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Bareroot and Balled-and-burlapped Red Oak and Green Ash Can Be Summer Transplanted using the Missouri Gravel Bed System

Chris Starbuck[1], Daniel K. Struve[2], and Hannah Mathers[2]

ADDITIONAL INDEX WORDS. tree establishment, root regeneration, nursery production, transplant shock

SUMMARY. Two experiments were conducted to determine if 5.1-cm-caliper (2 inches) 'Summit' green ash (*Fraxinus pensylvanica*), and 7.6-cm-caliper (3 inches) northern red oak (*Quercus rubra*) could be successfully summer transplanted after being heeled in pea gravel or wood chips prior to planting in the landscape. Spring harvested trees of each species were either balled and burlapped (B&B) or barerooted before heeling in pea gravel or wood chips. Compared to B&B 'Summit' green ash, bareroot stock had similar survival and shoot extension for three growing seasons after summer transplanting. Bareroot and B&B northern red oak trees had similar survival and central leader elongation for 3 years after summer transplanting. In the third year after transplanting, northern red oak bareroot trees heeled in pea had smaller trunk caliper than B&B trees heeled in wood chips. These two taxa can be summer transplanted B&B or bareroot if dormant stock is spring-dug and maintained in a heeling-in bed before transplanting. This method of reducing transplant shock by providing benign conditions for root regeneration can also be used to extended the planting season

[1]Department of Horticulture, University of Missouri, Columbia, MO 65203

[2]Department of Horticulture and Crop Science, The Ohio State University, 2001 Fyffe Court, Columbus, OH 43210. Reprint requests should be addressed to Daniel K. Struve. Email address: struve.1@osu.edu.
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for field-grown nursery stock; the method is called the Missouri gravel bed system.

Container production of trees has many advantages compared with field production: shorter production schedules attributed to more intensive management, reduced product weight, higher production densities, and an extended harvest period. Also, container production does not degrade nursery soil (Davidson et al., 1988). However, container stock may not establish as readily as field-grown material (Arnold, 1996; Blessing and Dana, 1987; Gilman and Beeson, 1996a; Gilman et al., 1996; Harris and Gilman, 1991). The slower establishment of container stock, relative to field bags and B&B stock, is partially explained by the low volume of plant available water in light bulk density container substrates (Nelms and Spomer, 1983), the higher density of fine roots in the root ball, potentially greater transpiration (Gilman and Beeson, 1996b; Harris and Gilman, 1991), and the smaller root volume relative to trunk caliper (and assumed canopy volume) of container-grown stock (Harris and Gilman, 1991).

Even with the limitations of container stock, container stock production has increased. An almost forgotten production method is field production of bareroot nursery stock. Bareroot stock has the advantage of ease of handling and soil conservation. Bareroot production is usually limited to smaller sized material, although large-caliper pin oaks (*Quercus palustris*) can be transplanted successfully (Magley and Struve, 1983). Unfortunately, bareroot stock has a limited harvest and planting window, being restricted to the period between frost-free soil and budbreak in the spring and between defoliation and frozen soil in the fall. Bareroot stock can be slower to establish than B&B stock (Cool, 1976) or container stock (Johnson et al., 1984) and is more susceptible to desiccation during harvest and transport.

If a method of handling bareroot stock was available that combined the rapid rate of establishment of B&B stock with the ease of handling and extended planting season of container stock, then reduced handling and replacement costs could be realized. In this paper we describe a possible system, the Missouri gravel bed system (MGBS), as a method for extending the planting season of large sized bareroot nursery stock. In the MGBS, dormant field-grown stock is heeled in a gravel mulch, so that it can be transplanted later in the growing season. To test the possibility of summer transplanting large-caliper bareroot trees, two experiments were conducted to compare survival and growth of bareroot or B&B 'Summit' green ash and northern red oak trees heeled in the MGBS prior to field planting in mid- to late-summer.

Materials and methods

The first experiment began on 16 Mar. 2001, when twelve 5.1-cm-caliper B&B 'Summit' green ash trees were received at the University of Missouri, Columbia, from Rosehill Nursery (Kansas City, Mo.). Trees were harvested with a mechanical tree spade according to American National Standards Institute (ANSI) standards (Amer. Assn. Nurserymen, 1996) and placed in burlap-lined wire baskets. At Columbia, six trees were barerooted by removing the burlap and spraying the soil ball with a stream of water. They were then heeled in a pea gravel berm underlain with 20-mil [0.02 inch (0.508 mm) thickness] polyvinylchloride (PVC) pond liner. The gravel was a standard, 6.4-mm-diameter (1/4 inch), screened river rock mixed with 10% (by weight) masonry sand. The berm was established on a 5% slope, allowing irrigation water to be collected and recirculated through a drip irrigation system consisting of two drip lines [in-line emitters on 30.5-cm (12 inches) centers with 3.4 $L \cdot h^{-1}$ (0.90 gal/h) emitters] placed 15.2 cm (6 inches) on either side of the tree trunks. A sump pump, activated by a time clock between 16 Mar. and 9 July, operated for 3 min every hour between 800 and 1800 HR. The remaining six B&B trees were heeled-in pea gravel, but irrigated manually, as required, to keep the soil balls moist. All trees were fertilized weekly from 16 Mar. until planting on 9 July with 200 $mg \cdot L^{-1}$ (ppm) N from 20N–8.8P–16.6K (20–20–20 Peters water-soluble fertilizer; Scotts, Marysville, Ohio).

On 9 July 2001 all trees were removed from the pea gravel. Exposed roots were sprayed with water and wrapped in tarps. Trees were transported approximately 91.4 m (100 yards) in a covered vehicle to the University of Missouri Turfgrass Research Center, Columbia, and transplanted into a clay loam soil [Mexico silt loam (fine, smectitic, mesic aeric vertic ediaqualf)], using a completely random design with six single-tree replications. Holes were dug by hand large enough in diameter to accommodate the root system. No particular care was taken to distribute root tips within the native backfill soil. The ambient temperature at planting was 35 °C (95 °F). After planting, each tree was staked, mulched, and irrigated with 37.9 L (10 gal) of water. Trees were watered once during the 2001 growing season and once in mid-July of 2002. Each tree was fertilized in Mar. 2002, with 14.18 g (0.5 oz) N from 29N–1.3P–3.3K granular fertilizer applied to the soil surface within the drip line. Weeds within the mulched area were manually controlled. The trees received no other maintenance.

Trunk caliper was measured on all trees 15.2 cm from the soil surface in late Sept. 2003. Annual twig extension of the five most vigorous shoots per tree was measured from 2001 to 2003.

In the second experiment, during Jan. 2001, trunk caliper (measured 15.2 cm from the root flare) and central leader length were recorded for each of 24 red oak trees. The cultural conditions were described in Struve et al. (2000). The trees were half-sibs, lined out as 0.9- to 1.8-m-tall (3–6 ft) container-grown whips in 1993, transplanted in 1996 as 3.81-cm-caliper (1.5 inch) trees and dug for this study in early Mar. 2001.

Because there was a range in trunk caliper, trees were assigned to one of four treatment groups so that each group had similar average caliper. Excess soil above the buttress roots was removed before digging. Trees were mechanically dug with a 106.7-cm (42 inches) tree spade (model 742; CareTree Systems, Columbus, Ohio). The ball diameter was adjusted to give a 10 root ball diameter : 1 trunk caliper ratio. All the trees were dug on 9 Mar. 2001, placed in wire baskets lined with untreated burlap, top laced, and set back in their holes. On 14 Mar., the plants were moved to a specially constructed heeling-in area. Two 3.7 × 4.9 m (12 × 16 ft) × 0.9 m high wooden heeling-in boxes were built. Six of the B&B trees were placed in the boxes and mulched with either screened river bed pea gravel [6.4-mm diameter; Olen Corp., Columbus, Ohio) or fresh hardwood wood chips (chipped within 4 d of heeling in). The gravel and wood chips completely filled the space between the root balls and covered the root ball surface by 2.5 cm (1 inch). The remaining half of the B&B plants were removed from the wire baskets and soil removed similarly to the 'Summit' green ash trees. When barerooted, six trees were placed in each box and heeled in with either pea gravel or wood chips, adjusting plant depth so that the buttress roots were 2.5 cm below the mulch surface. Heeling-in boxes were in full sun for most of the day, receiving only partial afternoon shade from adjacent trees.

Trees were irrigated using Spot Spitters [0.61 $L \cdot min^{-1}$ (0.16 gal/min), model 030-001001; Roberts Irrigation Products, San Marcos, Calif.] to maintain non-limiting water substrate levels. There was a separate irrigation zone for each mulch type. Each plant was fertigated weekly with 1.2 L (0.32 gal) of 100 $mg \cdot L^{-1}$ N from 21.0N–3.0P–4.4K (21N–7P–7K Peters water-soluble fertilizer; Scotts).

On 6 Sept. 2001, the trees were removed from the heeling-in bed and the five longest regenerated roots per tree measured from the burlap surface (or pruned root surface for bareroot trees) to the root tip. After measuring, the exposed roots were covered with two layers of moist burlap, loaded on a trailer, and transported to the planting site 0.80 km (0.5 mile) away. Tree canopies were not covered during transport. Trees were planted in 1.8-m-square, 0.6-m-deep (2 ft) holes in a Crosby silt loam soil (fine, mixed, mesic, aelic ochraqualfs) in an established lawn. Holes were opened with a backhoe and finished by hand digging. Trees were set in the holes with buttress root flares slightly above grade, and holes were back-filled with native soil. The trees were mulched with a 5.1-cm-deep layer of hardwood chips spread over a 1.8-m-diameter circle at the base of each tree. Trees were irrigated as needed in Fall 2001 and during the 2002 growing season. There was no irrigation applied in 2002 or 2003. The trees were planted in full sun, on 9.1-m (30 ft) centers in a randomized design using six single-tree replications per treatment.

Annually for 3 years after transplanting (2001–03), five leaves from each tree were collected and their leaf area determined using a leaf area meter (model 3100; LiCor, Lincoln, Nebr.). For each tree, trunk caliper 15.2 cm from the buttress root flare and central leader extension were recorded annually for 3 years. All data was subjected to analysis of variance (ANOVA) using the one-way procedure within SPSS for personal computers (SPSS, Chicago). Means were separated using the Student–Neuman–Keuls test at the α = 0.05 level of significance.

Results and discussion

No green ash died during the heeling-in period or after transplanting into the landscape. Shoot extension in 2000 (the year before transplanting) averaged 74 cm (29.1 inches). Shoot elongation during the heeling-in period was greatly reduced, averaging 4.5 and 7.2 cm (1.77 and 2.83 inches) for the bareroot and B&B treatments, respectively (Table 1; Fig. 1). There was no difference in caliper between the treatments in 2003, 6.7 and 6.8 cm (2.64 and 2.68 inches), for bareroot and B&B trees, respectively.

Root elongation in the pea gravel for both B&B and bareroot trees was extensive and the roots were highly branched (data not presented), requiring that planting holes be dug wider than that for a typical B&B tree.

Leaves on some bareroot trees exhibited wilting immediately after planting in July 2001. However, after irrigation, the leaves quickly recovered

Table 1. Shoot growth and caliper of bareroot (BR) and balled-and-burlapped (B&B) 'Summit' green ash after heeling in a Missouri gravel bed system (2001) and after field planting (2002 and 2003).

	Shoot length (cm)[z]				Caliper (cm)
Treatment	2000	2001	2002	2003	2003
BR	74.3 A[y]	4.5 A	6.8 A	8.0 A	6.7 A
B&B	74.1 A	7.2 A	4.3 A	8.3 A	6.8 A

[z]1 cm = 0.4 inch.
[y]Means within a column followed by different letters are significantly different from each other using Student–Newman–Keuls test at an α = 0.05 level of significance. Each value is the mean of the five longest shoots from each of six single-plant replications.

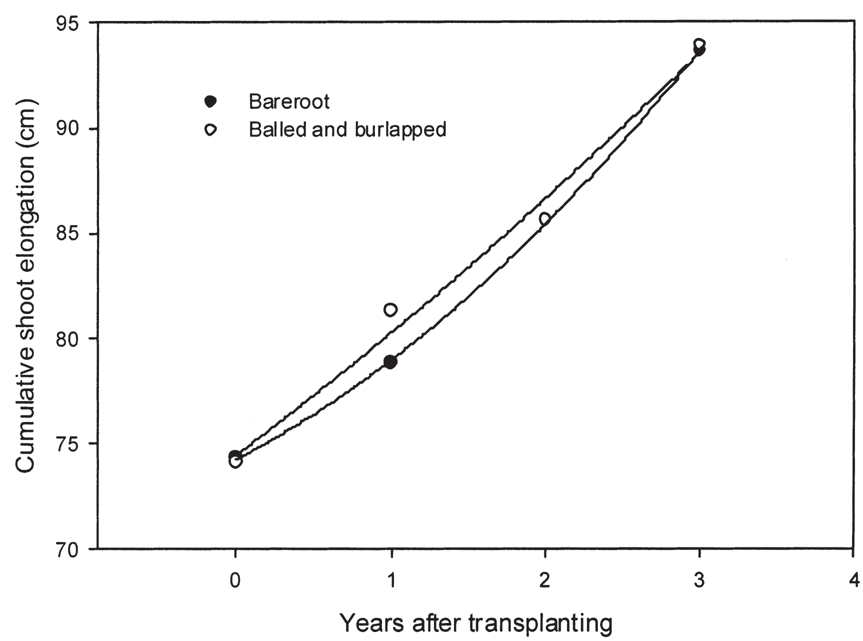

Fig. 1. Cumulative shoot elongation of 'Summit' green ash after heeling in a Missouri gravel bed system for 4 months and then transplanting to a field plot. Average shoot elongation the year before digging averaged 73.7 cm (29 inches). Each value is the mean of five shoots from each of six plants per treatment. The lines are described by the following equations: $CSE_{BR} = 74.25 + 3.85t + 0.88t^2$ ($r^2 = 0.99$, $P = 0.002$) and $CSE_{BB} = 74.45 + 5.55t + 0.27t^2$ ($r^2 = 0.98$, $P = 0.021$) where CSE_{BR} and CSE_{BB} are cumulative shoot elongation for bareroot and balled-and-burlapped trees, respectively, and t is years after transplanting; 1 cm = 0.4 inch.

Fig. 2. Root regeneration of 6.9-cm (2.7 inches) caliper field-grown red oak trees harvested balled and burlapped (left) and bare (right) in early September after being heeled in pea-gravel in April; 1 cm = 0.4 inch.

turgor and no further wilting was observed during the remainder of the growing season. Leaves on B&B trees did not wilt during the 2001 growing season; rainfall amounts were normal and well distributed during this period. Although precipitation in 2002 was above normal through May, the trees received only 6.4 mm of precipitation between 12 June and 9 July; during this period, all the trees exhibited slight wilting. After irrigation and subsequent precipitation events, all trees recovered fully from wilting, without exhibiting leaf scorch. No wilting was observed in 2003 despite hot, dry conditions.

There was no mortality for red oaks heeled in the pea gravel. All the B&B red oaks heeled in wood chips survived; however, five of six bareroot red oaks heeled in wood chips died. Death of the bareroot trees was attributed to high temperatures resulting from the decomposition of fresh wood chips; temperatures greater than 43 °C (110 °F) were recorded in the root zone (30.5 cm depth) within 5 d after heeling in. Fresh wood chips should not be used to heel in trees.

By early September, extensive root regeneration had occurred in all surviving trees (Fig. 2). Average regenerated root length ranged from 52 to 61 cm (20.5 to 24.0 inches); some roots exceeded 91 cm (35.8 inches). Also, extensive mycorrhizal development was seen for plants heeled in pea gravel and wood chips. Root regeneration potential in a benign substrate exceeded the 45-cm (17.7 inches) average for USDA plant hardiness zone 5 (Gilman, 1997; Watson, 1985) and was similar to predicted annual root extension rates in USDA hardiness zone 8. Establishment, based on obtaining the original spread of the root system [estimated at a diameter 1.5 times the tree height or approximately 4.6 m (15 ft) for a 3.0-m-tall (10 ft) tree], would be reached during the second growing season after transplanting, assuming similar root extension in the 2001 growing season as in 2000. Assuming similar root extension is not unreasonable as trees were regularly irrigated after transplanting during 2001.

There was no difference in central leader elongation among the treatment in 2000, the year before transplanting: 83.8, 61.0, and 55.9 cm (32.99, 24.02, and 22.01 inches) for the B&B trees heeled in wood chips, B&B trees heeled in pea gravel, or bareroot trees heeled in pea gravel, respectively (Table 2). Central leader elongation after transplanting was similar (Fig. 3). Initial average trunk caliper was similar among the treatments: 6.4, 7.6, and 7.9 cm (2.52, 2.99, and 3.11 inches) for the B&B trees heeled in wood chips; B&B trees heeled in pea gravel, and bareroot trees heeled in pea gravel, respectively. After three growing seasons, B&B trees heeled in wood chips had the largest trunk caliper (Fig. 4). There were no differences in average leaf area during the study (data not presented).

Transplant shock is initiated in transplanted dormant green ash and red oak plants because of root loss at harvest and because they elongate shoots and expand leaves before adventitious root regeneration occurs (Arnold and Struve, 1989; Johnson et al., 1984). Dormant transplanted red oak seedlings mediate transplant shock by reducing leaf area, thereby

Table 2. Pre- and post-transplant growth of red oak dug balled and burlapped (B&B) or bareroot (BR) in Mar. 2000 and then mulched in either fresh wood chips (WC) or pea gravel (PG) for 6 months before transplanting into a landscape site.

Treatment	Root	Central leader elongation (cm)[y]				Trunk caliper (cm)[x]				Leaf area (cm^2)[w]		
combination	length (cm)[z]	2000	2001	2002	2003	2000	2001	2002	2003	2001	2002	2003
B&B + WC	53 A[v]	85 A	46 A	53 A	69 A	6.4 A	7.8 A	8.9 A	10.4 B	78 A	95 A	82 A
B&B + PG	61 A	61 A	61 A	60 A	64 A	7.6 A	7.7 A	8.4 A	9.3 A	70 A	77 A	78 A
BR + PG	52 A	55 A	37 A	63 A	39 A	7.9 A	7.2 A	7.6 A	8.6 A	36 A	66 A	53 A

[z]Each value is the mean of the five longest roots on each of six trees; 1 cm = 0.4 inch.
[y]Each value is the mean of the central leader on each of six trees.
[x]Each value is the mean of six trees measured 15.2 cm (6 inches) from the root flair in October.
[w]Each value is the mean of five leaves collected from each of six trees. 1 cm^2 = 0.155 $inch^2$.
[v]Means within a column followed by different letters are significantly different from each other using the Student–Neuman–Keuls test at α = 0.05 level of significance.

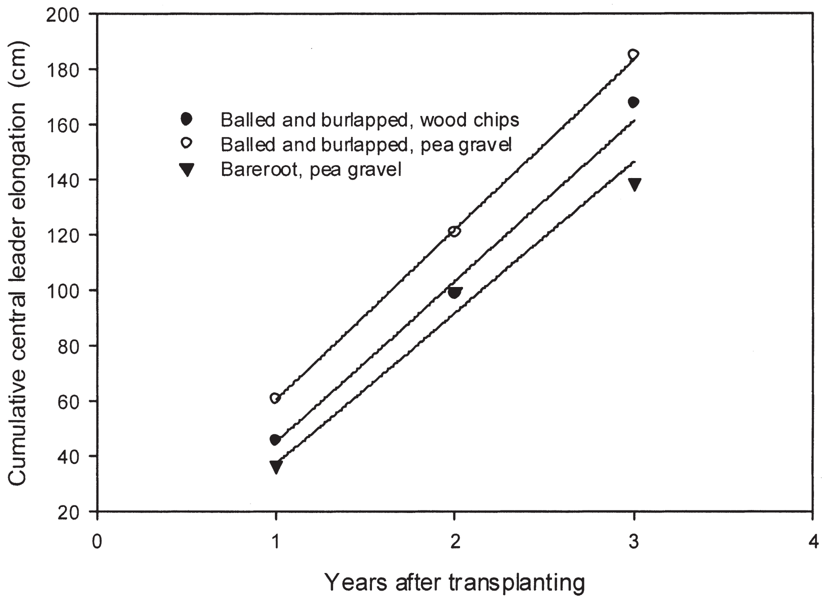

Fig. 3. Cumulative central leader elongation of 6.9 cm (2.7 inches) caliper red oak trees dug balled and burlapped or barerooted in March, heeled-in either wood chips or pea gravel before being transplanted into the landscape in September. Each value is the mean of six trees per treatment. The lines are described by the following equations: $CSE_{BBWC} = -12.48 + 57.99t$ ($r^2 = 0.99$, $P = 0.05$), $CSE_{BBPG} = -0.52 + 61.37t$ ($r^2 = 0.97$, $P = 0.001$) and $CSE_{BRPG} = -17.01 + 54.55t$ ($r^2 = 0.98$, $P = 0.07$) where CSE_{BBWC}, CSE_{BBPG}, and CSE_{BRPG} are cumulative shoot elongation for balled-and-burlapped trees heeled-in wood chips, balled-and-burlapped trees heeled-in pea gravel and bareroot trees heeled-in pea gravel, respectively, and t is years after transplanting; 1 cm = 0.4 inch.

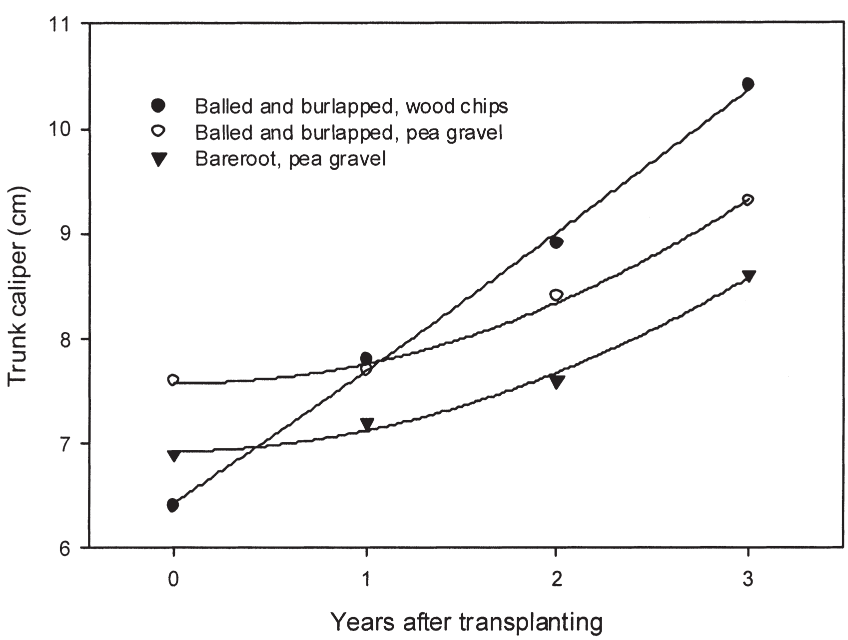

Fig. 4. Trunk caliper of 6.9 cm (2.7 inches) red oak trees dug balled and burlapped or barerooted in March, heeled-in either wood chips or pea gravel before being transplanted into the landscape in September. Each value is the mean of six trees per treatment. The lines are described by the following equations: $C_{BBWC} = 6.44 + 1.24t + 0.025t^2$ ($r^2 = 0.99$, $P = 0.05$), $C_{BBPG} = 7.58 - 0.020t + 0.20t^2$ ($r^2 = 0.98$, $P = 0.06$) and $C_{BRPG} = 6.93 + 0.025t + 0.18t^2$ ($r^2 = 0.97$, $P = 0.05$) where C_{BBWC}, C_{BBPG}, and C_{BRPG} are trunk caliper for balled-and-burlapped trees heeled-in wood chips, balled-and-burlapped trees heeled-in pea gravel and bareroot trees heeled-in pea gravel, respectively, and t is years after transplanting; 1 cm = 0.4 inch.

maintaining unit leaf gas exchange characteristics similar to those of non-transplanted seedlings (Struve and Joly, 1992). In this study, bareroot and B&B plants held in a MGBS showed few transplant shock symptoms. Central leader elongation in 2001 was similar to that in 2000, the season before transplanting. Reduced transplant shock was attributed to extensive root regeneration during the heeling-in period. Root elongation was near the expected annual maximum 68.6 cm (27 inches) in USDA plant hardiness zone 5 (Gilman, 1997; Watson, 1985), presumably because of the benign root zone environment of the MGBS. Pea gravel provided a well-aerated substrate for root regeneration; the irrigation system minimized water stress and delivered mineral nutrients to the root zone. Red oak root regeneration is significantly reduced by even moderate water stress (Larson, 1980; Larson and Whitmore, 1970). Heeling in B&B trees in fresh wood chips yielded similar advantages as pea gravel for B&B red oak; however, the heat generated from the decomposition of fresh wood chips killed bareroot red oaks and should not be used.

An additional aid to establishment in the landscape of field stock heeled in a MGBS is that larger holes have to be dug to accommodate the root system. Larger transplanting holes result in a larger soil volume that is modified, which can increase root regeneration and reduce establishment time (Smalley and Wood, 1995; Watson, 1986; Watson et al., 1992, 1993).

Two measures of establishment following transplant have been proposed: 1) the time required to reestablish the pre-transplant twig and trunk growth or time need to reach a relative constant shoot extension rate and 2) the time required to reestablish the original crown : root spread ratio (Gilman, 1997). The 5.1-cm-caliper 'Summit" green ash trees were established within two growing seasons based on time to required to establish a constant annual twig extension rate. Red oaks established during the first year, based on either the time to establish constant annual twig extension or the time required to resume pre-transplant growth rate. Based on Mar. to Sept. 2001 root elongation and assuming at least 50.8 cm (20 inches) per year root elongation, the red oaks (which averaged 3.0 m tall in Spring 2001) would become established in 1.7 years in USDA hardiness zone 5, assuming an established tree has a 2 root spread : 1 height ratio (Watson and Himelick, 1982). This is almost twice as fast as predicted by Gilman (1990, 1997). Gilman proposed a range of establishment rates from 3 or 12 months per inch tree caliper in USDA hardiness zones 9 or 5, respectively. Establishment based on a third index, the time required to achieve similar small twig xylem water potentials after irrigation is discontinued (Beeson, 1994), could not be determined.

Another benefit of the MGBS is the extension of transplanting season for field-grown stock. Digging plants in spring and placing them in a MGBS allows for summer transplanting. If bareroot stock is used, there is the additional benefit of ease of handling due to reduced plant weight; one person can carry a bareroot 10.2-cm-caliper (4 inches) red oak tree. A disadvantage of the MGBS would be the increased potential for desiccation damage from an exposed root system. Regenerated roots and tree canopies must be protected from desiccation during shipping and handling on the job site. The MGBS reduced transplant shock by creating an environment that promoted rapid root regeneration. Because of increased root regeneration potential, larger planting holes need to be dug, which may also aid in establishment. The MGBS allows for summer transplanting of field-grown material.

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