Root and Shoot Growth Response of Balled-and-Burlapped and Pot-in-Pot Sugar Maple to Transplanting at Five Phenological Growth Stages[1]

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Abstract

The combined effects of phenological growth stage of a tree (e.g., bud break or bud set) and production method on plant response to transplanting are not well documented. This experiment therefore examined shoot extension, trunk diameter increase, and new root length production in balled-and-burlapped (B&B) and pot-in-pot (PIP) sugar maples (*Acer saccharum* Marsh.) transplanted at five different phenological stages between fall 2000 and early summer 2001 (leaf drop, root quiescence, root activation, bud break, or bud set). Growth measurements were made at bud set and root quiescence in 2001 at bud set in 2002. For B&B trees, total new root length on rhizotron windows was generally greatest for trees planted at bud break and lowest for trees planted at leaf drop. Trees transplanted at leaf drop or root quiescence had the greatest trunk diameter increase, and there was no strong effect of phenological stage at planting on shoot extension. For PIP trees, evidence was weak for a phenological stage effect on post-transplant root length production and trunk diameter increase. Trees transplanted at leaf drop or bud break had the greatest shoot extension. Overall, under the well-irrigated conditions of this study, planting at bud break resulted in the most favorable transplant response for B&B trees, and PIP trees appeared to transplant with equal success at all phenological stages, including after bud set in July.

Index words: container, root growth periodicity, production system, seasonal, transplant shock.

Significance to the Nursery Industry

Early root system regeneration of transplanted trees is poorly understood, even though it is the key to successful tree establishment and subsequent reduction of reliance on irrigation. Our data indicate that for well irrigated transplants, bud break is probably the best time to transplant B&B sugar maples. Growth stage at transplant had no clear effect on transplant success of PIP trees in our study. Sugar maple can be successfully transplanted at all times of year, including at summer bud set if trees are well irrigated. The seasonal difference in post-transplant management (i.e. need for more frequent irrigation) is likely a more important consideration than growth stage at transplanting, as long as trees have set buds.

Introduction

Root systems of most nursery-grown landscape trees extend well beyond the edge of the canopy. Therefore, when field-grown trees are transplanted, only a small fraction (as little as 2%) of the root system is moved with the tree (2, 29) and most of the fine, absorbing roots are lost (3). Until the newly transplanted tree regenerates a new root system, water and nutrient absorption will very likely be limited. Thus, the more rapidly a root system is regenerated, the less moisture stress the transplanted tree will undergo and the greater the chance of survival (23).

The terms 'planting check' and 'transplant shock' have been used to refer to the period of prolonged reduction of top growth that results from an extreme imbalance between the root system and crown as a result of transplanting (16, 20). For B&B trees, the duration of planting check depends on the time required to rebuild an adequate root system to support the water and nutrients needs of the shoot. In contrast, the increasingly common use of container-grown trees means that significantly less root loss at transplanting can be expected (typical container transplant practices still include severance of circling roots). Nonetheless, transplant shock is common in containerized trees due to increased irrigation needs of the container substrate (4), and thus root exploration into mineral soils is critical to supply sufficient water to the new transplant. Successful establishment and growth of transplanted trees thus depends upon rapid regeneration of a new root system and exploration of the soil resource (10, 14, 27).

Many factors (e.g., season and genetics) affect root regeneration potential (21, 22). Season of transplant is important with respect to plant growth in two regards. First, seasons correspond to specific weather patterns (e.g., temperature, moisture) and light characteristics (e.g., day length, and light intensity and quality) that influence plant growth. Second, seasons correlate to specific periods of growth and maturity, or phenological stage of the plant (e.g., dormancy, bud break, leaf drop, bud set, flowering). While some species exhibit greater root regeneration potential when transplanted in spring (13), other species exhibit greater root regeneration potential when transplanted in fall (14). For example, early fall-transplanted sugar maple, northern red oak (*Quercus rubra* L.), and Turkish hazelnut (*Corylus colurna* L.) began root regeneration earlier in the first season following transplanting than mid-fall- and spring-transplanted trees (6, 10). Still other species (e.g., *Chionanthus virginicus* L.) may not regenerate roots until summer regardless of season of transplant (8).

Although fall transplanting may be superior to spring transplanting for many species as indicated above, root and shoot growth response and interaction with production type has not been presented for trees transplanted at specific phenological growth stages. Therefore, our objective was to determine the effects of transplanting B&B and PIP sugar maple at various phenological growth stages on new root growth, shoot extension, and trunk diameter increase. We

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present shoot extension, trunk diameter increase and root length (against observation windows) at the end of the first post-transplant growing season and the following June as well as root dry weight and length from destructive harvest at the end of the experiment.

Materials and Methods

Plant material. Sparsely-branched, bareroot sugar maples [1.2 m (4 ft) tall] were obtained from J. Frank Schmidt and Sons Co. (Boring, OR) and grown in a nursery bed or PIP production system for 2 years at the Urban Horticulture Center, Blacksburg, VA (USDA plant hardiness zone 6a). Trees were spaced 1.4 m (4.5 ft) apart in rows. Rows were spaced 3 m (10 ft) apart. Soil type was a Groseclose silt loam (clayey, mixed, mesic Typic Hapludults) with pH 6.2. The PIP production system consisted of 51-liter containers (#15) (B-15, Lerio, Mobile, AL) fitted in 51-liter (#15) socket containers spaced 1.2 m (4 ft) on center in rows 1.5 m (5 ft) apart. Black landscape fabric covered the area between the sockets, and an underground drainage system ensured proper drainage. Container substrate consisted of unamended pine bark (pH 6.2). In September 2000, 24 uniform-sized field-grown and PIP trees were selected for later planting at one of five phenological stages. Mean heights for B&B and PIP trees (SE mean in parentheses) were 2.62 (0.07) and 2.84 (0.08) m [8.60 (0.22) and 9.32 (0.25) ft], respectively. Mean trunk diameters, 15 cm (6 in) above the soil line, were 69.8 (3.0) and 72.0 (1.8) mm [2.75 (0.11) and 2.84 (0.07) in] for B&B and PIP trees, respectively.

Treatments. Treatments consisted of two production methods (B&B and PIP) and five transplant dates determined by selection of plants reaching one of five phenological stages (Table 1). Root quiescence and root activation stages were selected when rhizosphere temperatures dropped to a limiting range in the fall or rose above that range in the spring, respectively (5). A non-transplanted control treatment was included, but because rhizotrons for the non-transplanted control plants were located in the PIP system and nursery bed, they could not be randomized in the same bed as the transplanted trees. Means for these trees are included for illustration but are not included in statistical comparisons. There were four replications of each treatment combination (4 × 2 × 6 = 48 trees).

Rhizotron construction. Three types of rhizotrons (root observation chambers) were constructed. A field rhizotron (FR) was constructed for the non-transplanted field trees. PIP rhizotrons (PIPR) were constructed for the non-transplanted PIP trees. Finally, transplanted trees were placed into aboveground root rhizotrons (AGR). For a complete description of the construction of each rhizotron type, see Richardson-Calfee et al. (19).

Tree planting and harvest. Field-grown trees were hand dug with 51 cm (20 in) diameter root balls, wrapped with industry-standard copper sulfate-treated burlap (A.M. Leonard, Piqua, OH), and tightly laced with sisal twine (B&B). Circling roots on PIP trees were pruned to prevent further circling and encourage root exploration into the surrounding soil and substrate. A dense layer [approximately 1 cm (0.4 in)] of roots on the bottoms of the root balls of all PIP trees was also removed. Aboveground rhizotrons were carefully lowered over the tree tops, making sure not to damage the buds and twigs. Root balls were positioned close to [approximately 2 cm (0.8 in)], and centered in front of, the windows. After positioning the trees in the rhizotrons, a 1:1 (by vol) mixture of sphagnum peat and coarse sand was used to fill the space between the root balls and AGR windows. This mixture has similar physical properties to a well-drained mineral soil, but prevents silt buildup on rhizotron windows from obscuring view of roots. Burlap and twine were loosened from around the tree trunks but left intact around the root ball of field-grown trees. All transplanted trees were mulched with approximately 7 cm (3 in) shredded mixed-hardwood mulch. The non-transplanted PIP trees were fitted into PIPRs of the same size as their original containers after pruning circling roots from the outer layer of the root ball and removing the dense root layer at the bottom of the root balls. Unamended pine bark (pH 6.3) was used to fill any space between the root balls and PIPR windows. Thus non-transplanted PIP trees did experience some root severance, but did not have additional soil resources to explore. Except for installation of the rhizotron, no modifications were made to the four non-transplanted control trees that were left in the field. The same peat and sand mixture used to fill the space between the root balls and AGR windows was used to fill the space between the soil profile and FR windows.

Tree care: fertilization, irrigation, etc. Trees were fertilized in 2001 and 2002 with 200 g (7 oz) of encapsulated slow release fertilizer (15N–3.9P–10K, Osmocote Plus 15N–9P_2O_5–12K_2O, 8–9 Month Northern Formula, The Scotts Co., Marysville, OH) just before spring bud break each year. All trees were irrigated with a micro-irrigation system in such a manner as to maintain soil and substrate moisture near field/container capacity. During the first growing season (2001), trees in the AGR and FR were irrigated twice a week for approximately 2 hr. Trees were irrigated approximately once a week during 2002. Trees in the PIPR were irrigated twice a day for 15 minutes both years. Irrigation occurred less often when sufficient rainfall was received or after leaf drop. Minimal irrigation was applied during the winter months, when trees were dormant. Weeds were eliminated by hand pulling and applications of a variety of herbicides including glyphosate, a mixture of isoxaben and trifluralin; pendimethalin; and oryzalin, applied according to manufacturer's

Table 1. Determination of phenological stage and time of transplanting for balled-and-burlapped (B&B) and pot-in-pot sugar maple (PIP) treatments.

Phenological stage	Metric	Date of transplant
Leaf drop	More than 50% of leaves senesced	November 3, 2000
Root quiescence	Soil temperature drops between 5 and 10C	December 8, 2000
Root activation	Soil temperature rises between 5 and 1C	March 16, 2001
Bud break	50% of buds open or with visible leaves	April 13, 2001
Bud set	Twig extension ceased on 4 out of 5 shoots	July 13, 2001

recommendations. Due to strong wind, two trees from the July transplant treatment had to be staked after transplanting. Survival was 100% for all B&B trees. However, three PIP trees died over the course of the project. One tree transplanted at root activation and one tree transplanted at bud break died of unknown causes, and one tree transplanted at root activation snapped at the base of the trunk during a windstorm. Therefore, two replications remained for PIP trees transplanted at root activation, and three replications remained for PIP trees transplanted at bud break.

Measurements. Shoot extension for each tree was determined by obtaining the mean extension of five lateral shoots selected at bud break in Spring 2001. Shoots were randomly selected from the population of robust opening buds. Total extension of this shoot was measured at bud set in mid to late June. Shoot extension and trunk diameter increase in 2001 were not measured for trees transplanted at bud set since the shoots were already extended at time of transplant and significant seasonal trunk diameter increase had already occurred. Trunk diameter 15 cm (6 in) above the soil or substrate line was measured on all other trees just after transplanting or installation of the FR and PIPR. Trunks were marked to ensure the same measurement point at the conclusion of the experiment. Trunk diameter was the mean of two perpendicular measurements. Trunk diameter growth was the difference between diameter at transplanting and measurements made on December 1, 2001, and again on June 9, 2002.

Root length against the rhizotron windows was calculated at root quiescence on December 1, 2001, and prior to excavation of root systems on June 9, 2002, using the line-intersect method (15, 17, 25), which uses a grid to approximate length. Roots that turned black or disappeared from the viewing area were considered dead (11, 18, 26). Due to the development of extraordinarily dense root mats in two of the non-transplanted PIP trees, it became impossible to accurately count individual roots on the bottom row of the grid and this portion of the window was eliminated from measurements.

On June10, 2002, root systems of all transplanted trees were excavated to quantify post-transplant root regeneration. All roots outside of the original root ball were removed from within the AGR and from 20 cm (8 in) directly beneath the ‘footprint’ [76 × 76 cm (30 × 30 in)] of the rhizotrons. Regenerated roots were stored in a dark 6C (43F) cooler until processing for weight and length measurements.

To determine the relationship between root length and mass, three representative samples of roots harvested from both the PIP and B&B treatments were randomly selected. Subsamples of each of the PIP and B&B samples were obtained by visually separating the root systems into four equal sized groups with equal representation of each root diameter class. Root length of a quarter of each of the six root systems was quantified using the WinRhizo V5.0A (Régent Instruments Inc., Québec, Canada) root analysis system. Following the estimation of root length, all root systems were dried to a constant mass at 52C (125F) and weighed.

Soil and substrate temperature were monitored with thermocouples placed 12 in (30 cm) deep in a randomly selected AGR, PIPR, FR, and nursery bed and twice weekly in mid afternoon.

Analysis. Shoot extension, trunk diameter increase, root length, and harvested root data were subjected to analysis of variance within the GLM procedure of SAS (Vers. 9.1, SAS Institute, Cary, NC). Comparisons of treatment means were made with the PDIFF option within the GLM procedure of SAS, with significance assigned to comparisons where $P < 0.075$.

Results and Discussion

Shoot growth. Analysis of variance revealed strong evidence of an interaction between phenological stage at transplanting and production method for 2001 and 2002 (Table 2). Transplanting resulted in distinct reductions in shoot extension among the B&B, but not the PIP trees (Fig. 1). Reduced shoot extension is a common response of field grown trees to transplanting and has been reported by others (9, 28). Non-transplanted PIP trees likely became pot bound as the 2001 season progressed, so it is not surprising that shoot extension of non-transplanted trees was similar to transplanted trees. Post-transplant reductions in shoot extension in B&B trees are most likely due to the inability of the newly transplanted root systems to supply sufficient moisture to drive maximum shoot expansion, despite regular irrigation. Among B&B treatments, trees transplanted at time of root quiescence exhibited the greatest shoot extension, although evidence was weak in 2002. Among the PIP treatments, trees transplanted at leaf drop or at bud break had the greatest shoot extension.

Trunk growth. An interaction between phenological stage at transplanting and production method was evident for 2001 and 2002 (Table 2). B&B trees transplanted at root quiescence had the most trunk diameter increase and all PIP trees had relatively equal trunk diameter increase, regardless of phenological stage at transplanting (Fig. 1).

Root growth Exclusive of trees transplanted at bud set, no new root growth was observed in any of the transplanted trees until after bud break the following spring (2001). Root

Table 2. Analysis of variance of shoot extension, trunk diameter increase, and posttransplant root length against rhizotron windows of balled-and-burlapped (B&B) and pot-in-pot (PIP) sugar maple transplanted at various phonological growth stages in 2000 and 2001. Data were collected at the end of the 2001 growing season and in June 2002. n = 4.

	P > F					
	Shoot extension		Trunk diameter increase		Root length	
	2001	2002	2001	2002	2001	2002
Phenological stage	0.087	0.008	0.001	0.001	0.008	0.003
Production method	0.855	0.470	0.037	0.060	0.010	0.007
Stage × method	0.001	0.001	0.012	0.022	0.004	0.001

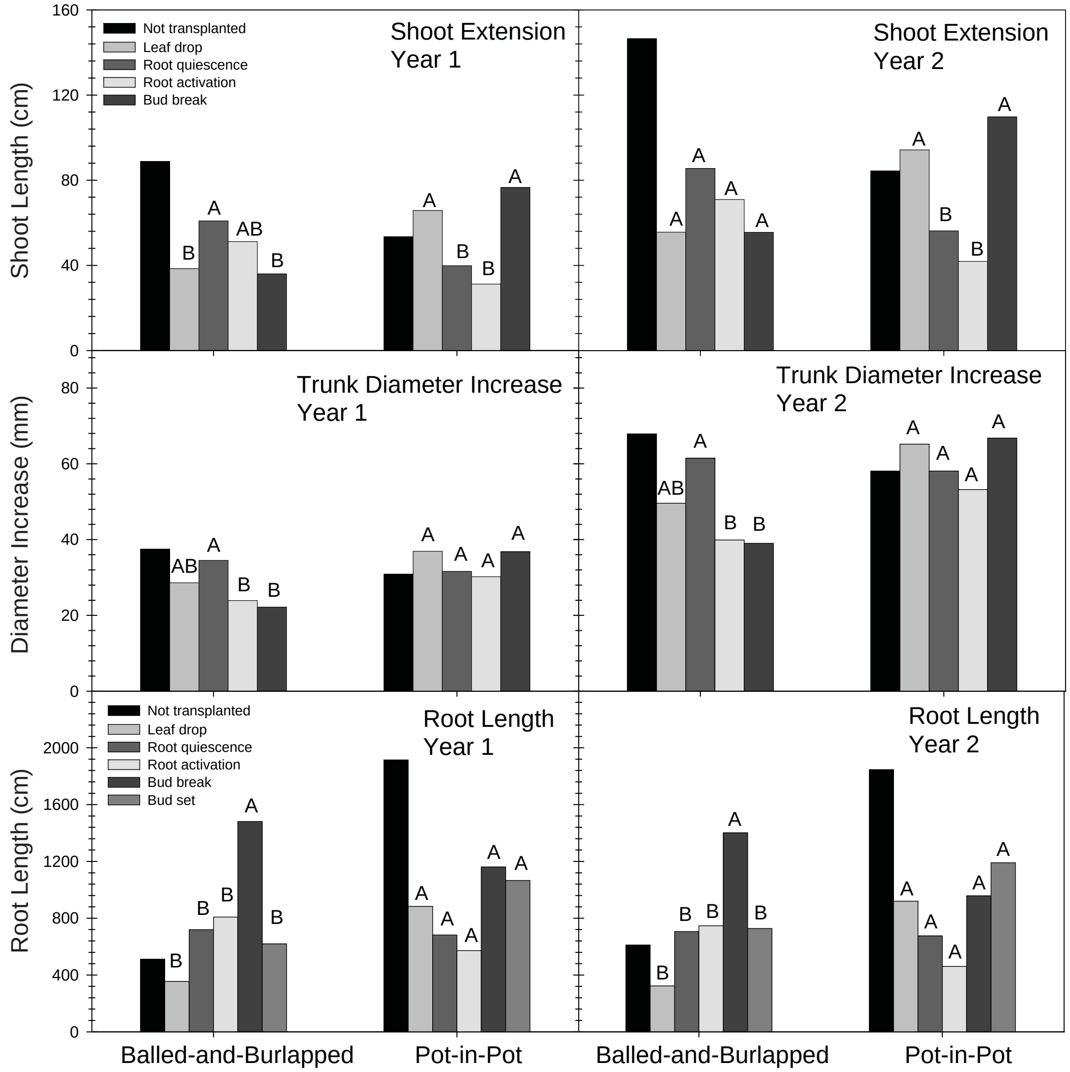

Fig. 1. Shoot extension, trunk diameter increase, and post-transplant root length against rhizotron windows of balled-and-burlapped (B&B) and pot-in-pot (PIP) sugar maple transplanted at various phonological growth stages in 2000 and 2001. Data were collected after growth ceased the first posttransplant growing season (year 1) and the following June (year 2). Letters on tops of bars indicate statistical difference assessed by individual t-tests at α = 0.075. Non-transplanted trees were excluded from statistical analysis. n = 4.

regeneration was observed on most of these trees by mid May and all transplants by mid-June. Harris et al. (6) reported that early-fall-transplanted sugar maple began root regeneration earlier than the mid-fall- and spring-transplanted treatments and that early-fall, late-fall, and early-spring-transplanted trees began root regeneration 48, 22, and 0 days, respectively, prior to bud break. Similarly, Taylor and Dumbroff (24) reported a rapid burst of growth in transplanted sugar maple seedlings in late March, approximately four weeks prior to bud break. Bud break in our study occurred around April 18; however, root regeneration was not observed in any of the transplanted trees until after May 2 or at least two weeks after bud break. Trees transplanted at bud break regenerated roots one week later than any of the other treatments, which was likely a result of physiological stresses or wound responses imposed by the transplanting process. Differences between the coordination of bud break and root regrowth in the study by Harris et al. (6) and this study were likely due to year-to-year climate variation and to the use of the PIPR growing system in their study. Besides climate differences, Taylor and Dumbroff (24) investigated transplant response of small seedlings, not landscape-sized trees as were used in our study.

While no root regeneration was observed in this study prior to bud break in any of the transplanted treatments, modest winter root growth was observed in the not-transplanted PIP trees and just prior to bud break in the non-transplanted field trees. However, similar to the Harris et al. (6) study, root zone temperatures were slightly higher in the PIP rhizotrons compared to the surrounding soil (Fig. 2) and this may have permitted more winter root growth of these trees. Trees transplanted at bud set regenerated roots approximately 21 days after transplanting (late July and early August), at a time when root growth was limited in all other treatments. Cripps (1) suggested that this type of anomalous root growth was a result of stimulation by root pruning, a result of the transplanting process.

In our study, root growth and mortality were not measured separately. Instead, root lengths reported incorporate processes of both growth and mortality and reflect the cumulative changes in length density of live roots. As such, a drop in total root length was evident, apparently from significant

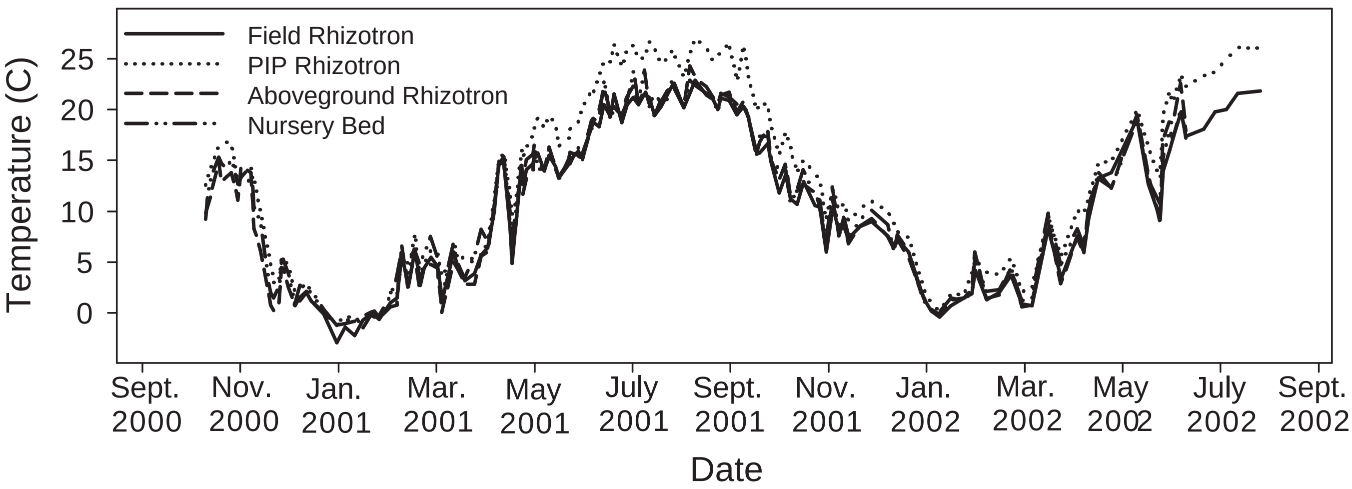

Fig. 2. Rhizosphere temperature at 30 cm (12 in) depth taken in the field rhizotron, pot-in-pot (PIP) rhizotron, aboveground rhizotron, and nursery bed.

mortality during winter at a time when soil temperatures prevent new root growth from occurring. In other words, when root length data were taken at bud set (June 9) in 2002, total root length had not returned to prior levels.

A significant interaction occurred between phenological stage at transplanting and production method (Table 2). Among the B&B treatments, trees transplanted at bud break had much greater root length than all other B&B treatments (Fig. 1). Since root initiation is in part related to plant hormones produced in active shoots (12, 30) and root growth potential is only briefly halted at bud break (5), root regrowth was likely very active for trees transplanted at this phenological stage. For this reason, practitioners often suggest that difficult to transplant trees, such as American beech (*Fagus americana* L.), be transplanted at bud break (personal observation). In addition, trees prone to desiccation would quickly take up water through new roots as long as rootballs were well irrigated. Although sugar maple is apparently not difficult to transplant, our data indicate that the greatest potential for root regrowth of B&B is for those transplanted at bud break. Reliable post-transplant irrigation, such as supplied in our study, would be essential for similar results. Evidence for a phenological stage effect for PIP trees was weak, possibly due in part to decreased replication resulting from the death of the three PIP trees.

A destructive harvest on June 10 did not indicate differences in phenological stage or production method as far as dry weight of harvested roots (Tables 3 and 4). When converted to length, however, PIP trees had more new root length than B&B trees. Container-grown trees produced in pine bark substrates have a root system morphology dominated by more plentiful and smaller diameter roots compared to field-grown trees of similar age (7). It is therefore not surprising that new root systems that originated from rootballs of PIP trees had more total root length than those arising from B&B rootballs. Tracking root length against rhizotron windows only allows measurement of a subset of a tree's root system. Nevertheless, it may be a more sensitive method for detecting root growth activity. Although destructive harvesting attempts to recover all roots, it is necessarily less precise. This lack of precision is likely why differences detected from the destructive harvest were not in agreement with data from the rhizotrons.

In this study, transplant timing was selected when plants were at specific phenological stages (Table 1) that are naturally associated with seasons and the seasonal effects of temperature. Trees transplanted at leaf drop (November 3) still had approximately one month before temperatures dropped to root quiescence levels (December 8). Trees transplanted at root quiescence had almost no opportunity for root growth until root activation (March 16). Trees transplanted at root activation had one month where temperatures were warm enough for root growth and there was also little competition for stored resources by developing shoots (until after bud break on April 13). Trees transplanted at bud break immediately experienced sufficiently warm soil for root regrowth. Thus, developing shoots would soon be able to send photosynthates to the developing roots. Trees planted at bud set (July 13) were in full leaf and would be the most prone to

Table 3. Regenerated root dry weight and length of balled-and-burlapped (B&B) and pot-in-pot (PIP) sugar maple transplanted at various phenological growth stages in 2000 and 2001. Data were collected in June 2002. SE mean in parentheses. n = 4.[z]

	Dry weight (g)		Length (m)	
Phenological stage	B&B	PIP	B&B	PIP
Leaf drop	199.6 (77.59)	257.6 (41.04)	2008.9 (78.09)	2886.3 (45.99)
Root quiescence	194.1 (41.50)	138.9 (38.55)	1953.0 (41.76)	1556.4 (43.20)
Root activation	134.4 (31.23)	194.3 (112.90)	1352.2 (31.43)	2177.5 (126.53)
Bud break	216.4 (43.61)	280.8 (35.19)	2177.7 (43.89)	3147.3 (39.43)
Bud set	95.9 (15.04)	190.8 (40.96)	964.7 (151.41)	2138.3 (45.90)

[z]See Table 4 for statistics.

Table 4. **Analysis of variance of regenerated root dry weight and length of balled-and-burlapped (B&B) and pot-in-pot (PIP) sugar maple transplanted at various phenological growth stages in 2000 and 2001. Data were collected in June 2002. n = 4.**

	***P* > F**	
	Dry weight	**Length**
Production method	0.156	0.041
Phenological stage	0.147	0.139
Production × stage	0.535	0.514

desiccation stress. However, this is a period of significant root regeneration potential due to the photosynthetic machinery being in place and the lack of competition from expanding shoots and trunk diameter (5). Trees transplanted at bud set grew well in this study. However, it is important to point out that all trees were provided regular irrigation. These phenological stages therefore offered a test of transplanting at times where a wide variety of root regrowth potential existed. Because of extreme desiccation risk, we did not test stages where shoots were actively extending. Although bud break was the best stage overall for transplanting B&B trees, transplanting at all stages was acceptable for both B&B and PIP trees. Difficult-to-transplant species would be more likely to be affected by the differing opportunities for root regrowth as presented by transplanting at these specific phenological growth stages.

B&B trees transplanted at bud break had more new root length but somewhat less top growth than trees planted at other times. This combination likely provides an advantage for transplant success. However, B&B sugar maple transplanted well at all phenological stages tested in this study. Even summer bud set appears to be an acceptable time to transplant sugar maple if transplants are well irrigated such as in this study. For PIP transplants, no clear effect of phenological stage on root growth was evident. Some phenological stages (e.g., bud set) may coincide with unfavorable weather or climatic factors, and seasonal shifts in management intensity, not phenological stage at transplant, are probably the limiting factors for transplanting sugar maple.

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