Survival and 14-Year Growth of Black, White, and Swamp White Oaks Established as Bareroot and RPM®-Containerized Planting Stock

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ABSTRACT

In this study, we report the results of a comparison of 5-year survival and 14-year growth of black, white, and swamp white oaks grown from planting stock produced by a conventional bareroot method and stock produced by the Root Production Method (RPM®) of Forrest Keeling Nursery. Five-year survival was 100% for black and white oak grown from RPM® stock, but only 63 and 75%, respectively, for trees grown from bareroot stock. The odds ratio for survival of RPM® planting stock of black and white oaks compared to bareroot stock were 21.9 and 12.1, respectively. All swamp white oak survived. After 14 years, diameter growth was greater for the RPM® than bareroot planting stock and ranged from a 35% increase in black oak to a 6% increase in swamp white oak. Average aboveground fresh weight for trees from RPM® planting stock equaled 530 lb compared to 333 lb for trees from bareroot seedlings ($P < 0.0001$). Compared with traditional bareroot seedlings, survival and growth of RPM® oak planting stock was greater through 14 years.

Keywords: *Quercus alba*, *Quercus velutina*, *Quercus bicolor*, whole tree weight, afforestation, plantation management, survivability, RPM®

With today's emphasis on shortening timber rotations and biomass production for carbon sequestration, wood products, or feedstocks for energy, research programs have been undertaken to increase tree growth and biomass yields (Boerjan 2005, Heinimo and Junquinger 2009, Paquette and Messier 2010, Sannigrahi et al. 2010, Harfouche et al. 2011, Merkle and Cunningham 2011, Osakabe et al. 2011). A technology that has been under development for more than 2 decades may have an important role to play in creating opportunities for landowners interested in shortening rotations and maximizing yields on a per-acre basis. The Root Production Method (RPM®) technology is a patented procedure for production of air-root pruned containerized planting stock developed and owned by Forrest Keeling Nursery, Elsberry, Missouri (Lovelace 1998). Containerized seedlings produced using the RPM® technology have been touted as being superior in survival and growth to bareroot seedlings (Dey et al. 2004, Krekeler et al. 2006). However, limited long-term scientific evidence supporting these claims exists in the literature. In this study, white (*Quercus alba* L.), black (*Q. velutina* Lam.), and swamp white (*Q. bicolor* Willd.) oak grown as RPM® or bareroot stock were compared on the basis of survival (after 5 years in the field) and growth response (1 year in container and 13 years in the field).

Methods

Seed Collection and Handling

Seed was collected from a single mother tree for each of black oak, white oak, and swamp white oak in the fall of 1995 and separated into two equal lots. One lot of each species was placed in plastic bags and stored for 4 weeks under moist conditions at 34° F before early-November planting in a tree nursery. The other lots were sown in bottomless mesh germination flats (18.5 × 14.5 × 2.5 in. deep) filled with a potting medium consisting of composted rice hulls, pine bark, and sand (4:4:2 by volume) amended with Scott's slow release fertilizer (22-3-8, NPK), micronutrients (Scott's Micromax granular), and a wetting agent (Terra-Sorb). Germination flats were wrapped in plastic and held inside a walk-in cooler at 34° F.

RPM® Seedling Production

In early February 1996, germination flats were removed from coolers and placed in a heated greenhouse on wire benches. As roots elongated, air pruning of the tap root occurred at a shallow depth (1.5–2 in.) forcing development of first-order, lateral roots near the root collar. Following completion of the first flush of growth (early March), the largest and most vigorous seedlings were selected (40% cull rate) and potted in plastic bottomless band containers (3.0 × 3.0 × 5.5 in.). These containers were filled with the same potting medium used in the flats, placed on wire benches in greenhouses and grown for approximately 60 days. During early May, seedlings were transplanted into 2.0-gal containers filled with the same potting medium used in the flats, held under mist outside the greenhouses for 2 days, and then lined out under overhead irrigation on white gravel beds for the remainder of their 210-day growing season. RPM® seedlings used in this study had a mean height of 2.23 ft and a mean caliper (1 in. above root collar) of 0.35 in. at the time of planting.

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Bareroot Seedling Production

In November of 1995, acorns were sown at 20/ft^2 to a depth of 1 in. and covered with 2 in. of mulch. One thousand lb/acre of 28-14-14 NPK had been previously incorporated into the tilled silty loam soil before mounding to create 4-ft-wide raised beds. An additional 1,000–1,500 lb/acre of the 28-14-14 NPK were applied in increments of 300–400 lb/acre throughout the remainder of the growing season. Seedlings were lifted in early March of 1997, graded for size (15% culled) and stored at 34° F until planted. At the time of planting, another 25% of the seedlings were culled, resulting in a mean seedling height of 0.81 ft and a caliper (1 in. above root collar) of 0.15 in.

Seedling Establishment

RPM®-containerized seedlings were field-planted during early October 1996. Bareroot seedlings were field-planted in March 1997. The planting site was located at the Horticulture and Agroforestry Research Center, New Franklin, Missouri (39° 02′ N and 92° 46′ W). Soils are Menfro silt loam with a 2% slope. The long-term mean annual precipitation for the study area is 38 in.

Prior to planting, 5-ft strips (20 ft center-to-center) were treated with a combination of glyphosate and simazine for weed control. Seedlings (RPM® and bareroot) were planted in the strips at 10-ft intervals. Four pairs of RPM® and four pairs of bareroot planting stock were randomly planted within single species rows for each of the three oak species. Each species was randomly assigned to 4 of 12 strips.

Data Collection

Survival of RPM® and bareroot planting stock was monitored annually through age 5 before an initial thinning. During a second dormant season thinning in February 2010 (13 years after outplanting), an additional 10, 15, and 5 trees from RPM® planting stock and 10, 7, and 6 trees from bareroot stock of swamp white, black, and white oaks, respectively, were harvested. Selection was made randomly in the office to remove one tree of each surviving pair. The trees to be removed were dictated by the need to create strategically positioned canopy gaps. Trees were cut at groundline and measured for dbh, total height, aboveground fresh weight, and stem-only fresh weight (tree weight minus branch weight). A 1,000-lb load cell connected to a SGCN Dillon electronic meter was hung from the bucket of a skid loader to determine tree and stem-fresh weight. Trees were attached to the load cell by a short cable and lifted until each tree cleared the ground.

Data Analysis

Survival data (first 5 years for all 32 RPM® and bareroot planting stock) were analyzed as a split plot in space. Trees on four of six treatment combinations had 100% survival and, since a logit value cannot be calculated on 100 or 0%, a dead tree (0) was added to each treatment within each of the four replications (rows) for each species. The main plot contained the effect of species and the subplot contained the effect of treatment and species − treatment interaction. Replication within species was used as the denominator to test main plot effects. Since each replication had multiple trees for each treatment (eight trees, four pairs for each treatment), the replication within species × treatment interaction was used as the denominator to test the subplot effects to avoid pseudoreplication. Procedure GLIMMIX in SAS, with logit link and a binomial distribution, was used for the analysis. Differences between logit means were tested using Fisher's least significant difference (LSD). These differences were expressed as odds ratio (antilog of the difference between two average logits).

Growth data from harvested trees were analyzed as a split plot in space in which the main plot contained the effects of species and row within species and the subplot contained the effect of planting stock and the interaction of species with planting stock. Treatment means for each replication were analyzed using PROC MIXED in SAS with Fisher's LSD used to determine mean differences (SAS Institute 2002).

Table 1. Comparison of 5-year survival for three oak species using RPM® and bareroot (BR) stock planted at the Horticulture and Agroforestry Research Farm, New Franklin, Missouri.

	Number planted	% Surv[a]	Odds ratio[b]	P-value
Black oak RPM®	32	100	21.9	0.019
Black oak BR	32	63		
White oak RPM®	32	100	12.1	0.048
White oak BR	32	75		
Swamp white oak RPM®	32	100	1.0	1.000
Swamp white oak BR	32	100		
RPM® (all species)	96	100	6.4	0.026
BR (all species)	96	79		

[a] Percent survival calculated from actual data, prior to logit analysis.
[b] Odds ratios were calculated by taking the antilog of the difference between average logit of RPM® minus average logit of bareroot.

Results and Discussion

Early 5-Year Survival of Bareroot and RPM® Oak Seedlings

For black and white oaks, RPM® survival was greater than bareroot. All RPM® black and white oak survived, compared to 63 and 75% survival, respectively, of bareroot seedlings. At a 95% confidence interval, survival differences between RPM® and bareroot planting stock were significantly better for both black and white oak RPM®s ($P = 0.019$ and 0.048, respectively; Table 1). Higher mortality of black and white oak trees of bareroot origin compared to containerized stock is consistent with what others have reported (Dixon et al. 1981, Parker et al. 1986). In floodplain plantings, Dey et al. (2004) reported RPM® oak seedlings consistently had higher survival (>94%) than the bareroot 1–0 planting stock (76%). Harris and Bassuk (1993) noted that nursery-dug trees may lose more than 90% of their tap root and lateral roots during lifting and transplanting severely impacting survival and growth response. Kormanik et al. (1995) found that 1–0 bareroot seedlings of northern red oak with more than 12 first-order lateral roots (FOLRs) survived and performed better in clearcuts than smaller seedlings with fewer than seven FOLRs. While specific measurements were not taken on the root systems of either the RPM® or bareroot planting stock used in our study, Shaw et al. (2003) found that RPM® planting stock of pin and swamp white oak had 3–7 times the dry mass and 4–9 times the volume of 1–0 bareroot seedlings (Figure 1).

It is apparent from the findings of our research, and those of others, that the use of planting stock with intact large root systems, such as those produced using the RPM® technology, has great potential for significantly improving the survival of some oak species

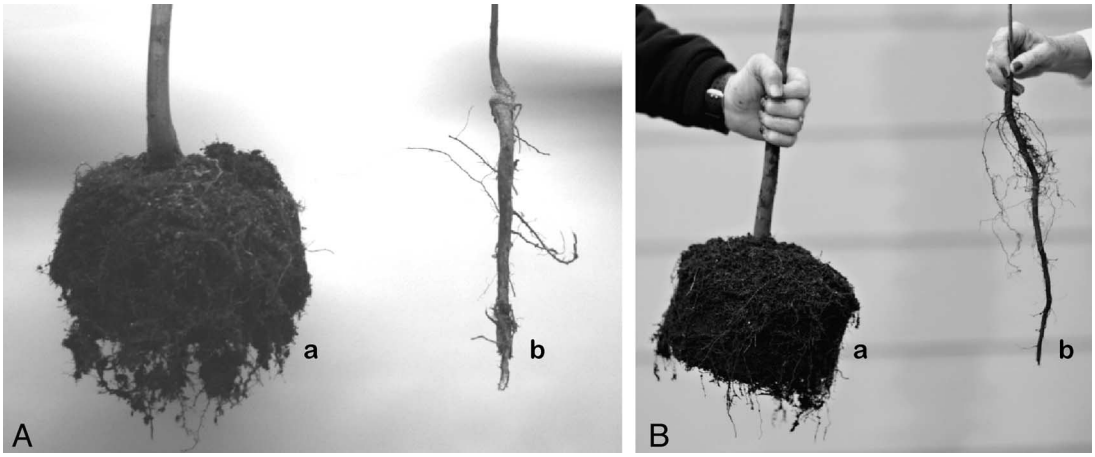

Figure 1. Comparison of root volume between 1-year-old RPM® (a) and bareroot (b) planting stock of white oak (A) and swamp white oak (B).

Table 2. Comparison of 14-year diameter at breast height (dbh), height (ht), tree, and stem-fresh weight for three oak species using RPM® or bareroot (BR) planting stock.

	N	dbh (in.)	P-value	ht (ft)	P-value	Tree weight[a] (lb)	P-value	Stem weight[b] (lb)	P-value
Black oak (RPM®)	15	8.40	0.0002	38.2	0.0088	622	0.0003	405	0.0002
Black oak (BR)	7	6.23		34.4		357		229	
White oak (RPM®)	5	7.76	0.0084	31.7	0.0010	499	0.0043	326	0.0050
White oak (BR)	6	5.85		25.2		231		161	
Swamp white oak (RPM®)	10	7.41	0.4088	33.6	0.1931	409	0.6481	274	0.4217
Swamp white oak (BR)	10	6.99		31.8		378		241	
RPM® (all species)	30	7.96	<0.0001	35.6	<0.0001	530	<0.0001	348	<0.0001
BR (all species)	23	6.46		30.9		333		216	

[a] Aboveground stem plus branches fresh weight.
[b] Total aboveground tree weight minus branch weight.

and could be a valuable tool in the regeneration of oak and other hardwood species.

Fourteen-Year Growth Responses

Following 14 growing seasons, diameters were consistently greater for the RPM® planting stock of black and white oak, ranging in advantage from 35% in black oak to 33% in white oak, as compared to bareroot stock. A 6% increase in diameter of swamp white oak was not significant. RPM® black and white oak also exhibited significant height growth advantages of 11 and 26%, respectively, over their bareroot counterparts (Table 2).

With the emphasis placed on biomass yield in today's markets for carbon sequestration and feedstock for energy, the fresh weight of stems and aboveground tree (stem plus branches) is of great importance. Total aboveground tree weight of RPM® white and black oak was significantly greater (2.16 and 1.74 times greater, respectively) than that of bareroot planting stock. RPM® swamp white oak had 8% greater fresh weight than its bareroot counterpart. The patterns for differences in stem weights (stem minus branches) were similar, with RPM® white oak planting stock producing 2 times greater weight, followed by 76 and 14% increases for RPM® black and swamp white oak, respectively, as compared to bareroot trees.

Many studies have demonstrated the importance of seedling quality in the successful regeneration of oak species (Johnson 1993, Spetich et al. 2002, Dey et al. 2010). Our results suggest a strong correlation between the size and quality of the planting stock and its success 13 years after outplanting. Survival and overall growth of RPM®-produced white and black oak seedlings were significantly greater than survival and growth of their 1–0 bareroot counterparts. While RPM® planting stock of swamp white oak outgrew bareroot seedlings, the differences in survival and growth were not significant.

These results have important implications in the establishment and growth of oak plantations whether for conventional timber, biomass, or other forest values. Our data demonstrate significant survival and growth advantages of using RPM® over 1–0 bareroot planting stock for white and black oak when intensively managed as a plantation on high-quality sites. The cost of RPM® planting stock is much greater than for bareroot seedlings. Although a cost-benefit analysis was not conducted in this study, it is likely that RPM® planting stock is not suited to all regeneration settings. However, numerous forest values exist that might justify the use of RPM® planting stock for tourism and recreation, watershed protection, carbon sequestration, creation of wildlife habitat, and ecological restoration (Pearce 2001). With the difficulties experienced in successfully regenerating many oak species, and the emphasis being placed today on maximizing growth responses, the use of superior oak seedlings with large root systems appears to have merit.

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