Can Growth of Seed-propagated Oaks be Predicted before Lining out in Nursery Rows?[1]

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Abstract

Growth rates of nursery-grown oaks (*Quercus* L.) vary considerably, and many oak species are not commonly grown because of slow growth when young. A method for rapid screening of young oak seedlings to predict potential growth in a production nursery was investigated. Acorns from single maternal trees of four Virginia-native oak species, *Quercus montana* Wild. (chestnut oak), *Quercus palustris* Münchh. (pin oak), *Quercus velutina* Lam. (black oak), and *Quercus alba* L. (white oak) were collected in Blacksburg, VA, in the fall of 1999 and subjected to stratification (moist-chilling) at 5C (41F). Single acorns were then planted in individual cells of 50-cell liner trays and grown in a heated greenhouse until individual seedlings had set first buds. Height at first budset was recorded for individual seedlings. Trees were then transplanted into 3.8 liter (#1) black plastic containers and grown outdoors in Blacksburg, VA, until June 2001, when they were transplanted to field soil. All trees were grown in the ground for three additional growing seasons, and final trunk diameters were measured in February 2004. Height at first budset was not related to trunk diameter at the end of the experiment for any species and was only weakly related to final height for black oak. Trunk diameter of seedlings when planted in field beds 1.5 years from seed was related to trunk diameter at the end of the experiment for all species, but little variation was explained by the relationship for chestnut oak or black oak. Plant height at field planting was not as predictive as trunk diameter for final trunk diameter, except for black oak. The utility of screening a group of oak seedlings at the liner stage for subsequent growth potential is species-specific. Screening white oak by trunk diameter appears especially promising.

Index words: coefficient of variation, field production, native trees, screening, seedling, genetic variability, *Quercus*.

Species used in this study: chestnut oak (*Quercus montana* Wild.); pin oak (*Quercus palustris* Münchh.); black oak (*Quercus velutina* Lam.); white oak (*Quercus alba* L.).

Significance to the Nursery Industry

A rapid method of screening seedlings of oak for future vigor could pay large dividends because rapid growing seedlings could be separated for special management considerations, and slow growers could be discarded before significant investment is made in their production. Screening young seedlings by their height at first bud set does not appear to be useful. Screening #1 container-grown liners by trunk caliper appears useful for white oak and pin oak, but not for chestnut oak and black oak. However, pin oaks were less variable than the other species, and all seedlings were relatively vigorous. Chestnut oak, although often slow growing in native woodland stands, grows rapidly when cultivated in nurseries and should be considered for production as a landscape tree, especially when targeting consumers who seek native species.

Introduction

Plant ecologists have long pondered the attributes that enable a seed or seedling to thrive in an uncertain environment. As well, nursery growers seek to produce superior trees with attributes that include fast growth in the nursery. Oaks as a group are considered a very desirable nursery crop and are grown by most tree-production nurseries. According to one survey, pin oak is the second most popular tree planted in the Unites States and *Quercus rubra* L. (northern red oak) ranks fifteenth (16). Using acorns from selected desirable mother trees as propagules can result in superior trees (22). However, oaks can exhibit tremendous intraspecific variability (2, 10).

Height and stem diameter are the most commonly used measurements when grading seedlings because they are easily measured and sometimes correlate with seedling survival and growth (23). Efforts to classify seedlings for their potential for post-transplant growth by the forest industry have resulted in a standardized system for testing 'root growth potential,' where subsamples of seedlings are potted and held in a test environment for 28 days to evaluate their performance (21). This system integrates environmental conditions, physiological state, and genetic capability and has been utilized by many researchers (e.g., 1, 6, 15).

The relationships among seed size, seedling germination, and early performance are of great interest, but reports from experiments offer mixed results. For example Karrfalt (9) reported that larger acorns led to larger seedlings for northern red oak and white oak, and Tilki (24) reported larger acorns to result in faster seedling emergence and seedling survival. Gonzales (8) reported that seed mass of *Virola koschnyi* Warb., a tropical tree native to Costa Rica, was positively related to seedling stem size, although germination was not related. Gómez (7) found seed mass to be positively associated with most fitness components, although larger seeds tended to suffer more than smaller seeds from predation. However, others have found that seed size was generally not a good predictor of seedling performance (11, 13) or vigor (20). Puttonen (19) reviewed seedling quality tests and suggested that there were too many determining factors, such as environment and nursery practices, to have one test that would have high predictive power for future growth.

Nursery growers have a vested interest in the question of vigor prediction because their economic livelihoods are at stake. As such, they have long been interested in ways to predict which plants will rapidly reach a saleable size and which plants will not. Selection of superior or inferior geno-

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types at an early stage of development can potentially return large economic dividends. Nursery growers would benefit from 'quick cull' methods where seeds or seedlings were screened quickly and easily at an early stage of production. Early screening that identifies inferior trees would probably return the most economic benefits because the investment of labor and overhead would be minimized for inferior trees. Early separation of superior genotypes would also be of benefit because this subgroup could be grown separately, making field-space management more efficient. Such screening would have particular value for native oak species because of their great genetic variability, potential for slow growth, and high value as a native shade tree.

The objective of this study was to determine if and when screening a population of young oak seedlings during production might be most beneficial to predict future growth in a nursery setting. A production system was used where acorns of four native species of oak were germinated and the seedlings transplanted to 3.8 liter (#1 gal) containers. Seedlings were then container grown for an additional year up to transplant (i.e. liner) size and subsequently grown to harvestable size in field beds. Height at the first budset after seed germination was chosen as an early and easy screen since growers could make a quick visual assessment of height. Trunk diameter size of the container-grown liners was also investigated as a potential screening point. Growth patterns of each species were also observed.

Materials and Methods

Acorns from single maternal chestnut oak, pin oak, black oak, and white oak were collected from the campus of Virginia Tech, Blacksburg, VA, in October 1999 and submerged in water. Acorns that did not float were subjected to stratification at 5C (41F) until January 2000. Individual mother trees were randomly selected from campus trees with a heavy seed crop. Provenance of the mother trees is unknown. Single acorns were then planted in individual cells of 50-cell plastic propagation trays (Prop-50-Rd, T.O. Plastics, Clearwater, MN) filled with Sunshine Mix #3 (Sun Gro Horticulture, Bellevue, WA). Individual cells were 4.9 × 5.8 cm (1.9 × 2.3 in) for top diameter and depth, respectively. Sixty-eight, 73, 73, and 80 acorns were planted for chestnut oak, pin oak, white oak, and black oak. Propagation trays were placed in a heated, glass greenhouse [day/night temperature = approximately 22/20C (72/68F)] under natural daylight only on the Virginia Tech campus in Blacksburg, VA. All acorns were randomly placed in propagation trays within each species. Species were separated at planting and throughout the rest of the experiment.

Height at first bud set was recorded for each seedling. Seedlings set first buds by April 14, April 14, March 31, and April 7 for all chestnut, pin, black, and white oaks, respectively. Height of individual seedlings was recorded at this time. All seedlings were tagged and transplanted into trade 3 liter (#1) (C300, Nursery Supplies, Chambersburg, PA) nursery containers filled with non-amended, semicomposted pine bark on April 17–19. Each seedling was fertilized with 10 g (2 tsp) of 15N-3.9P-10K (Osmocote Plus 15-9-12, 8–9 month Northern Formula; Scott's Company, Marysville, OH) and grown outdoors on gravel beds at the Urban Horticulture Center near the Virginia Tech campus. All trees were moved into an overwintering cold frame October 12, 2000, and left in place until June 19–21, 2001, at which time they were transplanted from the containers into Groseclose silt loam soil (clayey, mixed, mesic Typic Hapludults) with a pH of 6.2. Individual trees of each species were randomly planted in double rows in separate beds, with rows and individual trees within rows approximately 0.9 m (3 ft) apart. Greenhouse covering was removed in spring 2001, and plants were grown in full sun until planted in the field. Nursery rows were fertilized after transplanting and annually each subsequent spring with a 10N-4.3P-8.3K fertilizer (10-10-10, Weaver Fertilizer Co., Inc., Winston-Salem, NC) by evenly broadcasting 0.9 kg N (2 lb) per m^2 (10.8 ft^2) of ground area over entire nursery rows. Tree rows were maintained with shredded hardwood bark mulch for the duration of the experiment at a depth of approximately 5 cm (2 in).

Trunk diameter 2 cm (0.8 in) above substrate level was measured on all trees immediately prior to transplanting to field beds. All trees were grown in the ground for the remaining 2001 and the entire 2002 and 2003 growing seasons. Trunk diameters of all trees were measured 15 cm above ground level before budbreak on April 17, 2002, and again on January 20, 2003, and final measurements were made February 19, 2004, approximately four years from the original date seeds were planted. Pin oak trees were thinned in February 2003 to leave every third tree in rows.

Our main objective in this study was to test the efficacy of screening methods for predicting future growth of young seedlings. Observations of growth patterns in nursery production for each species were also made. Comparisons of growth patterns between species were not tested statistically since each species was not mixed in a common statistical design. Descriptive statistics were compiled utilizing the MEANS procedure of SAS (SAS vers. 9.2, SAS Institute, Cary, NC). The following relationships were determined utilizing regression analyses (Sigma Plot 11.0, Systat Software, Inc., San Jose, CA): 1) plant height at first budset after germination vs. plant height at the end of the experiment or 1 year earlier for pin oak, 2) plant height at first budset after germination vs. trunk diameter at the end of the experiment or one year earlier for pin oak, 3) plant height 1.5 years after germination when planted in the field (i.e. liners) vs. plant height at the end of the experiment or one year earlier for pin oak, 4) plant height of liners when planted in the field vs. trunk diameter at the end of the experiment or one year earlier for pin oak, and 5) trunk diameter of liners when planted in the field vs. trunk diameter at the end of the experiment or one year earlier for pin oak.

Results and Discussion

Stage-specific survival of each species is reflected by the number of plants measured at the various dates throughout the experiment (Table 1). Surviving trees include those living plants without major structural defects and those not browsed severely by rabbits. Pin oaks were thinned in February 2003 because their rapid growth would have resulted in severe crowding in nursery rows the following growing season. Final survival in the nursery row was 81, 100, 84, and 72% for chestnut oak, pin oak, white oak, and black oak, respectively. Pin oak grew very rapidly and reached a harvestable size [here considered to be 38–51 mm (1.5–2 in)] a full year before other species. Such rapid growth and a desirable form (i.e., strong central leader) of this species are major reasons that pin oak is a popular crop among nursery producers. At the end of year three, pin oaks were 2.4 m (8 ft) tall, and

Table 1. **Descriptive statistics of *Quercus montana* Wild. (chestnut oak), *Quercus palustris* Münchh. (pin oak), *Quercus velutina* Lam. (black oak), and *Quercus alba* L. (white oak) trees, seed propagated in spring 2000 and grown in field rows until 2004. Shoot height was measured at first bud set (April 2000) after seeds were planted. Seedlings were then transplanted into 3 liter nursery containers and overwintered in unheated cold frames. All trees were transplanted to field rows in June 2001.**

	N	Mean	Max	Min	σ[2y]	CV (%)[x]
	Chestnut oak					
Height April 2000 (cm)	68[z]	5.2	8.7	1.6	3.0	30.1
Trunk diameter (mm)						
October 2000	70	7.2	11.1	3.5	3.2	24.6
June 2001	61	10.4	15.8	2.0	5.9	23.4
April 2002	57	15.6	26.9	8.7	11.6	21.9
January 2003	57	27.4	40.6	10.9	33.6	21.1
February 2004	57	41.4	54.3	20.2	48.0	16.8
	Pin oak					
Height April 2000 (cm)	73	11.4	16.7	7.4	3.8	17.1
Trunk diameter (mm)						
October 2000	73	11.4	14.3	7.0	2.3	13.4
June 2001	73	13.2	16.1	8.7	2.3	11.4
April 2002	73	22.0	28.4	9.1	13.5	16.8
January 2003	73	39.3	54.1	13.9	40.3	16.1
February 2004	26[w]	66.2	83.1	37.0	75.4	13.1
	White oak					
Height April 2000 (cm)	75	6.8	11.7	1.6	3.5	27.5
Trunk diameter (mm)						
October 2000	73	4.4	8.2	1.8	2.7	37.0
June 2001	70	7.2	13.5	1.5	7.0	37.0
April 2002	66	10.5	18.5	5.0	11.0	31.4
January 2003	63	15.3	31.9	4.9	37.2	39.9
February 2004	62	23.7	48.0	6.3	92.8	40.7
	Black oak					
Height April 2000 (cm)	80	6.0	9.6	0.5	2.6	26.5
Trunk Diameter (mm)						
October 2000	80	7.8	12.0	4.6	3.8	25.0
June 2001	68	9.2	14.1	2.6	7.8	30.5
April 2002	65	12.5	19.1	4.5	11.7	27.4
January 2003	58	18.7	29.7	7.1	23.2	25.8
February 2004	58	29.9	47.5	8.8	83.0	30.5

[z]Two recalcitrant acorns not included.
[y]Variance.
[x]Coefficient of variation.
[w]Nursery rows were thinned in February 2003.

chestnut oaks were 1.9 m (6.3 ft) tall (Table 2). After thinning, the additional year resulted pin oaks with a mean trunk diameter of 66.2 mm (2.6 in) and a height of 3.6 m (11.8 ft). The closest species in vigor was chestnut oak, which took an additional year (until Feb 2004) to reach a harvestable size of 41 mm (1.6 in) trunk diameter (Table 1) and 3.2 m (10.6 ft) height. Although not as vigorous as pin oak in our nursery rows, our data indicate that chestnut oak grows rapidly. This species was observed to grow with a strong central leader and excellent branch form. White oak and black oak were in general not vigorous, and neither species had reached a harvestable size four years from seed. Farmer (4) also found that white oak was not a vigorous species and that chestnut oak was much more vigorous. In our study, black oak would be projected to reach harvestable size at the end of another growing season, but white oak would likely not quite be large

Table 2. **Mean height (m) of *Quercus montana* Wild. (chestnut oak), *Quercus palustris* Münchh. (pin oak), *Quercus velutina* Lam. (black oak), and *Quercus alba* L. (white oak) trees two and three growing seasons after transplanting to field beds from 3 liter containers. Number in parentheses = SE of means.**

	Chestnut oak	n	Pin oak	n	White oak	n	Black oak	n
January 20, 2003	1.92 (0.06)	56	2.36 (0.05)	73	0.73 (0.05)	55	1.13 (0.05)	57
February 19, 2004	3.22 (0.10)	56	3.61 (0.09)	26[z]	1.43 (0.08)	55	1.93 (0.08)	57

[z]Nursery row was thinned in February 2003.

enough (Fig. 1). Black oak should reach a trunk diameter of 44 mm (1.7 in), whereas white oak would achieve a trunk diameter of only 35 mm (1.4 in). At the same time, pin oak would grow to a trunk diameter of 97 mm (3.8 in), and chestnut oak would grow to a trunk diameter of 58 mm (2.3 in). This considerable difference in growth rates highlights the difficulties of growing black and white oak profitably. Both of these species are highly desirable in our native forests, and black and white oak trees remaining in urban forest fragments are prized for their stately statue and the ecosystem services they provide. Both of these species are therefore excellent candidates for selection of improved genotypes that would grow faster in nursery production systems.

Relative to the other species, the fast-growing pin oak is less variable. Variance and coefficient of variation (CV) of the various growth-measurement stages for all species are listed in Table 1. CV is a more useful statistic for comparison because it is the standard deviation expressed as percentage of the mean, whereas variance naturally rises as the mean rises. Both statistics are presented because they may be helpful to others when planning the number of replications for a particular experiment using these species at similar growth stages (3, 17). The generally high variation is likely a function of the very heterozygous nature of oak species (12). Long and Jones (13) found the mean CV for seedling growth data of 14 species of oaks in natural settings was 43.8%. After a study of seedling growth that pooled forest tree species in a natural setting, Palik and Pregitzer (18) reported a mean CV of 28.2. The much lower value compared to that reported for oaks by Long and Jones suggests oaks are more variable than most other species. The overall mean CV for the trunk diameter data of our four species was 25.2%. The lower value compared to that reported by Long and Jones is likely due in part to the more controlled conditions of our study.

Height at first budset was not related to trunk diameter at the end of the experiment for any species (data not presented) and was only weakly related to final height for black oak ($r^2 = 0.13$). It is intuitive that height at first budset may be correlated to acorn weight because more food reserves in seeds would likely support a strong first flush of growth from germinating seeds. The height of 1-year-old chestnut oaks has been reported to be highly correlated to acorn weight (14). Farmer (5) found that final size of 1-year-old oak seedlings was strongly related to initial leaf area after germination and that initial leaf area was positively related to acorn size. However, Kormanik et al. (11) determined that even though 1-year-old seedling height of red oaks was correlated with seed size, very high variability made it impractical to develop a nursery protocol of sowing graded acorns instead of grading seedlings after they were lifted from the nursery, and Long and Jones (13) reported that seed size was generally unrelated to seedling growth in their survey of 14 oak species. In all likelihood, larger seeds provide flexibility in plant:environment fitness that may or may not be called into play depending on environmental conditions.

Although we saw no apparent benefit to grading germinated acorns by the height of seedlings at first budset, grading liners at the outplanting stage may be beneficial. All species tested in our experiment showed a relationship between trunk diameter at outplanting and final trunk diameter measured in January 2003 (pin oak) or February 2004 (chestnut oak, white oak, black oak) (Fig. 2). Variability was high, as is particularly evident from the spread of data across the least

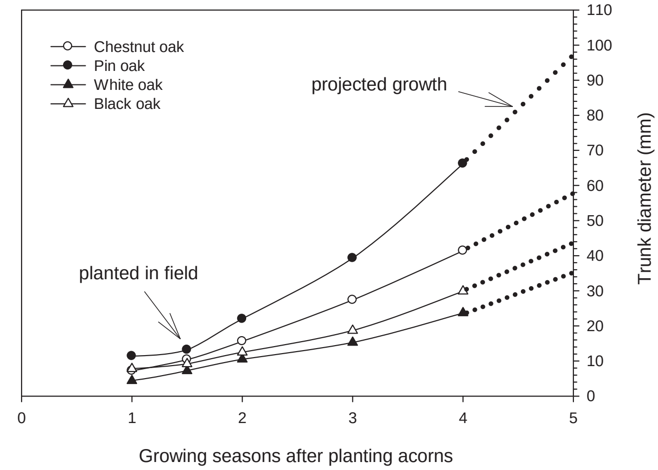

Fig 1. Mean trunk diameter and projected trunk diameter of *Quercus montana* Wild. (chestnut oak), *Quercus palustris* Münchh. (pin oak), *Quercus velutina* Lam. (black oak), and *Quercus alba* L. (white oak) trees in a field nursery production setting. N = 57, 26, 62, and 58 for chestnut oak, pin oak, black oak, and white oak, respectively at season 4. Pin oak was thinned at the end of season 3. N = 73 at the end of season 3 for pin oak.

squares line fit and the low r^2 values for chestnut oak ($r^2 = 0.25$) and black oak ($r^2 = 0.12$). Grading by trunk diameter of the liners of these two species would have little utility because many individual low-graded seedlings may actually be fairly vigorous, and many high-graded seedlings may exhibit low vigor. In contrast, variability was less intense for pin oak ($r^2 = 0.45$), and grading at this size could result in an overall crop of increased vigor. However, this species is so vigorous that even the low-graded trees can be expected to be rapid growers. The relationship between trunk diameter of liners measured June of 2001 and trunk diameter of trees measured in February 2004 was the strongest ($r^2 = 0.68$) for white oak (Fig. 2), in spite of having the highest variability in growth of the four species tested (Table 1). Because this species is also the slowest growing (Fig. 1), high and low grading by trunk diameter of the liners can potentially pay large dividends. For example, the upper 25% of trees could be targeted for accelerated growth and placed in separate nursery beds for common management, whereas the lowest 25% might be discarded as slow growers. Height of liners was not as good of a predictor of final trunk diameter for any species except black oak ($r^2 = 0.41$) but was a better predictor overall of final tree height ($r^2 = 0.26$, 0.42, 0.45, and 0.32 for chestnut oak, pin oak, white oak, and black oak, respectively).

In summary, our data indicate that pin oak is a very vigorous grower and can reach a trunk diameter of 39.3 and 66.2 mm (1.5 and 2.6 in) 3 and 4 years from seed, respectively, under conditions used in our study (Table 1). Chestnut oak is also a vigorous grower and can reach a trunk diameter of 41.4 mm (1.6 in) four years from seed. Black oak and white oak are much less vigorous and will take at least five years from seed to reach trunk diameters of 44 mm (1.7 in) for black oak and 35 mm (1.4 in) for white oak. Variability in growth is wide, especially for the slow-growing white oak. Growth of pin oak is much less variable. There is no utility in grading young seedlings by height at first bud set. Trunk diameter of #1 (trade 1 gal) container-grown liners

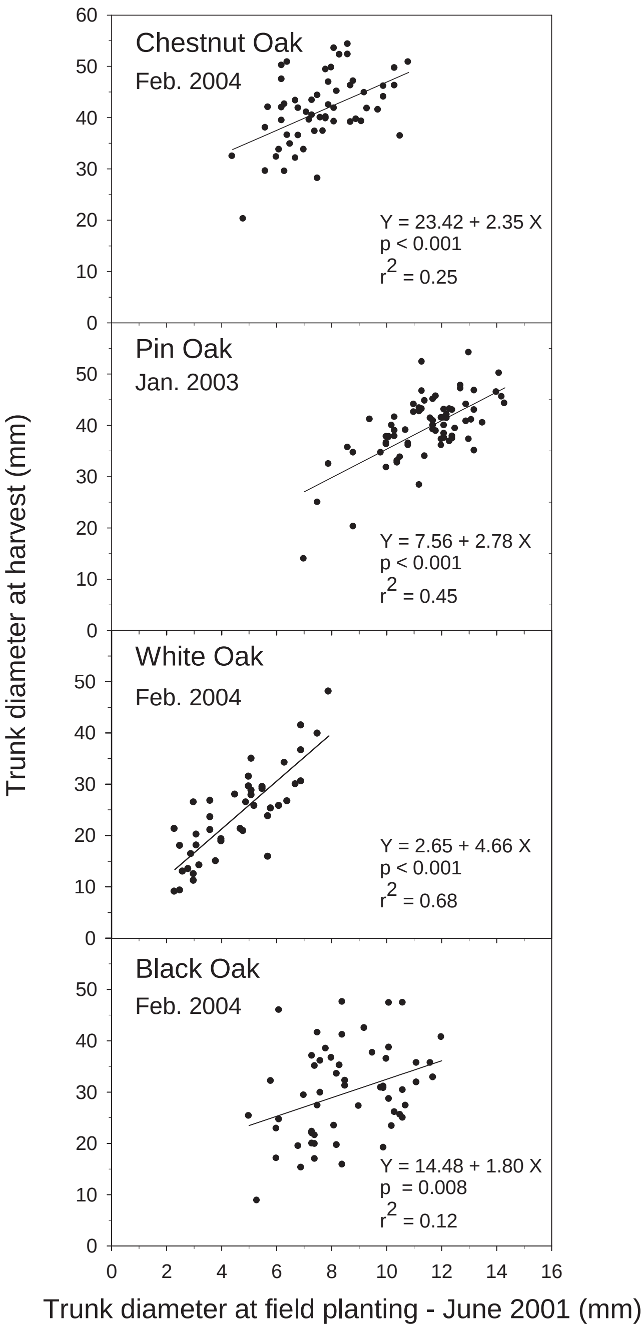

Fig. 2. The relationship between trunk diameter at time of lining out in field nursery rows to trunk diameter at the harvest time for *Quercus montana* Wild. (chestnut oak), *Quercus palustris* Münchh. (pin oak), *Quercus velutina* Lam. (black oak), and *Quercus alba* L. (white oak). Harvest time was determined to be at the end of 4 years after seeding for chestnut oak, black oak, and white oak and 3 years after seeding for pin oak. N = 57, 73, 62, and 58 for chestnut oak, pin oak, black oak, and white oak, respectively.

was related to trunk diameter at the end of the experiment for all species, but the amount of variation described by the relationship varies by species. The highest utility for grading based on the liner size was deemed to be for white oak and pin oak, with the lowest utility deemed to be for chestnut oak and black oak. Chestnut oak proved to be a vigorous grower when cultivated in nursery field production and has good potential as a nursery crop.

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