Performance of Nuttall Oak *(Quercus Texana* Buckl.) Provenances in the Western Gulf Region

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Abstract:-- Three series of three tests each of Nuttall oak *(Quercus texana* Buckl. formally *Q. nuttallii* Palmer) were established by the Western Gulf Forest Tree Improvement Program at three locations: Desha and Lonoke Counties in Arkansas and Sharkey County in Mississippi. The three series included 28-42 different half-sib families from throughout the natural range of Nuttall oak. Families were arbitrarily divided into provenances based on the river basin in which they originated. Significant provenance differences were found for survival in all series. Provenance differences for growth were highly significant for series 2 and 3, but not for series 1. The Red River provenance had the best growth performance in series 3 tests, 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 tests. The Western provenance performed well in series 1 and 3 tests but had poorer performance in series 2 tests. The interactions between site and provenance were significant for all growth traits in all series. Family-mean heritability estimates, however, were high ranging from 0.72-0.96 for height and 0.22-0.95 for diameter. There were good families from all sources indicating that family selection will be effective in this species.

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

INTRODUCTION

Nuttall oak *(Quercus texana* Buckl. formerly Q. *nuttallii* Palmer) is a member of the red oak group. It has a restricted natural range on bottomlands of the Gulf Coastal Plain of the southern US from Alabama to southern 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 the heavy, poorly drained, alluvial clay soils. Nuttall oak is an important species because it produces high quality sawtimber on poorly drained sites and because it is beneficial to wildlife, producing large acorn crops at young ages. Nuttall oak is currently favored for bottomland planting and restoration because it exhibits good survival on a range of sites and is fast growing (Ducks Unlimited 2001). Like most oaks, it is shade intolerant. Previous studies have mainly 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).

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There is no genetic information on this species. Considerable provenance variation has been reported in other red oaks *(Q. rubra;* Russell and Dawson 1995, *Q. nigra;* Adams 1989), implying provenance variation might also exist in Nuttall oak. Knowledge of such genetic variation, if it does exists in this species, would be important for selecting the best provenances for reforestation and to form the base population for a tree improvement program.

This report is based on three series of Nuttall oak provenance tests established between 1994 and 1997 by members of the Western Gulf Forest Tree Improvement Program – Hardwood Cooperative. The primary objective of the tests was to improve the Nuttall oak for restoration of marginal croplands and for wildlife management through testing and selection. Each test series include samples from throughout the range of Nuttall oak, providing opportunity to determine provenance and within-provenance variation in the species. This paper reports on 5 and 7-year survival and growth results for provenances and families of Nuttall oak established in three series of tests established in Mississippi and Arkansas. Presence of genotype by environment interactions was determined and heritabilities estimated.

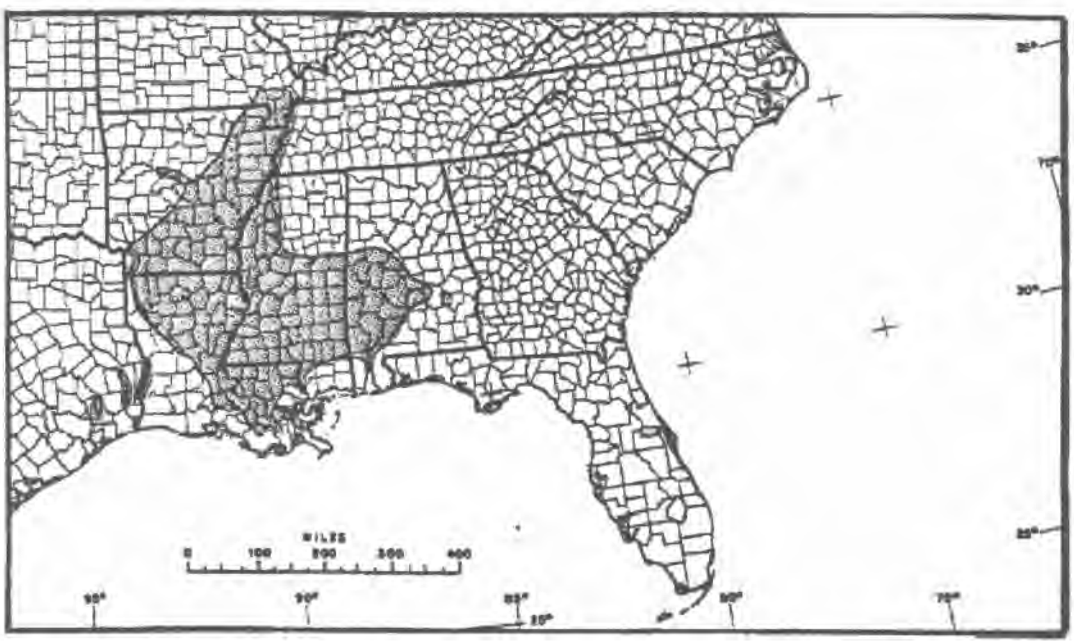

Figure 1. Natural distribution of *Quercus texana* Buckl. (formally Q. *nuttallii* Palmer) (Filer 1990).

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 2, Table 2). Series 1 was established in 1994, series 2 in 1995 and series 3 in 1997. The three series included 28-42 different half-sib families collected from throughout the natural range of Nuttall oak. Families were arbitrarily divided into provenances based on the river basin in which they originated. The provenances were Black-White, Ouachita, Mississippi, Red, Tallahatchie-Yalobusha Rivers and the sixth provenance (Western Region) originated in the western fringe of the main natural range of the species (Figure 2, Table 1).

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 2.4 x 2.4 m in all tests. All tests were assessed at 5 years with the exception of the Desha County test in series 2, which was measured at age 7, for survival, height (HT, m) and diameter (DBH, cm). Height and diameter were used to calculate volume of each tree using the following cone volume equation:

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

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), Issaquene (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)

Table 1. Details of seed origin of Nuttall oak provenances in the three series. Series number is in parenthesis.

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 at each age were pooled across the tests. Using the SAS PROC GLM procedure (SAS Institute 1989), analyses of variance (ANOVAs) were used to test for significant differences among sites, families, provenances, and replications.

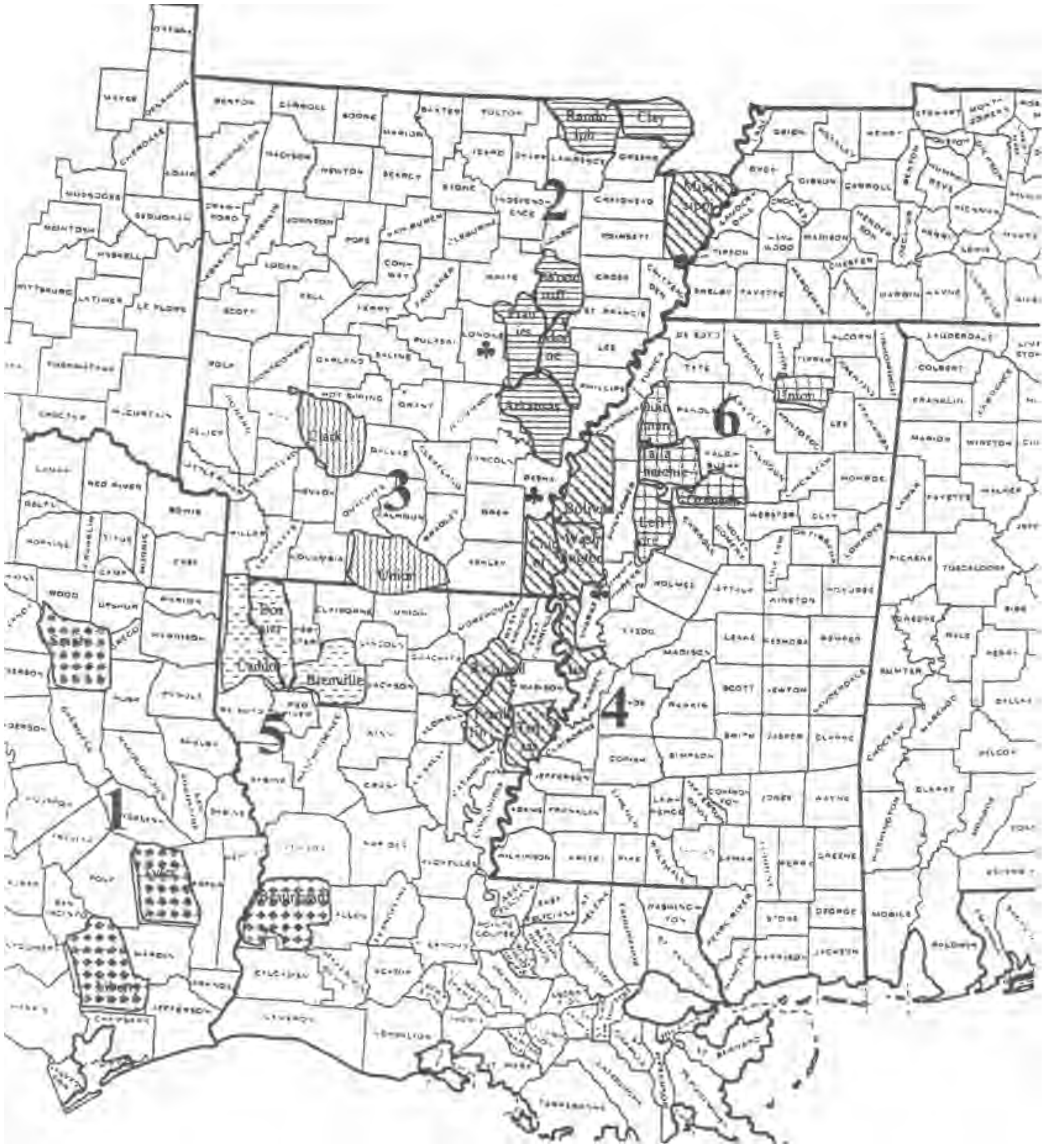

Figure 2. County/Parish locations of families used in the study are shaded. Western Region (Provenance 1), Black -White Rivers (Provenance 2), Ouachita River (Provenance 3), Mississippi River (Provenance 4), Red River (Provenance 5) and Tallahatchie-Yalobusha Rivers (Provenance 6). The test locations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

The interactions between site and provenance, replication and provenance, and site and family were also tested. 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.

Where significant differences were detected among provenances and among sites in the pooled data, Duncan's Multiple Range Test was used to compare means. Variance components were estimated using the VARCOMP procedure in SAS (SAS Institute 1985). 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

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

for individual tree heritability and family – mean heritability as

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

where:

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

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

Table 2. Details of field tests of Nuttall Oak provenances in the USA for all series.

Genotype by environment interaction (GxE) was estimated at both the provenance and family level using analysis of variance. The family mean correlations among traits were estimated as product-moment correlations using PROC CORR in SAS (SAS 1985).

RESULTS AND DISCUSSION

Survival

There were significant differences among provenances for survival at age 5 years in all three series, except for the Desha test in series 2 ($P < 0.05$) (Table 3). The provenance differences were probably not operationally meaningful as survival per provenance was generally good, ranging from 80.1% to 88.4% in series 1, 83.6 to 96.9% in series 2, and 91.7 to 96.8% in series 3 (Table 4). The Western sources tended to have slightly poorer survival in all series. Families within provenances were also significantly different for all three test series with the exception of the Desha test for series 2 ($P<0.05$) (Table 3). Survival was generally high at all sites for all series, apart from a rather low survival at Desha site (75.4%) in series 1. Sites were not significantly different ($P > 0.05$) for survival for series 3 (range: 91.7 – 93.6%), but were significantly different for series 1 (range: 75.4 – 96.3%) and series 2 (range: 89.8 – 97.4%) (Table 5). The excellent survival of Nuttall oak provenances in this study supports the results from previous studies that indicated that survival was 85% on Sharkey clay soil at two years (Krinard and Kennedy 1987), and those of Wittwer (1991) that showed a 78% survival for bottomland oaks planted in eastern Oklahoma at three years of age. However, poor survival due to drought observed at a test established in Angelina County in Texas (data not presented), suggests that even in this well adapted species survival can be low if conditions are not favorable.

Growth

There were significant differences among provenances ($P < 0.05$) for height, diameter and volume in series 2 and 3, and height in series 1 (Table 3). Families within provenances were significantly different for all growth traits in series 2 and 3, but not for volume in series 1.

In series 1, provenances were not statistically different for volume with similar volume growth performance at 5 years (range: 0.195- 0.247 dm^3). In series 2, the Ouachita River provenance had the best volume growth (0.184 dm^3) and the Black-White River provenance the poorest at 5 years (0.097 dm^3). In series 3, the Red River provenance had the best volume growth performance (0.314 dm^3), and Black-White River and the Mississippi River provenances (0.184 and 0.185 dm^3, respectively) performed the poorest in volume growth at 5 years (Table 4).

Individual site analysis (data not presented) indicated that local seed sources either performed equal to or poorer than some distant seed sources. For example in series 3, both local and distant seed sources had similar volume growth at the Lonoke site, but at Sharkey site, the local seed sources, Mississippi River provenance, were outperformed by

Sharkey site, the local seed sources, Mississippi River provenance, were outperformed by the more distant seed sources, Red River provenance. Similarly in series 3, the distant provenances, Western Region and Red River provenances, outperformed the more local seed sources at Sharkey and Desha sites.

Source of variance	DF	Survival (%)	Height (m)	DBH (cm)	Volume (dm^3.tree^{-1})
Series 1 (age 5 years)					
Site (S)	1	41174.1***	14.63***	108.70***	6.97***
Replication (Site) (R (S))	17	1939.1***	1.10***	4.46***	0.91***
P	3	3477.6***	0.47*	0.55ns	0.19ns
SXP	6	196.8ns	0.68**	1.41***	0.71*
PXR(S)	81	319.9ns	0.17ns	0.35ns	0.17ns
Family (F(P))	40	561.0*	0.47***	0.84***	0.36ns
SXF(P)	74	439.3ns	0.19ns	0.37ns	0.39ns
Residual	1004	360.7	0.16	0.34	0.18
Series 2 (age 5 years)					
Site (S)	1	4210.1***	43.31***	135.15***	3.85***
Replication (Site) (R (S))	18	334.4**	0.39***	1.44***	0.15***
P	3	2994.7***	0.50***	1.53***	0.10**
SXP	3	389.9*	0.48***	0.64*	0.08**
PXR(S)	54	156.6ns	0.06ns	0.20ns	0.02ns
F(P)	24	928.4***	0.30***	0.49***	0.05***
SXF(P)	24	186.3ns	0.12*	0.39**	0.04***
Residual	425	143.3	0.06	0.17	0.02
Series 2 (age 7 years)					
Replication (R)	9	788.5***	5.33***	8.21***	58.20***
Provenance (P)	3	217.4ns	4.01***	10.89***	34.85***
PXR	27	199.1ns	0.61ns	1.12ns	5.92ns
F(P)	23	162.4ns	2.22***	5.44***	22.49***
Residual	195	163.3	0.43	0.95	4.48
Series 3 (age 5 years)					
Site (S)	1	100.8ns	14.01	91.09***	1.00***
Replication (Site) (R (S))	16	1101.7***	1.04***	1.69***	0.13***
P	4	611.9**	3.64***	5.75***	0.60***
SXP	8	139.9ns	1.09***	1.59***	0.17***
PXR(S)	104	136.8ns	0.11ns	0.15ns	0.01ns
F(P)	38	549.1***	0.97***	1.15***	0.15***
SXF(P)	66	160.6***	0.14ns	0.19ns	0.04*
Residual	897	173.6	0.13	0.15	0.03

Table 3. Mean squares for analysis of variance for height, diameter and volume at 5 and 7 years for three series of Nuttall oak provenance tests +.+ ns, *, **, * * * = Not significant, significant at P< 5%, 1%, and 0.1%.

Provenance (River)	Survival (%)	Height (m)	Dbh (cm)	Volume ($dm^3.tree^{-1}$)
Series 1 (age 5 years)				
1. Western	80.1c	2.10ab	1.31a	0.247a
3. Ouachita	88.4a	2.14a	1.42a	0.195a
4. Mississippi	86.4ab	2.06b	1.34a	0.219a
6. Tallahatchie-Yalobusha Rivers	85.5b	2.04b	1.30a	0.231a
Series 2 (age 5 years				
1. Western	83.6b	1.83b	0.99bc	0.138b
2. Black-White	94.6a	1.80b	0.88c	0.097c
3. Ouachita	96.9a	1.99a	1.21a	0.184a
4. Mississippi	94.2a	1.86b	1.03b	0.13 l bc
Series 2 (age 7 years)				
1. Western	90.0a	4.60c	4.87c	4.36c
2. Black-White	96.0a	5.24b	6.09b	6.12b
3. Ouachita	96.3a	5.66a	6.59a	7.34a
4. Mississippi	96.4a	5.10b	6.00b	5.52b
Series 3 (age 5 years)				
1. Western	91.1bc	2.25a	2.00b	0.279b
2. Black-White	91.7c	1.92d	1.71c	0.184c
3. Ouachita	94.4b	2.13b	1.94b	0.254b
4. Mississippi	96.8a	2.01c	1.65c	0.185c
5. Red	93.1bc	2.24a	2.11a	0.314a

Table 4. Nuttall oak provenance means across three sites for survival, height, dbh and volume at age 5 and 7 years^{+}. + Means within a column with different letters differ at the 5% level of significance on a Duncan's Multiple Range Test.

Unfortunately, provenance performance was not consistent across series making it difficult to draw conclusions. The instability of provenance performance across the different series may be due to the fact that the provenances were arbitrarily divided and may not reflect true biological differences. A case in point is the Mississippi County, Arkansas sources which originated at the same latitude as the Black-White River, yet the selections were grouped with the Mississippi River provenance which was generally more southern. The instability of provenances may have also resulted from differences in the number and origin of families in each series. For example, the Western Region provenance in series 2 was comprised of families from Smith County only, but in series 3 it was comprised of families from Liberty and Tyler Counties in Texas and Beauregard Parish, Louisiana. Similarly, Mississippi River provenance in series 2 was comprised of families from Mississippi County, Arkansas only, while in series 3 it includes families originating in Franklin, Richland and Tensas Parishes in Louisiana.

By comparing data from age 7 measurements of series 2 with age 5 measurements from series 1 and 3 tests located on adjacent sites in Desha County, it would appear that Nuttall oak is capable of rapid growth between 5 and 7 years. At 5 years provenances were on average 2.20 m in height, and at 7 years they averaged 5.21 m in height, an increment of more than 100% (Table 5). Similarly for volume, provenances averaged 0.280 dm^3 at 5 years and 6.014 dm^3 at 7 years, an increment of more than 20 fold. The slow growth of Nuttall oak at 5 years appears to support the observations that Nuttall oak seedlings allocate much of their growth to their root systems in the first few years and exhibit slow early growth (Taylor and Golden 2002). The results at 7 years suggest that Nuttall oak is fast growing once established.

Site	Survival (%)	Height (m)	Dbh (cm)	Volume ($dm^3.tree^{-1}$)
Series 1 (age 5 years)				
Lonoke	96.3a	2.23a	1.63a	0.236b
Sharkey	81.5b	1.78b	0.72b	0.094c
Desha	75.4c	2.23a	1.67a	0.360a
Series 2 (age 5 years)				
Lonoke	89.8b	2.18a	1.58a	0.214a
Sharkey	97.4a	1.47b	0.29b	0.009b
Series 2 (age 7 years)				
Desha	95.6	5.21	6.02	6.014
Series 3 (age 5 years)				
Lonoke	93.6a	2.38a	1.66b	0.247b
Sharkey	93.5a	1.97c	2.55a	0.349a
Desha	91.7a	2.15b	1.62b	0.199c

Table 5. Site means for survival, height dbh and volume at age 5 and 7 years+.

+ Means within a column with different superscripts differ at the 5% level of significance on a Duncan's Multiple Range Test.

Genotype x environment interactions

Provenance by site interactions for survival were not significant ($P > 0.05$) for all series, except series 2 (Table 3). Site by family interactions for survival were not significant for series 1 and 2. The interactions between site and provenance were significant ($P < 0.05$) for all growth traits indicating the presence of genotype by environment interaction.

Heritabilities and trait-trait correlations

The family-mean heritability estimates and individual-tree heritability estimates were very high for all traits (Table 6), suggesting that phenotypic variation observed was due to family and individual tree effects. Generally, there were good families from all provenances. For example in series 1, the top 10 families in volume growth were composed of 5 from Western Region, 2 from Ouachita River, 2 from Tallahatchie-Yalobusha Rivers and 1 from Mississippi River provenances. This suggests that family selection will be effective in this species. This suggests that significant gains can be made through selection of the best families and the best individuals. Correlations among growth traits were moderate to high, suggesting selecting on one trait will result in an increase in the other traits. Correlations between survival with growth traits were weak for series 1 and 3, and moderate for the Desha test in series 2.

Trait	hi	hF	HT	DBH	VOL
Series 1 (age 5 years)					
SUR	0.04	0.41	0.13**	0.09**	
HT	0.14	0.83		0.81**	
DBH	**0.18**	0.80			
VOL					
Series 2 (age 5 years)					
SUR	0.80	0.90	Ons	-0.01ns	0.11*
HT	0.52	0.72		0.92**	0.80**
DBH	0.08	0.22			0.90**
VOL					
Series 2 (age 7 years)					
SUR			0.51**	0.52**	0.46**
HT				0.93**	0.92**
DBH					0.94**
VOL					
Series 3 (age 5 years)					
SUR	0.33	0.81	0.16**	0.17**	0.19**
HT	0.85	0.96		0.44**	0.67**
DBH	0.56	0.95			0.83**
VOL	0.47	0.91			

Table 6. Individual tree heritability, family-mean heritability and phenotypic correlations for survival, height, diameter and volume for Nuttall oak at age 5 and 7 years [+] - [+] ns, *, **, = Not significant, significant at P < 5%, and 1%

CONCLUSION

Nuttall oak provenances 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 indicate that genetic improvement of Nuttall oak would be successful. Provenance effects were inconsistent, 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. The better performing provenances tended to be from the Ouachita and Red River basins while the poorer provenances tended to be from the Black-White and Mississippi drainages. The Western sources tended to have lightly poorer survival. It must be emphasized that these conclusions are based on arbitrary provenance divisions with limited numbers of families per provenance. As with other outcrossing species there was significant tree to tree variation as evidenced by relatively high heritabilities. Therefore tree improvement and orchard establishment programs should concentrate on identifying the best individuals regardless of provenance.

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