Propagation Container and Timing of Propagation Affects Growth of Oak Seedlings[1]

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Abstract

Two experiments were conducted to determine the container effect and the timeline of seed propagation on germination and subsequent shoot and root development for container-grown oaks. *Quercus nigra* and *Q. texana* had equal or better growth and better root ratings when acorns were sown in Anderson tree bands compared to five other traditional propagation containers that had at least half the root volume. Germination percentage of *Q. bicolor*, *Q. phellos* and *Q. shumardii* was similar at 10 weeks after sowing whether acorns were sown in March, April, May or June. *Q. bicolor* and *Q. phellos* acorns sown in March had similar height and trunk diameter during the 30 week growing period in year 1 compared to acorns sown in April, May, or June that had a 25, 20, or 15 week growing period, respectively. *Q. shumardii* seedlings had greater shoot growth when acorns were sown in April or May compared to March or June. However, there was no difference in trunk diameter. By the end of the second year, *Q. shumardii* repotted into #3 nursery containers had similar growth among all sowing dates. Though some statistical differences occurred with shoot and root growth during the second year for *Q. bicolor* and *Q. phellos*, these differences did not appear to be the result of propagation time but probably a result of genetic variability.

Index words: acorns, nursery production, root growth.

Species used in this study: *Quercus bicolor*, *Quercus nigra*, *Quercus phellos*, *Quercus shumardii*, *Quercus texana* (formally *Quercus nuttallii).*

Significance to Industry

Oaks are one of the most important landscape trees and account for more than $98M in annual nursery sales. Many oaks are now propagated in containers instead of the field or beds, which reduces root loss, transplant shock and mortality. The root architecture can be impeded when oak seedlings are grown for an extended period in small propagation containers before repotting into larger nursery containers. This research shows that a larger propagation container coupled with changing the propagation period from March to June resulted in seedlings that were similar in height and caliper growth as plants from early-sown acorns, as well as a desirable root system in half the amount of production time. When growing or purchasing container propagated seedling oaks for re-potting, nursery managers need to pay special attention to the seedling root systems. Seedlings that have been left in small propagation containers for an extended period can have excessive root circling or kinked or matted roots on the sides and bottom of the root ball. This can predispose plants to future root problems in the production or landscape phase.

Introduction

Oaks are one of the most important landscape plants and account for more than $98M in nursery sales annually (23). In many nurseries, oaks are propagated by sowing acorns in outdoor beds or rows in late fall or early spring and grown for one to two years. Undercutting is performed several times to prevent tap root growth and enhance fibrous root growth but often at the expense of shoot growth (21). Seedlings are lifted, graded and sold as bare root plants for field and container production. Some nurseries propagate oaks by placing acorns in small containers in late winter/early spring in plastic covered overwintering houses and grow for a year before transplanting into larger containers or field settings.

Several researchers have reported the advantages of container grown oaks compared to bare root plants. Bovre (3) found container grown seedling oaks thrive better than bare root, especially when transplanting takes place outside of the spring planting season. Wilson et al. (27) reported container grown red oak seedlings had larger first order lateral roots, significantly more fibrous roots and had 100% survival the first year after transplanting than bare root stock which suffered from shoot dieback, variable shoot growth, and 25% mortality. Research to promote growth of container grown seedling oaks in heated greenhouses or use of extended photoperiods has shown greater benefits than traditional bare root plants grown in outdoor seed beds (3, 20).

Researchers have investigated several cultural issues pertaining to container grown oaks for ornamental use including seed provenance (15), seed viability (3), fertility (16, 18), irrigation methods (4), container substrate (19), liner growth (9) and root architecture (26). However, the container style, size and dimension can have a tremendous impact on root morphology and plant growth (1, 14, 17). Hathaway and Whitcomb (11) found that seedlings grown in the smallest containers were not significantly different from those in the largest containers when subjected to high fertility rates. Harris and Gilman (10) investigated the detriments of deflected, kinked and constricted roots from container production and the lasting effect into landscape settings. The advantages of cupric hydroxide-treated containers (2) and air root pruning containers (6) that reduce root circling have been reported. However, these containers are not widely used in propagation but used during the liner phase of production with larger container plants.

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Previous research has addressed the issue of root quality from container production (7, 17) and methodology to improve or remediate the root system to reduce the long term effects (8). Most of this research has been conducted with plants at least two years old. However, it has been recognized that delayed transplanting of seedlings grown in small pots can compromise the quality of a tree's root system for years to come (6) and that development of good root architecture should be addressed in the infancy of plant growth and development (25). Therefore, the objective of this project was to evaluate the container effect and the timeline of seed propagation on germination and subsequent shoot and root development for container grown oaks.

Materials and Methods

Experiment 1. Acorns of *Quercus texana* Buckley (formally *Q.nuttallii*, Palmer), Nuttall oak and *Q. nigra* L., water oak, were purchased in fall 2007 and submerged in water to identify viable seed, then stratified in moist peat at 5C (41F) (28). Acorns were removed from chilling on April 23, 2008, and sixty-four of each species were sown individually into each of six container styles: 1) bottomless tree bands [9.2 × 9.2 × 15.2 cm (3⅝ × 3⅝ × 6 in)] (Anderson Dye and Mfg. Co., Portland, OR) (AB), 2) short bottomless tree bands [9.2 × 9.2 × 7.6 cm (3⅝ × 3⅝ × 3 in)] (SAB), 3) Jiffy product 240 [8.9 × 8.9 × 10.2 cm (3½ × 3½ × 4 in)] (Jiffy Products of America, Lorain, OH) (JP), 4) Pro Tray 1801 [7.9 × 7.9 × 8.9 cm (3⅛ × 3⅛ × 3½ in)] (Kunal Plastic, Delhi, India) sprayed with Spinout®, a copper hydroxide root control chemical (SePro, Carmel, IN) (PRO), 5) Ray Leach Con-tainer SC10 cone [3.8 cm diameter × 21 cm (1½ in diameter × 8¼ in)] (Stuewe & Sons, Tangent, OR) (RLC), and 6) RMII-18, pull apart cell tray with individual cells [7.9 × 7.9 × 10.2 cm (3⅛ × 3⅛ × 4 in)] (Rootmaker® Products Company, Huntsville, AL) (RMII). Containers were filled with a pine bark substrate amended with 1.8 kg (3.0 lb) of 19-5-9 (19N-2.2P-7.5K) Osmocote Pro controlled-release fertilizer (The Scotts Co., Marysville, OH) and 0.6 kg (1.0 lb) of Micromax (The Scotts Co., Marysville, OH) per m^3 (per $yard^3$). The acorns were placed on the substrate surface and each was gently pressed until about three fourths of the acorn was recessed into the substrate. Sixteen like containers were placed in a bottom mesh flat, except for the RLC cone which were placed in RL-98 tray, then placed in a poly-covered greenhouse in a completely random design within species at the TSU Nursery Research Center in McMinnville, TN.

Mist irrigation was applied as needed to maintain substrate surface moisture. Germination counts were recorded at 2, 4, 8 and 12 weeks after sowing (data not shown). On October 1, 2008, height and trunk diameter [measured at 1 cm (0.4 in) above substrate] were recorded. Seedlings were removed from their containers and roots were rated on the following scale: 1 = no visible roots on the substrate perimeter, 2 = roots were visible on one-fourth of the substrate perimeter, 3 = roots were visible on half of the substrate perimeter, 4 = roots were visible on three-fourths of the substrate perimeter and 5 = roots entirely covered the perimeter of the root ball. Five seedlings from each replication were randomly selected and harvested for shoot and root dry weights by severing shoots from the roots at the substrate surface. Pine bark substrate was gently blown from the root mass using a compressed air system. Both roots and shoots were dried in a forced-air oven at 56C (133F).

The remaining seedlings were placed back into their respective containers and maintained in the greenhouse until the following spring. Supplemental heat was used if the nighttime temperature was expected to be less than 1.7C (35F). On April 15, 2009, seedlings were measured and roots rated, then harvested as described above.

Experiment 2. Acorns of *Quercus bicolor*, Willd., swamp white oak, *Q. phellos* L., willow oak, and *Q. shumardii* Buckl., shumard oak, were purchased in the fall of 2009 and submerged in water to identify viable seed, then stratified in moist peat at 5C (41F) (28). Sixty-four acorns of each species were removed from chilling on March 10, April 14, May 12, and June 7, 2010, and sown individually into bottomless tree bands [9.2 × 9.2 × 15.2 cm (3⅝ × 3⅝ × 6 in)] (Anderson Dye and Mfg. Co., Portland, OR) containing a pine bark substrate amended with 1.8 kg (3.0 lb) of 19-5-9 (19N-2.2P-7.5K) Osmocote Pro controlled-release fertilizer and 0.6 kg (1.0 lb) of Micromax per m^3 (per $yard^3$). The acorns were sown as described above and immediately placed in a poly-covered greenhouse in a completely random design within species.

Mist irrigation was applied as needed to maintain substrate surface moisture. Germination counts were recorded each week for 30, 25, 21, and 17 weeks after the March 10, April 14, May 12, and June 7 sowing dates, respectively (germination data shown for weeks 5, 10, and 15 after sowing). In October 2010, height and trunk diameter [measured at 1 cm (0.4 in) above substrate] were recorded. Dormant seedlings were maintained in the greenhouse until spring 2010. Supplemental heat was used if the nighttime temperature was less than 1.7C (35F).

In April 2011, 10 seedlings randomly selected from each replication (flat) were potted into 11.3 liter (#3) nursery containers with pine bark substrate amended with 6.5 kg (11.0 lb) of 19-5-9 (19N-2.2P-7.5K) Osmocote Pro controlled-release fertilizer and 0.9 kg (1.5 lb) of Micromax per m^3 (per $yard^3$) then placed in a completely randomized design, by species on an outdoor gravel pad. Prior to potting, the roots on the periphery of the root ball were pruned to eliminate circling roots. Plants were watered with an overhead irrigation system unless rainfall exceeded 1.3 cm (0.5 in) within 12 hours of the next irrigation event. Weed control and pest management were maintained with traditional nursery practices during the growing season.

On September 23, 2011, height and trunk diameter, measured 15 cm (6 in) above the substrate surface, were recorded. Roots were rated using the scale described above (data not shown). Five plants from each experimental unit were harvested for shoot and root dry weights by severing shoots from the roots at the substrate surface. Pine bark substrate was gently blown from the root mass using a compressed air system. Both roots and shoots were dried in a forced-air oven at 56C (133F).

Initially in experiment 1, containers were arranged in a completely randomized design with four replications of sixteen containers for each species. After the first harvest in October 2008, four replications were maintained with five plants per experimental unit. In experiment 2, containers were arranged in a completely randomized design with four replications of sixteen containers for each species. In April 2011, ten plants from each sowing date were repotted and maintained in four replications.

Table 1. Height, trunk diameter, root ratings and root and shoot dry weights of *Quercus nigra* and *Q. texana* from acorns sown in April 2008.

	October 2008					April 2009				
Container style	**Height, cm**	**Trunk diameter, mm[z]**	**Root rating[y]**	**Shoot dry weight, g**	**Root dry weight, g**	**Height, cm**	**Trunk diameter, mm[z]**	**Root rating[y]**	**Shoot dry weight, g**	**Root dry weight, g**
					Q. nigra					
Anderson band (AB)	13.4a[x]	2.8a	2.4c	1.3a	1.4a	35.3a	4.1a	3.8bc	4.1a	2.6a
Modified Anderson band (SAB)	11.1b	2.4a	2.2c	0.9bc	1.3a	33.5ab	3.8a	4.0b	3.5ab	2.5a
Jiffy Pot (JP)	11.6ab	2.5a	2.2c	1.0b	1.1ab	29.4bc	3.7ab	4.0b	3.4ab	2.8a
Pro Tray with Spinout (PRO)	9.7bc	2.5a	2.0c	0.9bc	1.3a	25.0cd	3.4bc	3.5c	2.6bc	2.1a
Ray Leach con-tainer (RLC)	6.4d	2.6a	4.2a	0.7c	0.8bc	17.6e	2.8d	5.0a	1.4c	1.1b
Rootmaker (RMII)	8.7c	2.3a	3.0b	0.8bc	0.7c	23.1d	3.1cd	3.4c	2.5bc	2.1a
LSD	2.1	0.5	0.5	0.3	0.4	5.2	0.4	0.4	1.5	1.0
					Q. texana					
Anderson band (AB)	25.8a	4.5a	3.8bc	1.9a	1.8a	44.4a	8.1a	4.2bc	5.5a	6.9a
Modified Anderson band (SAB)	22.7b	4.1b	3.5cd	1.5bc	1.3b	43.8a	7.0b	4.9a	4.8a	7.0a
Jiffy Pot (JP)	20.3c	4.3ab	3.4d	1.9a	1.3b	38.1ab	7.2b	4.5b	4.5a	5.4ab
Pro Tray with Spinout (PRO)	19.0c	4.2ab	3.3d	1.3bc	1.0bc	32.7b	6.7bc	3.8d	3.5a	4.1b
Ray Leach con-tainer (RLC)	15.6d	3.5c	5.0a	1.1c	0.8c	30.1b	5.9c	5.0a	3.6a	4.4b
Rootmaker (RMII)	19.8c	4.3ab	4.0b	1.6ab	1.4ab	38.5ab	7.3b	4.0cd	4.9a	5.3ab
LSD	2.1	0.3	0.4	0.4	0.5	8.6	0.8	0.3	2.9	2.4

[z]Trunk diameter measured at 1 cm (0.4 in) above container substrate surface.

[y]Rooting rating scale = following scale: 1 = no visible roots on the substrate perimeter, 2 = roots were visible on one-fourth of the substrate perimeter, 3 = roots were visible on half of the substrate perimeter, 4 = roots were visible on three-fourths of the substrate perimeter and 5 = roots entirely covered the perimeter of the root ball.

[x]Means within columns followed by the same letter are not significantly different using Fisher's least significant difference, $P \leq 0.05$.

Germination data was subjected to analysis of variance following arcsine square root transformation. All data were subjected to analysis of variance with the GLM procedure of SAS (Version 9.1, SAS Institute, Cary, NC) and differences among treatments were separated by a Fisher's least significant difference, $P \leq 0.05$.

Results and Discussion

Experiment 1. Acorns were considered germinated when the first set of leaves were unfurling; germination started as early as two weeks after sowing with *Q. texana*. By week 7, about 60% of *Q. nigra* and 70% of the *Q. texana* acorns had uniformly germinated among the propagation containers (data not shown).

On October 1, 2008, six months after sowing, plant height was greatest, 13.4 cm (5.3 in), with *Q. nigra* seedlings in the AB compared to plants in other containers, with the exception of plants in the JP which were similar (Table 1). The smallest plants were propagated in the RLC. Trunk diameter was similar among all seedlings. The RLC had the smallest volume of the containers in this test and roots were more visible on the outside of the root ball and were deflected downward along the outside of the root ball. In contrast, plants in the AB, RMII, JP and PRO had larger root mass, but fewer roots visible along the periphery of the root ball.

Shoot dry weight was similar among the plants harvested in October. Root dry weight was similar with plants grown in the AB, SAB, JP and PRO and significantly more than root weight with plants grown in the RMII and the RLC.

By April 2009, plants had broken dormancy in the poly-covered greenhouse and were vigorous growing. More height growth occurred with plants in the AB compared to the other containers, with the exception of plants in the SAB which were similar (Table 1). The plants in the RLC containers had the least amount of spring shoot growth, 17.6 cm (6.9 in), which was about half compared to the plants in the AB. Trunk diameter was greatest in the AB and SAB, though similar to the seedlings in the JP. Seedlings in the RLC had the smallest trunk diameter.

The RLC plants continued to have the most roots along the outside of the root ball, suggesting that container volume was too small for oak propagation. The SAB and JB had more roots on the periphery than seedlings in the RMII and the PRO.

Shoot dry weight was greater in the AB compared to the RLC, but similar to seedlings grown in the SAB and JP. Root dry weight was similar among seedlings in all containers except for those grown in the RLC, which had the lowest root mass.

Q. texana, a vigorous growing oak, had the greatest height by October 2008 when acorns were sown in the AB compared to other containers (Table 1). Seedlings in RMII, JP, and Pro were shorter than plants in the AB and SAB but were larger than seedlings in the RLC. Trunk diameter was larger with plants in the AB compared to seedlings in the SAB or the RLC, but similar to seedlings in the RMII, JP, and the PRO. Shoot dry weight was largest with plants in the AB and JP and similar to plants in the RMII. Plants in the RLC had the least amount of shoot mass but were similar to plants in the SAB and PRO.

By April 2009, *Q. texana* seedlings had broken dormancy and the largest plants were in the AB and SAB compared to plants in the PRO and RLC but were similar to plants in the JP and RMII. However, trunk diameter was largest in the AB than other treatments. The RLC and SAB plants had the highest root rating with most visible roots on the periphery of the root system. The PRO plants received the lowest root rating but were similar to those in the RMII. Shoot dry weight was similar among all seedlings. Root dry weight in some instances outweighed the shoot dry weight. Plants in the AB and SAB had greater root weights than plants in the PRO or RLC, but similar to those in the JP and RMII.

In most parameters recorded, *Q. texana* had more shoot and root growth than *Q. nigra* seedlings. The *Q. texana* roots were more vigorous and visible on the root ball than the roots of *Q. nigra*. Many of the roots were larger in diameter which resulted in more than twice the root weight. The volume of the AB container (1.1 liter) was at least twice as large as the other containers and allowed adequate space for root growth during the 12 month experiment. Knight et al. (12) found similar results with direct sticking of hollies; shoot and root growth was influenced by container volume. Watkinson and Pill (24) reported that more shoot growth of coreopsis was achieved by using large plug cells and large post-transplanting containers. When bark was removed from the root system after the first 6 months, the container outline could be visually identified, especially with the *Q. texana* seedlings. This is an indication that deflection of the roots was occurring regardless of whether the roots were visible from the periphery of the root ball. By 12 months after sowing, the smaller containers had more roots that were kinked and circling within the container than plants grown in the AB. Many of these roots were not visible from the peripheral view, especially roots in the RMII and the PRO containers. The RMII and PRO have air root and chemical pruning capabilities, respectively; however, the roots in these containers were becoming matted along the bottom of the root ball, indicating that the effectiveness of the air and chemical pruning was failing. The author believes that the root architecture of the seedlings would be better structured if the seedlings had been up-potted into larger containers in the fall (October 2008) after the first 6 months, especially before the roots developed a more aggressive root system with deflected, kinked and circling roots. The only exception would be the seedlings grown in the AB which provided a larger root volume than the other containers. The RLC container was considered unacceptable for oak germination and subsequent growth.

Table 2. Germination percentage of *Quercus bicolor*, *Q. phellos*, and *Q. shumardii* acorns sown in March, April, May and June.

Date of sowing acorns	Week 5	Week 10	Week 15
		Q. bicolor	
March 10	25.0b[z]	70.3a	75.0a
April 14	20.8b	72.9a	77.1a
May 12	39.6ab	66.7a	66.7a
June 7	58.3a	75.0a	75.0a
LSD	32.8	29	27.8
		Q. phellos	
March 10	67.2b	75.0a	75.0b
April 14	84.4a	90.6a	92.2a
May 12	81.2ab	79.7a	84.4ab
June 7	79.7ab	85.9a	89.1a
LSD	16	16.8	14
		Q. shumardii	
March 10	62.5b	85.9a	85.9a
April 14	84.4ab	95.3a	95.3a
May 12	81.2ab	85.9a	87.5a
June 7	93.8a	93.8a	93.8a
LSD	26.5	15.3	14.0

[z]Germination percentage was subjected to analysis of variance following arcsine square root transformation. Means within columns followed by the same letter are not significantly different using Fisher's least significant difference, $P \leq 0.05$.

Experiment 2 — Germination. Acorns were considered germinated when the first set of leaves was unfurling. Regardless of the month *Q. bicolor* acorns were sown, germination was first documented at 4 weeks after sowing (data only shown for weeks 5, 10, and 15) (Table 2). There was a significant increase in germination by week 5 (58.3%) when acorns were sown in June compared to March or April (25 and 20.8%) but had similar germination to the acorns sown in May (39.6%). By week 10, germination was similar across all sowing dates and the trend continued through week 15.

Within 2 weeks of sowing, over 30% of *Q. phellos* acorns had germinated when sown in April, May and June and by week 5, 80% or more had germinated (Table 2). Acorns sown in March did not germinate until week 4, but by week 10, germination percentage was similar among sowing dates. By week 15, germination had increased slightly for April, May and June while acorns sown in March were still at 75%.

Q. shumardii acorns germinated within 2 weeks if sown in April, May and June. Acorns sown in March did not germinate until week 4. By week 5, over 93% of the acorns sown in June had germinated compared to 63% of those sown in March (Table 2). By week 10, germination was similar among sowing dates.

There is no recommended stratification period for *Q. bicolor* which is typical for species in the white oak group. These acorns are often sown in the fall of the year without any prechilling, but if stored as those in this experiment, moisture content of the acorns must be kept above 30%. *Q. phellos* and *Q. shumardii* acorns received more than the 30 to 90 and 60 to 120 day stratification period, respectively (28). The reduction in seed germination for the March sowing is probably due to poor root radical development during the cooler ambient temperatures, whereas acorns sown in May and June responded to the warmer ambient day/night time temperatures. However, sound, undamaged acorns generally have a germination capacity between 75 and 95 percent (22). Germination is hypogeal and under favorable conditions is generally complete in 3 to 5 weeks (22). In this experiment, most of the acorn germination occurred by week 10 and there was no increase in germination percentage after week 15 for the three species.

Experiment 2 — Seedling growth. Seedling growth of *Q. bicolor* after germination (year 1) was fairly uniform with the four sowing dates (Table 3). By the end of the growing season trunk diameter was largest with seedlings from acorns sown in April compared to May and June, and similar to those sown in March. In year 2, the height growth of *Q. bicolor* was more variable than in year 1. Acorns sown in April exhibited the greatest shoot growth compared to plants from the May or June sowing, but were similar to plants from the March sowing. Shoot dry weight of acorns sown in April were larger than May or June and almost double those sown in

Table 3. **Height and trunk diameter growth, shoot and root dry weights, and root:shoot ratio of *Quercus bicolor*, *Q. phellos*, and *Q. shumardii* from acorns sown in March, April, May and June.**

Date of sowing acorns	Height, cm		Trunk diameter, mm		September, Year 2		
	October, Year 1	September, Year 2	October, Year 1[z]	September, Year 2[y]	Shoot dry wt, g	Root dry wt, g	Root to Shoot ratio (R:S)
				Q. bicolor			
March 10	26.6ax	140.1ab	4.8ab	12.2a	77.4c	71.2b	1.00a
April 14	26.7a	159.3a	5.0a	13.5a	132.4a	123.5a	0.94a
May 12	30.2a	135.0b	4.3c	12.7a	99.2b	110.9a	1.10a
June 7	25.0a	127.2b	4.4bc	12.3a	103.9b	115.5a	1.10a
LSD	8.0	22.7	0.4	1.4	21.6	35.2	0.4
				Q. phellos			
March 10	49.7b	228.4a	4.1ab	13.5b	173.6a	31.5b	0.19b
April 14	56.1a	238.9a	4.5a	14.6ab	230.3a	53.6a	0.23b
May 12	49.5b	249.3a	4.1b	14.3ab	251.6a	40.8ab	0.16b
June 7	51.3ab	238.5a	4.1b	15.3a	213.4a	70.1a	0.33a
LSD	6	21.9	0.4	1.5	33.9	25.4	0.4
				Q. shumardii			
March 10	35.0c	228.4a	4.8a	12.4a	150.4a	47.8a	0.32a
April 14	53.5a	211.7a	5.0a	12.9a	165.9a	50.6a	0.29a
May 12	55.5a	207.8a	4.8a	12.6a	166.6a	48.2a	0.29a
June 7	44.6b	219.3a	4.2b	12.2a	214.5a	68.0a	0.31a
LSD	7.5	27.9	0.4	2.2	48.5	28.3	0.2

[z]Trunk diameter measured at 1 cm (0.4 in) above container substrate surface.

[y]Trunk diameter measured at 15 cm (6.0 in) above container substrate surface.

[x]Means within columns followed by the same letter are not significantly different using Fisher's least significant difference, P ≤ 0.05.

March. Oaks are very heterozygous which can be expressed by seedling growth variations (13). Initially, height growth of some oak species was predicted by the size of the acorn (5) but Long and Jones reported seed size was generally unrelated to seedling growth of many oaks, but was more reflective of environmental conditions. The root system was not visually extensive on the perimeter of the root ball and averaged 2.5 out of a rating of 5 with no evidence of circling roots (data not shown) prior to potting in the spring. At the end of year 2, all seedlings had significant amount of roots matted at the bottom (rating 4.6) of the #3 nursery container with very few roots along the sides (rating 2.8) of the root ball. Root mass was similar among sowing dates except for March which had the least amount of dry mass. However, the root to shoot ratio (R:S) was similar among the sowing dates. The R:S of *Q. bicolor* was more than three times the ratio for the other species, indicating slower shoot growth in relation to the root growth.

The April, sown *Q. phellos* acorns grew more rapidly in height than plants in the March or May sowing date and were similar to the June plants (Table 3). However, the trunk diameter from April was the largest compared to May and June and similar to the plants from the March sowing. At the end of year 2, the height growth of acorns sown in April, May and June were very similar with only 21 cm (8.3 in) difference in height between the March (the shortest) and May (the tallest). The trunk growth was largest with the June sowing, but only significantly different in diameter from the March date. Shoot dry weight was similar among all *Q. phellos* seedlings. Root dry weight was variable among the different sowing dates. Seedling root dry weight from the June sowing was more than double the mass from the March sowing though not significantly different from the April and May sowing. Prior to potting into #3 nursery containers, the average root system was rated at 4.2 overall among all sowing dates (data not shown). At the end of year 2, *Q. phellos* had the most uniform growth on the perimeter of the root ball with an average rating of 4.3 along the sides and 4.3 on the bottom. There was root matting at the bottom of the root ball but was not as extensive as *Q. bicolor*. The R:S of *Q. phellos* was greater with the acorns sown in June compared to other months.

Q. shumardii acorns sown in April and May had the most shoot growth compared to acorns sown in March (which had the least growth) and the acorns sown in June (Table 3). Trunk diameter was the smallest with acorns sown in June compared to the other three dates. However, by the end of year 2, height and caliper growth were similar among all sowing dates. The root systems in the Anderson band pot were rated at 3.8 among all sowing dates (data not shown). Less root development was expected on the acorns sown in May and June compared to those sown in March and April; however, root ratings seen on the periphery of the root ball were similar among all sowing dates. At the end of year 2, the roots of *Q. shumardii* in the #3 nursery container were more visible on the upper half of the root ball (rated at 3.5 along the sides), but less (rated 2.8) on the bottom. Shoot and root dry weights were similar among the sowing dates; this was also reflected in the R:S. Overall, this species had the most uniform growth in the test.

Tinus (21) suggested raising two crops of *Q. macrocarpa* by germinating the first crop in a greenhouse in early spring then hardening the plants off in a shade house and initiate the second crop in the early summer. His research report did not include the size of the container or the quality of the ensuing root system. The results of experiment 1 suggests that seedlings in the small propagation containers were held too long before re-potting into larger nursery containers and can predispose seedlings to potential girdling roots. Using a larger propagation container coupled with changing the propagation period from March to June resulted in seedlings that were similar in height and caliper growth as well as root development in half the amount of time during the first year. Acorns sown in March had a 30 week growing period compared to April, May, and June with a 25, 20, and 15 week growing period, respectively. This success can be attributed to the use of propagation containers with an adequate substrate volume to support root growth during propagation and summer growth that prevents roots from extensive circling and producing potential girdling roots. Though some statistical differences occurred with shoot and root growth during year 2, it did not appear to be the result of propagation time but probably a result of genetic variability. The results show that a change from a traditional practice can result in quality container grown liners of oaks without additional cost input.

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