moisture, and trees were stacked gently in the bed of a dump truck. The truck bed was securely tarped for transport and upon arrival, BR trees were stored in a cool, shaded shed until planted two to five days later.

## Planting Procedure

Seventy sites throughout the city of Ithaca were selected for pairing a total of 140 B&B and BR trees in tree lawns. At each site, one B&B and one BR tree of the same species and transplanting season were planted. B&B trees and their BR counterparts were planted in close proximity—usually, 4.5 to 6.0 m (15 to 20 ft)—thereby ensuring similar soil type and microclimate (Figure 1). Tree lawn width varied from 1.5 m (5 ft) in downtown areas to greater than 4.5 m (15 ft) in residential areas.

Fall trees were planted October 31, 1997, and November 3 and 4, 1997. Spring trees were planted April 20 through 22, 1998. BR planting holes were dug with shovels; B&B holes were dug with a backhoe. Regardless of digging equipment, holes were comparable in width, and glazing of the sides of the planting hole was not observed. Turf was removed and holes were made at least as wide as the spread of the root system. Trees were planted so that the beginning of the root flare was just visible at grade. All trees were watered in immediately after planting and received 5 to 10 cm (2 to 4 in.) of wood-chip mulch in a 46-cm (18-in.) radius from the trunk. With only two exceptions, trees were not staked. Starting in the spring of 1998, all trees in the main study received 20-gal (75-L) Treegator® drip irrigation bags that were filled at the discretion of the city of Ithaca forestry crew, usually once a week during dry stretches.

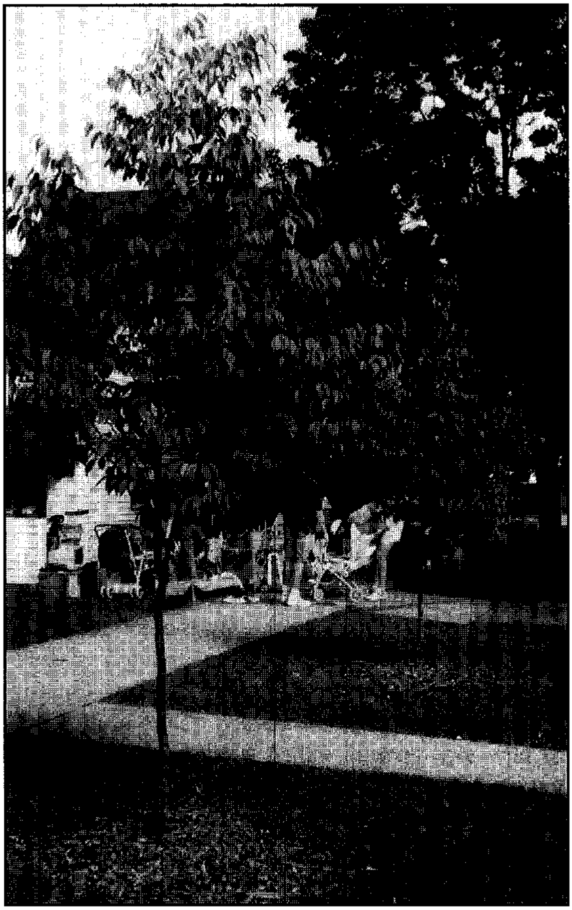

**Figure 1. Paired B&B and bare-root *Ostrya virginiana* on city street representing typical spacing in this study. Tree closest to viewer is B&B; tree farther back is bare root.**

All 20 swamp white oak trees in the irrigation-withheld study were lined out in B&B–BR pairs along one street to minimize microclimatic and soil differences between sites. They were watered only once at planting and thereafter received no irrigation.

## Data Collection

In August 1998, when terminal buds had set, four growth responses were measured on all trees. First, shoot extension was measured to the nearest half centimeter on three mid-canopy, full-sun terminal shoots per tree, and the mean was calculated. Second, dieback was also measured on three mid-canopy terminal shoots per tree, and the mean was calculated. We devised a third visual index called "leaf canopy rating" to give an approximation of the fullness of the canopy relative to its branch density. Leaf canopy complemented the other measurements by taking into account the extent of dieback and bud break failure *within* the canopy. For leaf canopy rating, a percentage scale in increments of ten was used, with 100% corresponding to a tree that had fully leafed out and had no measurable dieback within the canopy. Figure 2 gives examples of this rating on hackberry. Finally, average area per leaf was calculated from a sample of half of the trees. Ten mid-canopy, representative leaves per tree were measured with a LI-COR LI-3100 leaf area meter. The mean area in square centimeters per leaf was then calculated. The same measurements were repeated in August 1999 to give second-year growth data. Soil samples weighing at least 50 g (1.8 oz) were taken from the majority of the sites by extracting soil 15 cm (6 in.) below turf roots with a shovel. Samples were dried and analyzed for pH and gravel, and for sand, silt and clay fractions.

## Statistical Analysis

The statistical software package SPSS 9.0 was used to analyze the data. Means of paired B&B and BR trees planted within the same season were analyzed using paired t-tests. Means for both root types between

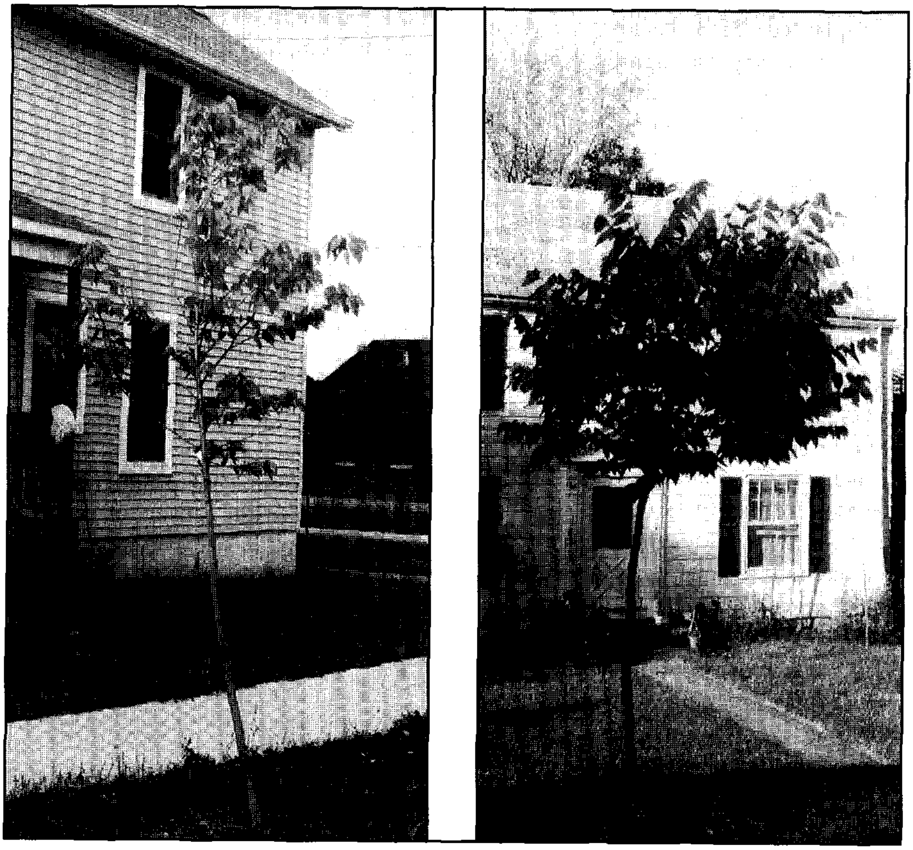

**Figure 2. A visual "leaf canopy rating" was devised to capture the fullness of the canopy relative to its branch structure. The hackberry on the left rated 60%; the hackberry on the right rated 90%.**

seasons were analyzed using independent samples t-tests. Because leaf canopy ratings were recorded as percentages and their mean distribution was not normal, leaf canopy means were analyzed using the nonparametric Wilcoxon signed rank test (for comparing within season) and the Mann-Whitney U-test (for comparing between season). Analysis of covariance was used to look at the potential influence of soil texture, specifically the sand fraction, on the results.

## RESULTS

Survival rates were excellent for all treatment combinations except spring-planted BR hophornbeam (Table 1). Four trees were lost to vandalism or theft and were thus excluded from consideration in this study.

### Comparing Production Methods

**Hackberry.** In year one, fall-planted BR hackberry outperformed fall-planted B&B hackberry. Mean area per leaf on BR hackberry was significantly ($P < .05$) greater (54% larger) than on B&B trees. In year two, fall-planted B&B and BR hackberry showed no significant differences in any of the responses.

For spring-planted hackberry, B&B trees fared better than BR in year one. Shoot extension, leaf canopy, and leaf area were all greater for B&B trees than for BR trees, though only leaf canopy was significant (122% larger). Dieback on spring-planted BR trees was significantly greater (125% larger) than on spring B&B trees. In year two, the same trends were seen but were not significant except for leaf canopy (Table 2).

**Hophornbeam.** In both the first and second growing seasons, fall-planted B&B and BR hophornbeam showed no difference in growth responses. Spring-planted trees, however, showed a significant trend in favor of B&B production in the first year. Shoot extension, leaf canopy, and leaf area were all significantly greater (236%, 67%, and 216%, respectively) for B&B trees than for BR trees. In year two, only leaf area was significantly greater (Table 3).

**Swamp white oak.** First-year measurements on fall-planted swamp white oak suggested a small B&B advantage over BR. Shoot extension was not statistically different, but leaf canopy and leaf area were significantly greater for B&B trees. In the second year, however, there was no difference between growth responses of fall-planted B&B and BR swamp white oak. Spring-planted trees measured in the first year showed some-

**Table 1. Survival rates for three species after first and second growing seasons. Season listed refers to season of planting. Percent survival is followed in parentheses by total number of trees of given treatment.**

| Species and production method | Fall Year 1 | Spring Year 1 | Fall Year 2 | Spring Year 2 |
|---|---|---|---|---|
| Hackberry, B&B | 100 (9) | 100 (10) | 89 (9) | 100 (10) |
| Hackberry, BR | 100 (9) | 100 (10) | 100 (9) | 90 (10) |
| Hophornbeam, B&B | 100 (10) | 100 (8) | 100 (10) | 100 (8) |
| Hophornbeam, BR | 100 (10) | 100 (10) | 100 (10) | 50 (10) |
| Swamp white oak, B&B | 100 (10) | 100 (20) | 100 (10) | 100 (20) |
| Swamp white oak, BR | 100 (10) | 100 (20) | 100 (10) | 95 (20) |

**Table 2. Comparing production method for hackberry within season of planting. Means read across the table are pairwise comparisons. Shoot extension (SE) given in centimeters, leaf canopy rating (LC) given in %, leaf area (LA) given in square centimeters, and dieback (DB) in centimeters.**

| Year and season | B&B SE | BR SE | B&B LC | BR LC | B&B LA | BR LA | B&B DB | BR DB |
|---|---|---|---|---|---|---|---|---|
| *Year 1* | | | | | | | | |
| Fall | 8.2 | 15.2 | 55 | 65 | 12.5 | 19.2* | 14.3 | 17.8 |
| Spring | 11.6 | 8.9 | 80* | 36 | 14.9 | 11.7 | 5.1 | 11.5* |
| *Year 2* | | | | | | | | |
| Fall | 17.7 | 17.4 | 84 | 87 | 31.0 | 27.8 | .31 | .00 |
| Spring | 13.2 | 10.3 | 80* | 71 | 28.1 | 22.2 | 1.0 | 1.3 |

*Indicates significant difference ($P < .05$) between B&B and BR means. For leaf canopy ratings, significance was determined by the nonparametric Wilcoxon signed rank test.

**Table 3. Comparing production method for hophornbeam within season of planting. Means read across the table are pairwise comparisons. Shoot extension (SE) given in centimeters, leaf canopy rating (LC) given in %, leaf area (LA) given in square centimeters, and dieback (DB) in centimeters.**

| Year and season | B&B SE | BR SE | B&B LC | BR LC | B&B LA | BR LA | B&B DB | BR DB |
|---|---|---|---|---|---|---|---|---|
| *Year 1* | | | | | | | | |
| Fall | 5.1 | 5.2 | 88 | 86 | 10.7 | 8.7 | .30 | .00 |
| Spring | 8.1* | 2.4 | 97* | 58 | 11.7* | 3.7 | .23 | 3.3 |
| *Year 2* | | | | | | | | |
| Fall | 8.6 | 7.1 | 83 | 87 | 26.1 | 19.6 | .00 | .00 |
| Spring | 12.7 | 8.1 | 97 | 83 | 22.6* | 17.6 | .00 | .00 |

*Indicates significant difference ($P < .05$) between B&B and BR means. For leaf canopy ratings, significance was determined by the nonparametric Wilcoxon signed rank test.

what larger growth means for B&B trees than for BR trees, but only leaf canopy was significantly greater. Second-year data showed no difference between B&B and BR swamp white oak planted in spring (Table 4).

## Comparing Season of Transplanting

**Hackberry.** Spring-planted B&B hackberry showed trends towards greater growth than fall-planted B&B trees, though only leaf canopy (43% larger) was significantly greater. In the second year, however, there were no differences in growth responses between fall and spring B&B trees.

BR hackberry grew better when planted in fall. In year one, mean leaf canopy and leaf area were significantly greater (81% and 64%, respectively) on fall-planted BR trees than on spring-planted BR trees. In year two, the same trends persisted in favor of planting BR trees in fall, though only leaf canopy (21% larger) was significantly greater (Table 5).

**Hophornbeam.** Growth means were higher for spring-planted B&B trees than for fall-planted B&B trees, though only leaf canopy was significantly greater. In the second year, differences noted were not statistically significant.

In the first year, fall-planted BR hophornbeam clearly performed better than those planted in spring. All four response means were significant: Fall-planted trees had 73% larger shoot extension, 46% larger leaf canopy, 135% larger leaf area, and no dieback compared to a mean dieback of 4.7 cm (1.8 in.) on spring trees. In year two, 50% of the spring-planted BR hophornbeam died. Yet of those that survived, no significant difference between spring trees and their fall-planted BR counterparts was noted (Table 6).

**Swamp white oak.** In the first year, some evidence suggested that both B&B and BR swamp white oak fared better in fall than spring. Fall-planted B&B trees had significantly greater leaf canopy and leaf area than their spring B&B counterparts.

Fall-planted BR trees had significantly greater shoot extension (39% larger) and leaf canopy (13% larger) than their spring BR counterparts. In the second year, no statistically significant differences were noted (Table 7).

## Comparing Irrigation-Withheld Trees

Ten B&B and ten BR swamp white oak trees were planted in pairs in spring. Trees were watered in at planting but received no subsequent irrigation. In

**Table 4. Comparing production method for swamp white oak within season of planting. Means read across the table are pairwise comparisons. Shoot extension (SE) given in centimeters, leaf canopy rating (LC) given in %, leaf area (LA) given in square centimeters, and dieback (DB) in centimeters.**

| Year and season | B&B SE | BR SE | B&B LC | BR LC | B&B LA | BR LA | B&B DB | BR DB |
|---|---|---|---|---|---|---|---|---|
| *Year 1* | | | | | | | | |
| Fall | 12.4 | 9.7 | 98* | 90 | 35.1* | 24.0 | .00 | .03 |
| Spring | 8.8 | 7.0 | 91* | 80 | 22.4 | 21.4 | .00 | .75 |
| *Year 2* | | | | | | | | |
| Fall | 6.9 | 6.9 | 98 | 96 | 59.7 | 57.0 | .00 | .00 |
| Spring | 4.9 | 4.4 | 94 | 91 | 51.3 | 56.0 | .00 | .00 |

*Indicates significant difference ($P < .05$) between B&B and BR means. For leaf canopy ratings, significance was determined by the nonparametric Wilcoxon signed rank test.

**Table 5. Comparing transplanting season for hackberry. Means read across the table are pairwise comparisons. Shoot extension (SE) given in centimeters, leaf canopy rating (LC) given in %, leaf area (LA) given in square centimeters, and dieback (DB) in centimeters.**

| Year and method | Fall SE | Spr. SE | Fall LC | Spr. LC | Fall LA | Spr. LA | Fall DB | Spr. DB |
|---|---|---|---|---|---|---|---|---|
| *Year 1* | | | | | | | | |
| B&B | 8.5 | 11.6 | 56 | 80* | 12.5 | 14.9 | 14.1* | 5.1 |
| BR | 14.8 | 8.9 | 65* | 36 | 19.2* | 11.7 | 17.0 | 11.5 |
| *Year 2* | | | | | | | | |
| B&B | 16.8 | 14.2 | 84 | 81 | 31.0 | 28.0 | .27 | .90 |
| BR | 15.6 | 10.2 | 86* | 71 | 28.0 | 22.0 | .13 | 1.3* |

*Indicates significant difference ($P < .05$) between fall and spring means. For leaf canopy ratings, significance was determined by the nonparametric Mann-Whitney U-test.

**Table 6. Comparing transplanting season for hophornbeam. Means read across the table are pairwise comparisons. Shoot extension (SE) given in centimeters, leaf canopy rating (LC) given in %, leaf area (LA) given in square centimeters, and dieback (DB) in centimeters.**

| Year and method | Fall SE | Spr. SE | Fall LC | Spr. LC | Fall LA | Spr. LA | Fall DB | Spr. DB |
|---|---|---|---|---|---|---|---|---|
| *Year 1* | | | | | | | | |
| B&B | 5.1 | 8.1 | 88 | 97* | 10.7 | 11.7 | .30 | .23 |
| BR | 5.2* | 3.0 | 86* | 59 | 8.7* | 3.7 | .00 | 4.7* |
| *Year 2* | | | | | | | | |
| B&B | 8.6 | 12.6 | 83 | 90 | 26.0 | 23.0 | .00 | .38 |
| BR | 7.1 | 9.3 | 87 | 76 | 20.0 | 18.0 | .00 | .00 |

*Indicates significant difference ($P < .05$) between fall and spring means. For leaf canopy ratings, significance was determined by the nonparametric Mann-Whitney U-test.

**Table 7. Comparing transplanting season for swamp white oak. Means read across the table are pairwise comparisons. Shoot extension (SE) given in centimeters, leaf canopy rating (LC) given in %, leaf area (LA) given in square centimeters, and dieback (DB) in centimeters.**

| Year and method | Fall SE | Spr. SE | Fall LC | Spr. LC | Fall LA | Spr. LA | Fall DB | Spr. DB |
|---|---|---|---|---|---|---|---|---|
| *Year 1* | | | | | | | | |
| B&B | 12.4 | 8.8 | 98* | 91 | 35.1* | 22.4 | .00 | .00 |
| BR | 9.7* | 7.0 | 90* | 80 | 24.0 | 21.4 | .03 | .75 |
| *Year 2* | | | | | | | | |
| B&B | 6.9 | 4.9 | 98 | 94 | 60.0 | 51.0 | .00 | .00 |
| BR | 6.9 | 4.4 | 96 | 91 | 57.0 | 56.0 | .00 | .00 |

*Indicates significant difference ($P < .05$) between fall and spring means. For leaf canopy ratings, significance was determined by the nonparametric Mann-Whitney U-test.

**Table 8. Comparing B&B to bare root swamp white oak in the irrigation-withheld study. Means read across the table are pairwise comparisons. Shoot extension (SE) given in centimeters, leaf canopy rating (LC) given in %, leaf area (LA) given in square centimeters, and dieback (DB) in centimeters.**

| Year | B&B SE | BR SE | B&B LC | BR LC | B&B LA | BR LA | B&B DB | BR DB |
|---|---|---|---|---|---|---|---|---|
| Year 1 | 7.1 | 8.0 | 88* | 82 | 27.2* | 19.9 | .30 | .68 |
| Year 2 | 6.2 | 6.3 | 86 | 91 | 53.1 | 59.6 | .19 | .00 |

*Indicates significant difference ($P < .05$) between B&B and BR means. For leaf canopy ratings, significance was determined by the nonparametric Wilcoxon signed rank test.

year one, mean leaf canopy and leaf area were significantly greater on the B&B trees (7% and 37%, respectively). In year two, there were no significant differences between B&B and BR trees (Table 8).

## Soil Sampling Results

Results showed a surprisingly uniform soil texture and pH across sites. Most sites were characterized by loam, gravelly loam, silt loam, or gravelly silt loam soils; two-thirds of the sites had more than 50% combined sand and gravel fraction. The majority of the sites were in the 6.6 to 7.5 pH range. The covariate analysis on sand fraction addressed the concern that some sites might be drier than others. The analysis revealed no significant effects of this variable on the growth responses for any of the trees in either year (data not shown).

# DISCUSSION

## Hackberry

In this study, fall-planted BR hackberry grew just as well as fall-planted B&B hackberry. Furthermore, fall-planted BR trees grew better than spring-planted ones. The success of fall-planted BR hackberry in this study confirms some industry opinions and contradicts others. Hightshoe (1988) recommends BR fall planting of hackberry if done "with care." Berrang and Karnosky (1983) say that hackberry can be planted in fall or spring. Bailey nurseries (1999) suggests avoiding planting hackberry in late fall, and Princeton nurseries (1999) lists hackberry as "very risky" to transplant, BR or B&B, in fall.

Fall planting comes with myriad potential advantages from which the BR hackberry in this study may have benefited. A previous study established that root growth in Ithaca ceases around the end of October (Harris and Bassuk 1994). Trees in this study were planted in late October and early November; therefore, fall root growth was unlikely to be one of those advantages. However, the physiological processes in roots that precede root growth might get underway in fall, giving fall-planted trees an advantage in the next growing season (Harris et al. 1996). Another benefit of fall planting is reduced water stress. Transpirational demand of leaves and shoots is lower in fall than spring because ambient temperatures are cooler, days are shorter, shoot extension has ceased, and plant cells have lignified (Good and Corell 1982). Roots of fall-transplanted trees are in place longer before new spring shoot growth begins, and root-to-soil contact is improved as a result. The roots of spring-harvested trees, by contrast, are severed shortly before shoot growth begins in spring. Hinesley (1986) suggests that fall-planted trees may do better because spring harvests interfere with the production of root-produced hormones necessary for good shoot extension.

Spring-planted B&B hackberry grew better than their spring-planted BR counterparts. This finding conforms to the conventional thinking that B&B transplanting is less stressful and leads to faster establishment than BR planting (Pirone et al. 1988). This outcome validates the recommendation by Hightshoe (1988) that hackberry be planted B&B in spring. However, the result in this study differs from that of Magley and Struve (1983) who found that spring-planted pin oak performed equally well when harvested by tree spade (equivalent in most respects to B&B) or BR. The result in this study also differs from Vanstone and Ronald (1981) who found that spring-dug BR hackberry actually surpassed tree spade hackberry in growth by the second year. A four-day holding period before dipping might have put the spring BR hackberry in this study at a disadvantage relative to the B&B trees. Whereas fall BR hackberry were dipped and transported the same day they were dug, spring trees were dipped and transported four days after they were dug. A shorter holding period might have resulted in less root desiccation and a growth response more comparable to that of the B&B trees.

When compared across seasons, B&B and BR hackberry grew equally well in fall and spring. This contradicts Dirr (1998), Princeton nurseries (1999), Bailey nurseries (1999), and others who specify spring planting or warn against fall planting.

### Hophornbeam

In this study, fall-planted B&B and fall-planted BR hophornbeam grew equally well. Both fall-planted B&B and BR hophornbeam grew equally well as their spring-planted counterparts. Significant differences were present only when comparing spring-planted trees; then, B&B outperformed BR. It is possible that spring-planted BR hophornbeam would have performed just as well if not subject to early bud break and a five-day holding period before dipping. Nonetheless, based on the results of this study, if one must plant in spring, B&B appears to be the better choice. If fall-planting is an option, the results of this study suggest that BR is just as good. This finding contradicts many sources recommending spring planting for hophornbeam (Berrang and Karnosky 1983; Hightshoe 1988; Schein 1993; Watson and Himelick 1997; Dirr 1998) or that caution against fall planting (Bailey Nurseries 1999; Princeton Nurseries 1999). This contradiction may be explained by the fact that the BR trees in this study had the benefit of the hydrogel root-dip protocol.

### Swamp White Oak

Comparison of paired B&B and BR swamp white oak in both fall and spring showed no advantage to either production method. Oaks generally are considered fall transplanting hazards (Bailey Nurseries 1999; Northern Nurseries 1999; Princeton Nurseries 1999) or are recommended for spring planting (Berrang and Karnosky 1983; Schein 1993; Watson and Himelick 1997). By year two of this study, growth of swamp white oak showed no significant difference between fall and spring planting, only a mild trend in favor of fall.

### Comparing First and Second Growing Seasons

In the first year, there were significant differences in growth responses between many treatment combinations of season, species, and production method. By the end of the second year following transplanting, however, most of these differences disappeared. This finding is consistent with Vanstone and Ronald (1981) who found that the first-year effects of transplanting method on their species (including hackberry) did not persist into the second year.

The second year of this study was characterized by the driest April through July on record in Ithaca, New York. Whereas hackberry and hophornbeam put on more shoot extension in year two than in year one in spite of the drought, swamp white oak set less shoot growth in year two. Yet of the three species, swamp white oak had the heaviest leaf canopy and largest leaf area both years and had negligible dieback in both seasons. It appears that swamp white oak, while not incurring dieback, responded to the drought by reducing shoot extension though a full canopy of large leaves was maintained. In the first year, hackberry had the longest shoot extension of the three species, but also had the most dieback. Rapid growth was noted in the wet spring and early summer of 1998, growth that was then checked by dieback in the drought of mid- to late summer. In the second year, hackberry again exhibited the most growth of the three species, but this time had negligible dieback. Root growth that took place in the intervening period between first- and second-year measurements may have been sufficient to support the rapid second-year shoot growth without exhibiting any dieback. For all three species, leaf area approximately doubled from year one to year two in spite of the second-year drought.

### Comparing Irrigation-Withheld Trees

For 40-mm-caliper (1.5-in.) swamp white oak—hydrogel-dipped if BR and normal handling if

B&B—there does not appear to be any advantage to planting B&B in terms of ability to cope with drought stress. The second year of this experiment was the driest April through July on record; in that year, there was no difference in growth response between B&B and BR trees. This finding challenges the conventional thinking that under drought stress, B&B trees are at an advantage over BR trees.

It is important to look at second-year growth in this study. If looking at only first-year data, one could assume that because B&B trees had significantly more leaf canopy and leaf area than BR trees, B&B was superior. However, year two showed a leveling out of differences in the midst of record drought.

### Research in Urban Settings

One concern about conducting research in urban settings was the role of lurking variables. For example, it was thought that soil texture might have a confounding influence on measurements between sites. In Ithaca, where the great majority of soils in this study were found to be gravelly loams, loams, or silt loams, the concern was not with wet soils but with excessive drainage and limited soil moisture during two dry summers. The covariate analysis on sand fraction addressed the concern that some sites might be drier than others. The analysis revealed no significant effects of this variable on the growth responses for any of the trees in either year. Soil pH was also tested and was found sufficiently uniform to prevent concern that it might confound results. Other lurking variables include whether a home owner watered trees or not, dog urination patterns, children shaking tree trunks, and the like. This variability was not possible to control or quantify; however, the study employed a large number of replicates to ensure that these variables would average out in the summary statistics.

It should be noted that the months of December through March in the winter of 1997–1998 and December through February in the winter of 1998–1999 were warmer than normal. These comparatively warmer winters may have benefited fall-planted trees in this study by making winter injury less likely.

## CONCLUSION

Based on this study of B&B and hydrogel-dipped BR trees harvested at 40-mm-caliper (1.5-in.) and planted in the urban environment of Ithaca, New York, recommendations on three street tree species can be made. Hackberry can be successfully transplanted fall or spring, B&B or BR. BR hackberry grows better in fall than spring, and in spring, B&B trees may grow better than BR trees, but all combinations are viable. Hophornbeam can be successfully transplanted in the fall or spring, B&B or BR, although spring BR planting may be risky, especially if trees are not fully dormant when harvested. Swamp white oak can be transplanted with success fall or spring, B&B or BR. For all three species, differences in growth observed in the first year can be expected to even out in subsequent years. For swamp white oak, B&B does not appear to offer an advantage over BR trees in times of drought stress.

It is important to note several caveats. BR trees were hydrogel dipped per the process described in the materials and methods section. The dipping procedure is a critical difference between the handling in this study and common BR handling. Because we do not assume that larger-caliper BR trees would perform the same way as small-caliper trees, only trees under 50 mm (2 in.) caliper should be used to ensure survival and transplanting success. Trees must receive adequate early maintenance in terms of mulching and watering. Finally, results in other municipalities may vary depending on weather patterns and soil types. Soils on sites in this study were primarily gravelly loams or silt loams; when dealing with clay soils, researchers may see different results.

This study suggests that BR planting can be just as viable as B&B transplanting for species that tolerate being moved BR, are of relatively small caliper, are root dipped, and are given proper early maintenance. This has many time- and money-saving implications for the field of urban forestry. BR trees are on average one-third to one-half less expensive than B&B trees. Because they are so much lighter and many more can fit on the bed of a truck, they are cheaper to ship. Planting BR trees costs virtually nothing when done by volunteers with shovels. The cost of planting a B&B tree, by contrast, is markedly higher because the sheer weight of the ball requires machinery and machinery operators to load the tree, unload it, and to get it into the ground. Because of the machinery used to harvest them, BR trees have about 200% more roots than B&B trees (Haug 1996). Furthermore, proper planting depth is enhanced by seeing the root flare on BR trees, and soil interface problems are avoided. Finally, nursery field soil is not depleted by BR harvesting. Given all these advantages and if, as in this study, BR trees can be moved with just as much success as B&B trees, BR deserves a second look from municipalities.

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*[1*]Former Graduate Student*
*Urban Horticulture Institute*
*Cornell University*
*Ithaca, NY*
*(Home address)*
*P.O. Box 241*
*Trumansburg, NY 14886*
*email mb90@cornell.edu*

*(continued)*

[2]*Director*
*Urban Horticulture Institute*
*20 Plant Science Building*
*Cornell University*
*Ithaca NY 14853*
*email nlb2@cornell.edu*

**Corresponding author*

**Résume.** Dans cette étude, des micocouliers (*Celtis occidentalis*), des ostryers de Virginie (*Ostrya virginiana*) et des chênes bicolores (*Quercus bicolor*) de 40 mm produits en panier de broche et à racines nues ont été regroupés ensembles et plantés sur des sites autour de la ville de Ithaca dans l'état de New York. La moitié des arbres ont été plantés en automne et l'autre moitié au printemps. Les racines des arbres à racines nues ont été enduites d'un hydrogel en pépinière afin de prévenir la dessication de ces dernières après l'arrachage. Les taux de survie ont été excellents pour toutes les combinaisons de traitement à l'exception des ostryers à racines nues plantés au printemps qui ont eu un taux de mortalité de 50%. Des mesures de croissance ont été prises en août de la première et de la seconde saison de croissance. Les résultats de la première année ont montré plusieurs différences significatives entre les divers groupes. À la fin de la seconde saison cependant, peu de différences significatives persistaient entre les divers groupes. Durant la première saison de croissance, les micocouliers à racines nues plantés en automne ont mieux poussé que ceux en paniers de broche. La croissance des micocouliers en panier de broche plantés au printemps était meilleure. Les ostryers plantés en automne, à racines nues ou en panier de broche, ont bien répondu. Le chêne bicolore poussait quelque peu mieux en panier de broche qu'à racines nues peu importe la saison de plantation. Les chênes bicolores plantés à racines nues ou en panier de broche en automne poussaient quelque peu mieux que leurs congénères plantés au printemps. Une étude séparée sur le chêne bicolore s'est attardée sur l'impact de la diminution de l'irrigation sur les sujets plantés au printemps, à racines nues et en panier de broche. Les chênes à racines nues et ceux en panier de broche ont poussé de manière équivalente après deux saisons de croissance caractérisées par une sécheresse.

**Zusammenfassung.** In dieser Studie wurden ballierte und als Wurzelware gerodete *Celtis occidentalis, Ostrya virginiana* und *Quercus bicolor* paarweise auf Standorte in der Stadt Ithaka, N.Y., gepflanzt. Die eine Hälfte wurde im Herbst, in anderen im Frühling gepflanzt. Die Wurzelware erhielt ein Hydrogel Wurzeldip, um ein Wurzelsterben nach dem Roden zu minimieren. Die Überlebensraten waren ausgezeichnet bis auf die im Frühling als Wurzelware gepflanzten *Ostrya*, die zu 50 % ausfielen. Im August der ersten und zweiten Wachstumsperiode wurden Wachstumsmessungen vorgenommen. Gegen Ende der zweiten Wachstumsphase zeigten sich nur wenige deutliche Unterschiede zwischen den Behandlungen. Während der ersten Wachstumsphase wuchs die im Herbst gesetzte *Celtis* als Wurzelware besser als die ballierte. Das Wachstum der im Frühling gepflanzten *Celtis* war besser bei den ballierten Bäumen. Im Herbst gesetzte *Ostrya*, balliert und als Wurzelware reagierte ähnlich, aber die im Frühling gesetzten ballierten Pflanzen wuchsen besser. *Quercus* mit Ballen wuchs etwas besser als ohne, unabhängig von der Jahreszeit. Beide *Quercus* wuchen im Herbst besser als die im Frühling gepflanzten. Eine separate Studie an der *Quercus bicolor* beschäftigte sich mit dem Einfluß von ausgesetzter Wässerung auf im Frühling gepflanzter Bäume, balliert und ohne Ballen. Beide reagierten gleich gut nach zwei Wachstumsperioden, die durch Trockenheit gekennzeichnet waren.

Resumen. En este estudio fueron plantados parejas de árboles, de 40 mm (1.5 in) de diámetro a raíz desnuda (RD) y con bola en arpillera (B&B), de Celtis occidentalis, Ostrya virginiana y Quercus bicolor, en sitios alrededor de la ciudad de Ithaca, New York, USA. La mitad de los árboles fueron plantados en otoño y la otra en primavera. Los RD recibieron en el vivero un hidrogel en las raíces para prevenir la desecación posterior a la cosecha. Las tasas de supervivencia fueron excelentes para todas las combinaciones de tratamientos excepto para los O. Virginiana plantados en primavera, los cuales experimentaron un 50% de mortalidad. Se tomaron mediciones de crecimiento en Agosto en la primera y segunda estación de crecimiento. Los resultados del primer año mostraron muchas diferencias significativas entre los tratamientos. Para el final de la segunda estación de crecimiento, sin embargo, persistieron muy pocas diferencias. Durante la primera estación de crecimiento, los C. occidentalis plantados en otoño a RD crecieron mejor que los B&B. El crecimiento en primavera fue mejor en los árboles de C. Occidentalis plantados en B&B. Los O. Virginiana plantados en otoño respondieron bien tanto a RD como en B&B. Q. Bicolor creció algo mejor en B&B que a RD, sin importar la estación. Ambos Q. Bicolor a RD y en B&B plantados en otoño crecieron algo mejor que sus contrapartes de primavera. Un estudio separado con Q. Bicolor revisó el efecto del riego en primavera tanto a RD como con B&B. Los dos se comportaron igualmente bien después de las dos estaciones de crecimiento caracterizadas por sequía.