Performance of Nuttal Oak (*Querqus texana* Buckl.) Provenances at Age 10 in the Western Gulf Region

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Abstract: Nuttall oak (*Quercus texana* Buckl.) is a member of the red oak family with a natural range restricted to the bottomlands of the Gulf Coastal Plain from Alabama to Texas and from Missouri to the coast. It is extremely hardy and fast growing and is therefore a highly desirable species for bottomland planting and restoration. Three series of three tests each of Nuttall oak were established by members of the Western Gulf Forest Tree Improvement Program at three locations transecting the central part of the range in a north-south direction. The three series included 28-42 different half-sib families from throughout the western and northern part of the natural range. These families were arbitrarily divided into provenances based on the river basin in which the parent originated. The primary recommendations on wild seed procurement made at age 5 were confirmed at age 10. The Red River provenance had the best growth performance in Series 3, but it was not represented in the other two test series. The best provenance in Series 2, the Ouachita River provenance, ranked second in Series 3. Family-mean heritability estimates were high ranging from 0.73-0.98 for height and 0.57-0.78 for diameter indicating that the potential for genetic improvement of growth in Nuttall oak is substantial. Orchard establishment with tested parents began in 2007 based on 10-year old performance estimates from 115 individuals. The 30 selected parents should produce seed with a 17% gain in 10-year-old volume over wild seed.

Keywords: Provenance variation, heritability, genotype x environment interactions, Nuttall oak, *Quercus texana* Buckl.

INTRODUCTION

Nuttall oak (*Quercus texana* Buckl. formally Q. *nuttallii* Palmer) is a member of the red oak group. It has a natural range restricted to the bottomlands of the Gulf Coastal Plain of the southern US from Alabama to eastern Texas, north in the Mississippi Valley to Arkansas, southeastern Missouri and western Tennessee (Figure 1, Filer 1990). It is the most tolerant of the red oak species to heavy, poorly drained, alluvial clay soils. Therefore, Nuttall oak is favored for bottomland planting because it exhibits good survival on a range of sites and is fast growing (Ducks Unlimited 2001). Nuttall oak is an important species because it produces high quality

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sawtimber and because it is beneficial to wildlife, producing large acorn crops at young ages. Like most oaks, it is shade intolerant and planting open areas following harvesting is a viable method of stand restoration. Previous studies have focused on natural regeneration, direct seeding, and comparison of growth performance of Nuttall oak with other species (Bonner 1966, Johnson 1975, Krinard and Johnson 1981). Genetic information is limited to the previously reported five-year results from the plantings in this study (Gwaze et al. 2003). Provenances along the Red and Ouachita Rivers appeared to be the best sources of wild seed. Family-mean heritabilities were high indicating that individual selection would be effective in improving height, diameter, and volume growth.

These plantings are part of the Western Gulf Forest Tree Improvement Program (WGFTIP) effort to establish seed orchards with progeny tested parents from this species. Open-pollinated seed were collected from 210 parents and established in five series of progeny tests across multiple locations. Collectively, the test series included samples from throughout the northern, central, and western range of Nuttall oak, providing an opportunity to determine provenance and within-provenance variation in the species. Scion material was collected from most of the parent trees and preserved in scion banks maintained by the Texas Forest Service and the Mississippi Forestry Commission. Progeny test information will be used to select tested parents for seed orchard establishment. This paper reports on 10-year survival and growth results from the first three test series. The primary objectives were to provide information on seed sources to those buying wild seed and to estimate expected gains from seed orchard establishment. Genotype by environment interaction, heritabilities and age-age phenotypic correlations were considered.

MATERIALS AND METHODS

Three series of three tests each were established at three locations: Desha and Lonoke Counties in Arkansas and Sharkey County in Mississippi (Figure 1, Table 1). Series 1 was established in 1994, series 2 in 1995 and series 3 in 1997. The three series included 28 to 42 different half-sib families. Families were arbitrarily divided into provenances based on the river basin in which they originated. The provenances were Black-White, Ouachita, Mississippi, Red, and Tallahatchie-Yalobusha Rivers. The sixth provenance (Western Region) originated in the western fringe of the main natural range of the species and was not representative of a single river drainage (Figure 2, Table 2). Some provenances were represented in all three tests series while others were represented in only one (Table 3). There were no families in common between test series.

The test designs were the same at each location, a randomized complete block design replicated ten times with four-tree row plots for families. Spacing was 3 x 3 m in all tests. All tests were assessed at 10 years of age for survival, height (HT, m) and diameter (DBH, cm). Height and diameter were used to calculate volume of each living tree using the following cone volume equation:

$$Volume\ (dm^3) = HT \bullet DBH^2 \bullet 0.02618$$

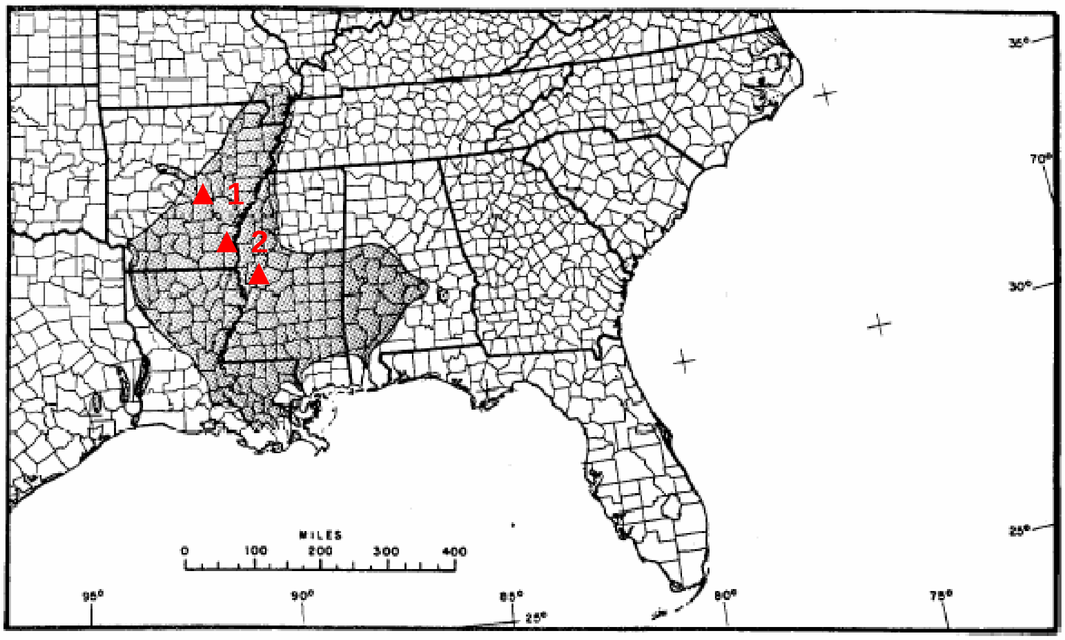

Figure 1. Natural distribution of *Quercus texana* Buckl. (formally Q. *nuttallii* Palmer) (Filer 1990). Progeny test locations are marked with ▲.

Table 1. Details of field tests of Nuttall oak provenances in the USA for all series.

Test (Figure 1)	Cooperator	Location		Mean Rainfall (mm)
		County	State	
1	Arkansas Forestry Commission	Lonoke	Arkansas	1041-1143
2	Potlatch	Desha	Arkansas	1168-1170
3	Mississippi Forestry Commission	Sharkey	Mississippi	1168-1170

Plot means were used for all analyses. Analyses were carried out for survival, height, diameter and volume for each series separately. In each series, data were pooled across the tests and the SAS PROC GLM procedure with a random statement for mixed models (SAS Institute 1988) was used to test for significant differences among sites, families, provenances, replications and the interactions between site and provenance, replication and provenance, and site and family. The following linear model was used for the pooled analysis across sites in each series:

$$Y_{ijklm} = \mu + S_i + R_{j(i)} + P_k + F_{l(k)} + SP_{ik} + SF_{il(k)} + e_{ijklm}$$

where Y_{ijklm} is the observation on the m^{th} plot of the l^{th} family of the k^{th} provenance in the j^{th} replication in the i^{th} site, μ is the population mean, S_i is the random variable for site,

$R_{j(i)}$ is the random variable for replication nested within site, P_j is the fixed effect of provenance, $F_{l(k)}$ is the random variable for family nested within provenance, SP_{ik} is the random interaction site by provenance, $SF_{il(k)}$ is the random interaction site by family nested within provenance, e_{ijklm} is the error term.

Table 2. Details of seed origin of Nuttall oak provenances in the three series. Series number is in parenthesis.

Provenance number	Provenance Name	State	Counties/Parishes
1	Western Region	Texas Louisiana	Liberty (1,3), Smith (2), Tyler (3) Beauregard (3)
2	Black-White Rivers	Arkansas	Arkansas (2), Clay (2), Monroe (2), Prairie (2), Randolph (2,3), Woodruff (3)
3	Ouachita River	Arkansas	Clark (3), Union (1,2,3)
4	Mississippi River	Arkansas Louisiana Mississippi	Mississippi (1,2), Chicot (1) Franklin (3), Richland (3), Tensas (3) Bolivar (1), Issaquena (1), Washington (1)
5	Red River	Louisiana	Bienville (3), Bossier (3), Caddo (3)
6	Tallahatchie-Yalobusha Rivers	Mississippi	Leflore (1), Quitman (1), Grenada (1), Tallahatchie (1), Union (1)

Where significant differences were detected among provenances in the pooled data, Duncan's Multiple Range Test was used to compare means using site x provenance as the error term. This should be viewed as indicative only as the actual error term requires a pseudo F-test with a contribution from the family within provenance variance. Variance components were estimated using the VARCOMP procedure in SAS (SAS Institute 1988). Heritability estimates were determined using family variances for individual trees and at the family mean level. Since single-site heritability estimates are biased upwards because of genotype-environment interaction, only unbiased heritability was estimated using data pooled across the sites as for individual tree heritability [1] and family mean heritability [2] as

$$h^2_{F(P)} = 4 \text{ x } \sigma^2_{F(P)} / [\sigma^2_{F(P)} + \sigma^2_{SF(P)} + \sigma^2_e], \quad [1]$$

$$h^2_{F(P)} = \sigma^2_{F(P)} / [\sigma^2_{F(P)} + \sigma^2_{SF(P)} / s + \sigma^2_e / nrs] \quad [2]$$

where:

n = mean for number of trees per plot, r =number of replicates and s =number of sites.

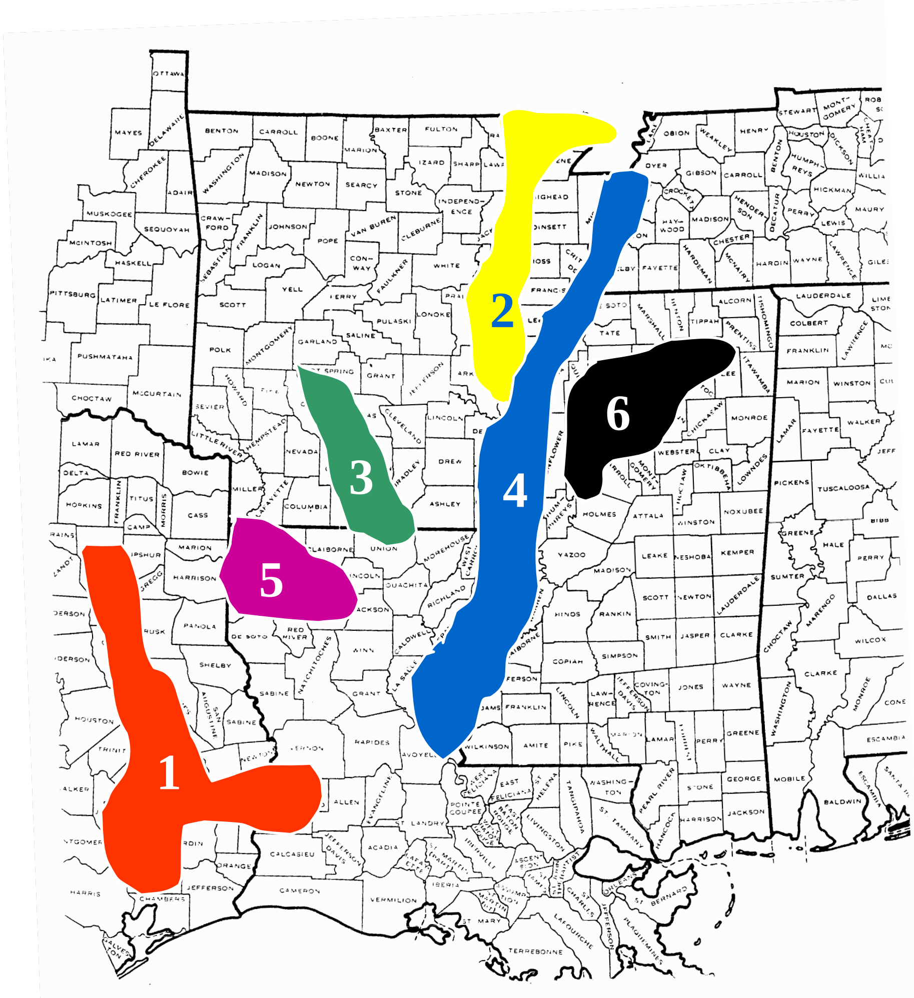

Figure 2. County/Parish locations of families used in the study are: Western Region (Provenance 1), Black -White Rivers (Provenance 2), Ouachita River (Provenance 3), Mississippi River (Provenance 4), Red River (Provenance 5) and Tallahatchie-Yalobusha Rivers (Provenance 6).

Table 3. The number of open-pollinated families representing each provenance by test series.

		Test Series			
	Provenance	1	2	3	Total
1	Western Region (WR)	15	3	12	30
2	Black – White Rivers (BW)		20	5	25
3	Ouachita River (OU)	6	2	6	14
4	Mississippi River (MS)	12	3	4	19
5	Red River (RR)			12	12
6	Tallahatchie – Yalobusha Rivers (TY)	8			8

Genotype by environment interaction (GxE) was evaluated for both the provenance and family level using GLM (SAS 1988). The family-mean correlations among different traits and among the same trait at different ages were estimated as product-moment correlations using PROC CORR in SAS (SAS 1988).

RESULTS AND DISCUSSION

Location means by test series are summarized in Table 4. Survival was outstanding at all locations with the exception of Test Series 1 at Desha County. Even there, survival was operationally acceptable at 73 percent. These survivals, which were obtained with bare root seedlings, emphasized the hardiness of this species and its suitability for reforestation and reclamation efforts. Growth rates were acceptable for oaks at all three locations ranging from 5.2 m to 8.1 m for 10-year height.

Table 4. Location means by test series.

	Survival (%)	Height (m)	Diameter (cm)	Volume (dm^3/tree)
Lonoke				
Series 1	96.0	8.1	9.8	21.6
Series 2	98.2	7.0	9.2	17.4
Series 3	93.4	7.7	9.5	19.5
Desha				
Series 1	73.4	5.5	6.6	5.9
Series 2	97.4	7.7	8.7	17.7
Series 3	91.5	5.2	6.3	6.6
Sharkey				
Series 1	80.5	5.7	7.2	7.7
Series 2	97.1	5.8	8.2	11.2
Series 3	92.0	5.2	6.5	6.6

Provenance Differences – Wild Seed Movement

There were significant differences ($P < 0.05$) among provenances for survival at age 10 in only the first series where mean performance ranged from 79.3 to 87.4 percent. The Ouachita River families had the highest survival while the Western provenance families had the poorest. Height differences were only marginally significant (alpha <0.10) in Series 2 and 3 while diameter varied significantly in all three test series (Table 5).

Volume per living tree was only marginally significant (alpha <0.10) in Series 3. The trend was for the Ouachita and Red River provenances to be the best while the Western provenance was poor to intermediate in performance.

Provenance by site interaction was significant for height, diameter and volume in both series 1 and 3 but only significant for survival in series 2. In only two cases did this GxE interaction term explain more of the variation than did the provenance effect. The first instance was survival in series 2 where the overall average exceeded 97 percent and any differences would be operationally meaningless. The second instance was for live-tree volume in Series 1 where the interaction resulted from changes in variance and rank changes were among intermediate sources (data not shown).

Table 5. Mean squares for analysis of variance for survival, height, diameter and volume at 10 years for three series of Nuttall oak provenance tests [1].

Source of variance	DF	Survival (%)	Height (m)	DBH (cm)	Volume (dm^3/tree)
Series 1					
Site (S)	2	22577.4***	318.8***	495.2***	9997.3***
Replication (Site) (R (S))	27	1966.0***	10.6***	23.0***	373.3***
Provenance (P)	3	4064.1**	5.5ns	63.2**	705.8ns
SXP	6	282.6ns	2.2**	10.2**	210.0***
PXR(S)	81	363.3ns	0.6ns	2.1ns	29.6ns
Family (F(P))	38	630.3ns	2.2***	7.6***	107.1***
SXF(P)	72	500.0**	0.8**	3.3***	49.1***
Residual	990	365.8	0.6	2.1	24.9
Series 2					
Site (S)	2	237.3ns	26.0***	7.1ns	431.4***
Replication (Site) (R (S))	27	830.3***	3.7***	6.3***	163.5***
Provenance (P)	3	567.9ns	23.3*	73.0*	555.1ns
SXP	6	426.4**	1.0ns	2.4ns	26.7ns
PXR(S)	81	122.3ns	0.5ns	1.2ns	23.0ns
F(P)	24	344.6**	9.5***	28.3***	270.4***
SXF(P)	47	165.0ns	0.8***	2.9***	43.1***
Residual	637	136.0	0.5	1.3	22.6
Series 3					
Site (S)	2	417.3ns	369.5***	576.5***	9920.2***
Replication (Site) (R (S))	27	960.5***	6.0***	11.3***	245.8***
Provenance (P)	4	714.4ns	18.9*	59.8*	815.9*
SXP	8	214.4ns	3.1***	12.7***	202.2***
PXR(S)	108	155.4ns	0.5ns	1.8ns	18.3ns
F(P)	34	1311.0***	5.0***	13.3***	132.8***
SXF(P)	66	233.3*	0.7ns	2.2ns	36.7***
Residual	898	180.1	0.5	1.8	22.7

[1] ns, *, **, *** = Not significant, significant at $P \leq$ 10%, 5%, and 1%

Table 6. Individual tree heritability, family-mean heritability and individual tree phenotypic correlations for survival, height, diameter and volume for Nuttall oak at age 10. All phenotypic correlations were significant at P<0.01.

Trait	h_i	h_F	HT	DBH	VOL
Series 1					
SUR	-	-	0.34	0.27	0.29
HT	0.38	0.73		0.90	0.90
DBH	0.23	0.57			0.95
VOL	0.15	0.32			
Series 2					
SUR	0.21	0.80	0.25	0.30	0.20
HT	1.00	0.98		0.75	0.86
DBH	1.00	0.94			0.90
VOL	1.00	0.92			
Series 3					
SUR	0.67	0.92	0.19	0.16	0.13
HT	0.71	0.75		0.91	0.90
DBH	0.63	0.78			0.95
VOL	0.55	0.77			

Recommendations to buyers of wild seed are to preferentially concentrate on collections from the central part of the range for planting in the areas represented by these progeny tests. This would include the Ouachita and Red River Basins. The differences among provenances tended to be minimal, however, and the only area that should clearly be avoided is the Western Region because of its demonstrated poorer survival and slower growth.

Family variation – Seed Orchard Establishment

There were strong differences among families for all of the traits analyzed in each of the series with the single exception of survival in Series 1. Individual and family mean heritabilities were high for all traits for which there were significant differences among families (Table 6). Heritabilities in Series 2 were clearly not reasonable but still support the assertion that genetic variance explains a large proportion of the total phenotypic differences. Such high heritabilities indicate that family selection will effectively improve performance and that GxE is a relatively unimportant part of the total variation. There were good families from all provenances validating the need for progeny testing. Positive and significant phenotypic correlations between traits implied that simultaneous gain can be made in all of the traits evaluated.

Family-mean phenotypic correlations were also calculated between early measurements and age 10 measurements (Table 7). This was age 5 to age 10 measurements in all cases except for Series 2 at Desha. This test's first measurement was not completed until age 7.

Table 7. Family-mean phenotypic correlations between early measurements (age 5 for all but Series 2 Desha County which was age 7) and age 10 measurements for traits with significant family differences at age 10. All phenotypic correlations significant at $P<0.01$.

Trait	SUR10	HT10	DBH10	VOL10
Series 1				
SUR5				
HT5		0.57	0.59	0.55
DBH5		0.49	0.52	0.54
VOL5		0.30	0.36	0.41
Series 2				
SUR5	0.76	0.32	0.45	0.31
HT5	0.07	0.70	0.26	0.47
DBH5	0.04	0.69	0.24	0.47
VOL5	0.08	0.68	0.25	0.47
Series 3				
SUR5	0.91	0.14	0.12	0.09
HT5	0.25	0.72	0.75	0.67
DBH5	0.12	0.10	0.26	0.19
VOL5	0.14	0.28	0.42	0.37

The highlighted diagonals represent the correlations among the same trait at different ages. Large correlations between the early and age 10 measurements for survival and height indicate that these traits could be selected for efficiently at the early measurement. Age-age correlations for diameter and volume tended to be lower and rank changes were observed among potential orchard candidates (data not shown) between measurement cycles. This implied that family selection should be delayed until at least age 10.

CONCLUSIONS

Nuttall oak had excellent survival and growth confirming it is a good choice for planting and restoring bottomlands. The provenance and family-within provenance variation and estimates of heritability indicated that genetic improvement of Nuttall oak would be successful. Provenance effects were moderate at best, but it would appear that seed collected toward the center of the range (northern Louisiana or southern Arkansas) should be favored when purchasing wild seed for the areas represented by the progeny tests reported here. The better performing provenances tended to be from the Ouachita and Red River basins while the poorer provenances tended to be from the Western Region. It should be noted that sources from Alabama and southern Louisiana were not included in this evaluation.

Relatively high family heritabilities and the fact that good families could originate from any provenance validated the need for progeny testing. Furthermore, relatively moderate age-age correlations for diameter and volume implied that family selection should be delayed until at least age 10. The large family variation relative to the provenance effect suggest that the seed orchard approach will provide significant gain compared to wild seed collection, even from the best provenances. The top 30 families from the 115 families with age 10 progeny test data have an average phenotypic superiority of 26 percent in volume growth at age 10. If this value is multiplied by family heritability, these parents may be expected to produce seed with an expected value of 17 percent improvement. Members of the WGFTIP-Hardwood cooperative, led by the Arkansas Forestry Commission, began Nuttall oak orchard establishment in 2007.

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