HERITABILITY OF FIRST-ORDER-LATERAL ROOTS IN FIVE *QUERCUS* SPECIES: EFFECT ON 1-0 SEEDLING QUALITY EVALUATION

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Abstract: Heritability estimates (h^2) were calculated for first-order lateral root (FOLR) numbers on a family plot mean basis for 5 *Quercus* species: *Q. alba*, *Q. falcata*, *Q. michauxii*, *Q. pagoda*, and *Q. rubra*. All species were grown with the same nursery soil fertility protocol and the same seedling bed density (54-67/m^2). Regardless of *Quercus* species, seedlings with the fewest FOLR (0-3) were not generally competitive in the nursery bed environment and had the smallest root collar diameter and height. In any family those individuals with the most robust root systems exhibited the fastest growth and occupied the dominant crown position. Based upon root morphology and stem characteristics, less than 50 percent of the seedlings from any species may be competitive and occupy a dominant crown position in the nursery.

INTRODUCTION

Most *Quercus* species have multiple use value in forest stands because of their importance for forest products and as mast producers for many species of mammals and birds. However, they are characteristically shade intolerant and, thus, are often difficult to regenerate on the better quality sites where intense vegetative competition occurs. This difficulty is most evident in the United States on the high quality mesic sites. Recently the need for advance regeneration of specific sizes has been considered a prerequisite for successful regeneration of *Quercus* species (Loftis and McGee 1993). However, this has proven to be very difficult since it may take several decades or longer to achieve.

A system to develop advanced regeneration by using 1-0 seedlings that are 1-1.5 m tall in the nursery which are then used as enrichment plantings to supplement natural regeneration when a stand is harvested has been presented (Kormanik 1986a, 1990; Kormanik *et al.* 1989, 1995). A prerequisite to successful enrichment plantings is that the large 1-0 seedlings must be capable of remaining in a dominant position for 3-5 years while recovering from transplant shock and establishing a root system. Seedlings with large robust root systems have the best opportunity to achieve this early competitive position (Ruehle and Kormanik 1986). Although a robust root system is normally associated with desirable stem characteristics, large stems themselves are not necessarily related to robust roots and competitive ability after outplanting (Feret and Kreb 1986). The number of first-order-lateral roots (FOLR) has been shown to be positively related to seedling competitiveness both in the nursery and after outplanting and has been a highly heritable trait with some species (Kormanik 1986b, Kormanik *et al.* 1990). Comparable FOLR heritability research has not been reported for *Quercus* species and may be important in evaluating oak seedlings prior to outplanting.

The objective of this paper is to determine the heritability of FOLR for five *Quercus* species and to determine the relationship between FOLR numbers and seedling competitive ability in the nursery.

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METHODS

This research is based on several heritability studies which have been preformed over a 10-12 year period as periodic acorn crops occurred for specific *Quercus* species. All seedlings were grown at the Institute for Tree/Root Biology (ITRB) Experimental nursery (USDA Forest Service Athens, GA USA).

Northern red oak acorns (*Quercus rubra*) for two trials were obtained from the Watauga seed orchard in western Tennessee maintained by Region 8 USDA Forest Service. All other *Quercus* species were collected in forest stands in South Carolina, North Carolina and Georgia as opportunity arose. All acorns used were open-pollinated half-sib collections from specific mother trees with acceptable form and whose crowns were clearly dominant in the main crown canopy. The selected mother trees (10-12 per study) had netting placed underneath the crown to facilitate acorn collection and to ensure that acorns from adjacent trees did not contaminate the selected individuals. The acorns were kept in cold storage (2-4^{0} C) until acorn drop was completed for the species being collected. The acorns were then soaked in water and only those that sank were used in these studies and the floaters were discarded. The acorns, regardless of species, were sown during the latter part of November or early December to obtain nursery bed densities of 54-67/m^2. There were 130 acorns per mother tree (13 acorns in each of 10 rows) initially sown in each plot. The nursery beds were fumigated at recommended rates with methyl bromide prior to sowing.

All oak species were grown under the nursery soil fertility baseline concept developed by the ITRB for production of nursery hardwood planting stock (Kormanik *et al.* 1994) This protocol facilitates evaluation of FOLR without morphological modification of roots or stems by root pruning or stem clipping of developing seedlings. The soil fertility protocol in these heritability trials used soil levels of Ca, K, P, Mg, Cu, Zn and B adjusted to 500, 80, 80, 50, 1-3, 3-8, 0.4-1.2 ppm, based on a standard ammonium acetate extraction, respectively. Nitrogen was applied as NH_4NO_3 at rates equivalent to 1345 Kg/ha. The first two applications were at a rate equivalent to 17 Kg/ha of product and the third at 80 Kg/ha. The next 6 applications were at 168 Kg/ha and the final two, if needed, were 112 Kg/ha. Nitrogen applications started in early to mid-May and continued at 10-day intervals until mid-September. The actual amount of NH_4NO_3 applied varied in different tests depending upon rainfall and other environmental factors.

Seedlings were irrigated with small daily applications of water until the root systems became established. After the first flush was completed and some seedlots were into their second flush, water was applied when soil moisture tensiometers registered 20-30 centibars at a depth of 15-22 cm. Beginning in mid-September until mid-October irrigation was employed only after tensiometers registered 70 centibars. Irrigation was not normally applied after mid-October.

Regardless of oak species, the seedlings were undercut to 25-30 cm and lifted in mid-February. One hundred seedlings were randomly selected from each of the two replications used in this research and data were collected from each seedling on root collar diameter (RCD), height (HT) and number of FOLR greater than 1 mm in diameter proximal to the taproot.

Each of the several studies analyzed consisted of a randomized block design with all families randomly assigned to plots within each of the two replications. However, not all acorns germinated or survived so number of seedlings varied by species and seedlot. Plot means were computed for the variables height, root collar diameter, and first-order-lateral-roots. Heritability (h^2) estimates were computed for FOLR number for each study according to: Kormanik *et al.* (1990) as:

$$h^2 = \frac{MS_F - MS_{RF}}{MS_F}$$

where MS_F = mean square for family and MS_{RF} = mean square for the replication x family interaction, which were obtained from the analysis of variance for the randomized block designs. An estimate of the standard error of h^2 was computed as:

$$S.E.(h^2) = \left[\frac{2d^2(d+n-2)}{n(d-2)^2(d-4)} \cdot \frac{MS^2_{RF}}{MS^2_F} \right]^{0.5}$$

where d = degrees of freedom for family and n = degrees of freedom for the replication x family interaction.

RESULTS AND DISCUSSION

Heritability Estimates

Heritability estimates (h^2) based on plot mean values for the five *Quercus* species are shown in Table 1. Where multiple studies are shown, the mother trees and years involved were different. Study 2 and 3 for *Q. rubra* were conducted with acorns obtained from the U.S. Forest Services' Region 8 Watauga seed orchard located in western Tennessee and the original parent trees were from various locations in Tennessee, North Carolina and Virginia. Acorns from all other studies essentially represented local collection from specific areas and may not reflect the heritability accurately for the species. However, earlier heritability estimates for loblolly pine (*Pinus taeda*) for FOLR were regional and estimates varied little during several years of testing even though different nursery fertility protocols were used to produce seedlings (Kormanik *et al.* 1990; 1991).

A pronounced difference in root morphology was apparent between *Q. rubra* and the other four oak species when assessing FOLR development. The diameters of many FOLR on *Q. rubra* seedlings were most frequently in the range of 2-3 mm with a few having diameters up to 4 mm. The FOLR of the other species were primarily in the range of 1-2 mm even though grown with the same seedling bed density.

Table 1--First-order-lateral-roots (FOLR) heritability estimates for 5 *Quercus* species in several studies.

Study	Heritability	Standard Error
	Q. rubra	
1	0.898	0.153
2	0.870	0.114
3	0.843	0.235
	Q. pagoda	
1	0.904	0.104
2	0.783	0.271
3	0.558	0.428
	Q. falcata	
1	0.656	0.333
	Q. alba	
1	0.843	0.138
2	0.918	0.073
	Q. michauxii	
1	0.742	0.227

Seedling Morphology and Stratification for FOLR

All oak species studied here have been observed to share a common trait. That is less than 50 percent of the seedlings have more than the mean FOLR number for that species. Furthermore, those seedlings, regardless of species, producing few lateral roots were predominantly in the lower nursery bed competitive position and have been found to be least competitive when they have been outplanted. Typical examples of the distribution of seedlings stratified by FOLR number are shown in Figure 1. In all cases, the number of seedlings exhibiting poor root morphology represents more than 50 percent of the seedling population. Characteristically in all heritability tests thus far conducted, the mean number of FOLR for open pollinated half-sib *Quercus* progeny has fallen between 4 and 6 except for *Q. falata*. This species tends to compete most successfully on the drier upland sites and tends to produce few FOLR except on the most vigorous seedlings.

Examples of the seedling morphological and growth characteristics are shown in Tables 2A and 2B for *Q. rubra* and *Q. alba*.[1] The *Q. rubra* acorns for this test were from single tree selections from the U.S. Forest Services' Watauga seed orchard. The *Q. alba* acorns were collected from forest stands in different locations throughout the Piedmont area in Georgia. In these tables the ranges and mean values are given for each family for FOLR numbers, RCD and HT of individuals from each half-sib family. During the past decade results of these trials with oak have demonstrated that individual seedlings having more than the mean number of FOLR for a given half-sib family will also have an RCD and HT greater than the mean. We have found that the mean number of FOLR from a given half-sib family is important in identifying the percentages of high quality competitive seedlings potentially available for out planting (Kormanik *et al.* 1995). All *Quercus* species studied thus far have comparative FOLR relationship with other morphological traits shown in Tables 2A and 2B. The same seedlots tested simultaneously in different locations and under different nursery protocols have comparable seedling percentages above and below the FOLR mean value even though the seedlings were of significantly different sizes.[1] However, it is unclear whether the best seedlings from the families with the lowest mean FOLR (i.e., Table 2A, sibling lots 2-23-850) can compete with the best from the families with the highest FOLR. Research is currently being conducted to answer this.

Of all the oak species investigated, *Q. alba* has been the most inconsistent performer in the nursery trials because of the poor germination exhibited by many sibling seedlots and the effect on seedling growth when powdery mildew (*Uncinula salicis*) characteristically develops during the middle of the growing season. It has not been clarified whether the small seedling size and fewer FOLR numbers are inherent to the species or the result of repeated infection by powdery mildew.

In all *Quercus* heritability studies thus far conducted with sibling seedlots, we have found no correlations between number of flushes, FOLR numbers, and seedling sizes in the nursery. Thus, it is quite apparent that the number of flushes are not under the same biological control as internodal elongation.

SUMMARY

1. First-order-lateral-root development appears to be a highly heritable trait in all *Quercus* species studied in these investigations.
2. FOLR development is closely related to seedling sizes and competitive position in the nursery bed. The larger numbers of FOLR are associated with the most competitive seedlings and the smallest with the least competitive ones.
3. The most competitive *Quercus* seedlings in any sibling population will be those that have more than the mean number FOLR for that sibling population.
4. Characteristically in these investigations desirable or competitive *Quercus* seedling represent less than 50 percent of the acorns that germinate and survive as 1-0 nursery stock.

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[1]Data from all studies are on file at the ITRB Forestry Sciences Lab, Athens, GA 30602

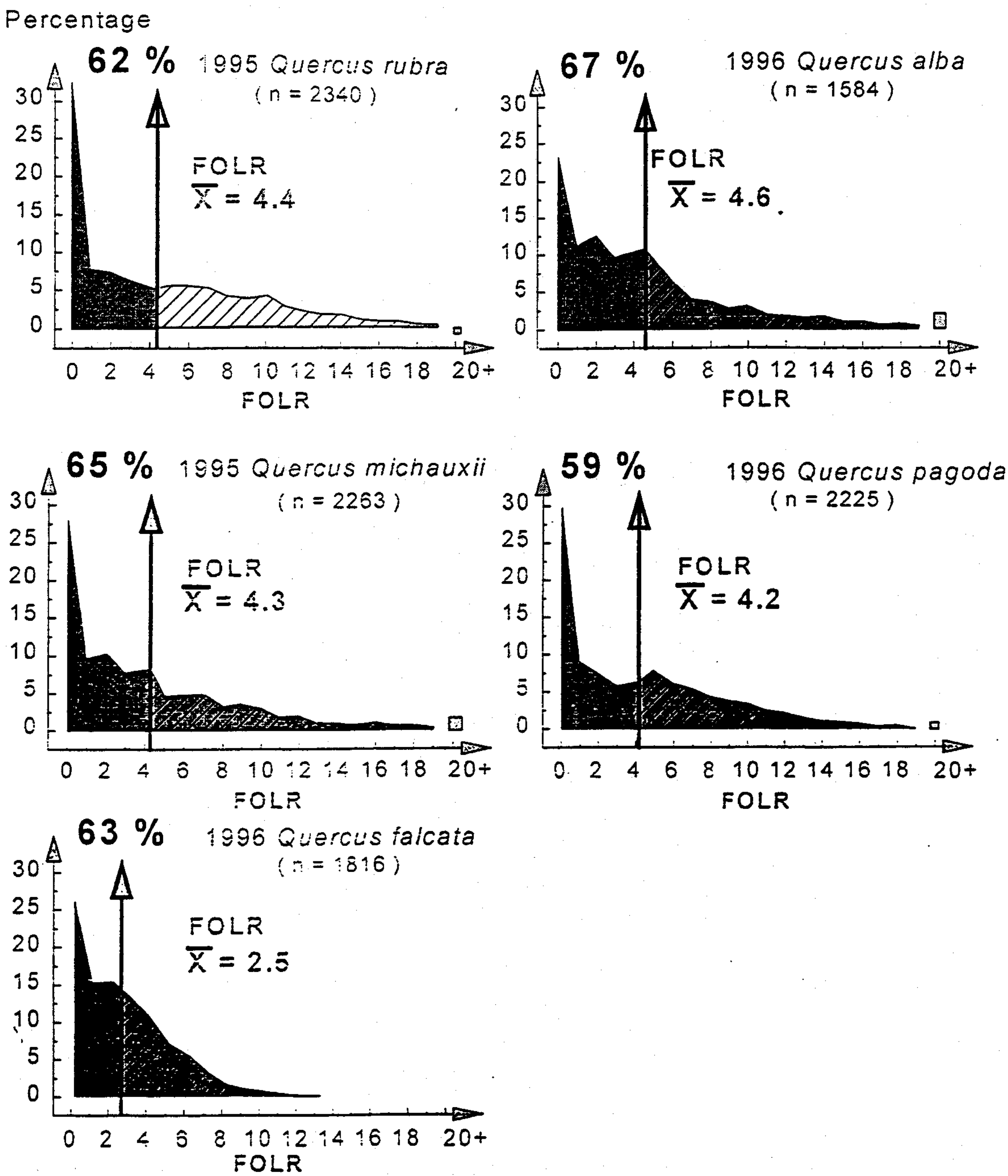

Figure 1. First-order-lateral-root (FOLR) distribution, mean FOLR values, and percentage of 1-0 seedlings having fewer than the mean FOLR value for the *Quercus* species. Percentages of seedlings with more than 19 FOLR were combined and presented as 20+.

Table 2A. *Quercus rubra* seedlings' root and stem morphological and growth characteristics.

1995	FOLR Number		Percent less than mean[1]	RCD (mm)		Ht (cm)	
Family	Mean	Range	$\leq x$	Mean	Range	Mean	Range
1-14-915	6.4	0-26	58	9.8	3.9-18.7	125	22-223
2-10-540	5.7	0-23	54	8.4	3.7-15.8	135	40-262
2-19-630	4.6	0-25	57	9.0	2.9-17.1	131	43-238
2-23-850	2.3	0-25	72	6.2	1.0-16.9	73	8-207
2-29-565	5.2	0-24	58	9.8	3.2-19.2	134	18-260
2-6-735	4.0	0-16	63	9.1	3.4-17.6	117	28-211
3-3-526	4.9	0-19	54	9.1	3.3-15.7	114	33-243
4-14-2459	5.9	1-20	52	10.5	3.4-18.9	125	22-253
4-2-902	3.6	0-15	63	8.4	3.6-15.2	124	46-223
4-27-100	4.2	0-19	56	9.3	2.9-17.9	141	33-243
4-4-882	4.0	0-19	57	8.8	3.9-16.4	126	47-243
6-14-200	5.0	0-20	58	8.5	3.0-15.69	121	41-232

[1]The percent of seedlings in a given family with their FOLR less than the mean FOLR number for that family.

Table 2B. *Quercus alba* seedlings' root and stem morphological and growth characteristics.

1995	FOLR Number		Percent less than mean[1]	RCD (mm)		Ht (cm)	
Family	Mean	Range	$\leq x$	Mean	Range	Mean	Range
KYWO11	3.4	0-17	63	7.5	2.0-13.8	46	12-128
KYWO 31	3.0	0-19	66	8.4	3.0-15.3	35	8-104
NAWO-01	2.5	0-16	67	7.2	3.2-13.6	28	8-87
NAWO 23	4.1	0-22	62	8.2	2.9-15.2	48	8-142
SAWO 28	6.2	0-36	64	8.4	2.2-19.3	45	12-171
NAWO-24	3.8	0-21	60	7.9	2.8-15.0	39	14-147
NAWO-29	2.3	0-18	67	6.5	1.0-15.3	25	8-100
SAWO 12	2.8	0-16	58	7.4	2.4-13.0	36	11-112
NAWO-28	2.1	0-18	72	6.5	2.5-11.6	24	6-68
SAWO 14	4.6	0-32	64	8.6	2.7-18.4	46	12-151
SAWO 3	3.9	0-27	61	8.7	3.6-18.0	39	12-110
SAWO 7	3.6	0-23	61	9.0	2.7-17.4	48	12-134

[1]The percent of seedlings in a given family with their FOLR less than the mean FOLR number for that family.

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