do not occur in the old tree population growing in Israel. Unfortunately, most chemotypes could not be related to specific seed source.

Thus, the establishment of seed orchards must start with a test for genetic stability of the chemotypes and with the selection of single plus trees of var. *horizontalis*, cv. *stricta* and intermediate forms, which also display resistance to the cypress canker. So far, no resistant seed source (population) was revaled in our study or in research abroad (Grasso and Raddi, 1979).

Acknowledgements

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Geographic Variation of Green Ash in the Western Gulf Region[1])

By K. W. Hendrix and W. J. Lowe[2])

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Abstract

At age 12, four green ash plantations containing 27 open-pollinated families from east Texas, southeast Louisiana, and southwest Arkansas were evaluated. Significant differences were indicated for height and specific gravity among the provenances; provenances from the western edge of the species' range had the slowest growth. Significant family within provenance differences existed for all traits except survival.

Family heritabilities for height, diameter and volume were moderate ($h^2 = 0.56$, 0.56 and 0.57, respectively); family heritability for specific gravity was high ($h^2 = 0.89$). Expected genetic gains for these traits from the combined analysis were 5.9%, 9.0%, 7.0% and 10.8%, respectively. Coefficients of genetic prediction between height, diameter and volume were nearly as large as family heritabilities; however, a weak negative relationship existed between diameter or volume and specific gravity.

Regressions of yield deviations on seed source latitude and longitude accurately predicted the performance of sampled provenances, However, the uneven provenance distribution made interpolation of performance to other provenances questionable. The regression of yield deviations on seed source and plantation latitude or longitude were also able to locate the optimum latitudes and longitudes for seed collection.

Key words: Fraxinus pennsylvanica, heritabilty, genetic gain.

Introduction

Green ash (*Fraxinus pennsylvanica* Marsh.) possesses suitable silvical characteristics for both plantation management and genetic improvement (Kellison, 1971). The high specific gravity and low moisture content of green ash wood enable it to produce a higher fiber yield per unit volume than sweetgum (*Liquidambar styraciflua* L.), sycamore (*Platanus occidentalis* L.) or cottonwood (*Populus deltoides* Bartr.). This partially compensates for the slower growth rate of green ash relative to these faster growing species (Jett and Zobel, 1974). Additionally, green ash is better suited to imperfectly drained soils and will thrive on sites unsuited for sycamore and cottonwood (Kellison *et al.*, 1979).

The majority of geographic variation studies on green ash have been established in New England and the Plains states where the species has shown excellent survival and growth in windbreaks (Read, 1958). These studies indicated significant geographic differences for growth, phenologi-

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[1]) This report is partially based upon the senior author's M. S. thesis submitted to the graduate school at Texas A & M University. This study was supported by the Texas Agricultural Experiment Station (MS-6227) and the Texas Forest Service.

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cal and morphological traits (Ying and Bagley, 1976; Carter, 1981; Van Deusen and Cunningham, 1982).

Both latitude and nonlatitude sources of variation were described for 10-year height for a green ash progeny-provenance stugy in Mississippi (Wells, 1986). Differences among families within provenances were detected from over one-half of the nine provenances contained in the study.

Stauder and Lowe (1983) reported no significant differences among east Texas provenances for survival or growth indicating that seed from east Texas may be planted anywhere within east Texas. Three progeny tests established concurrently with the provenance trials confirmed the lack of variation among provenances; however, significant variation was observed among open-pollinated families for height, diameter and volume growth but not survival. Family heritabilities were estimated to be 0.66, 0.66 and 0.51 for height, diameter and volume, respectively.

Specific gravity data[3]) from the study reported by Stauder and Lowe (1983) indicated that significant differences existed among provenances and open-pollinated families collected within east Texas. Specific gravity varied from 0.48 to 0.61 across the three planting locations. Family heritability for specific gravity from the combined analysis was 0.71.

The objectives of this study were to assess the effects of seed source, family within seed source and planting location on variation in survival, specific gravity, height, diameter and volume growth measured in four 12-year-old green ash plantations. Narrow-sense heritabilities, coefficients of genetic predictions (CGP's) and potential genetic gains were calculated. Seed movement guidelines were developed using the analysis of variance results and regression techniques.

Materials and Methods

In 1973, cooperators of the Western Gulf Forest Tree Improvement Program — Hardwood establish a geographic variation study which contained 29 open-pollinated families of green ash at seven locations. The four locations included in this study were (1) Zavalla, Texas (2) Camden, Arkansas, (3) Rodney Island, Mississippi and (4) Bogalusa, Louisiana. Twenty-seven families were grouped into five provenances. *Figure 1* illustrates the seed sources and test locations employed in the study. Each progeny test was established in a randomized complete block design with six replications and four-tree row plots.

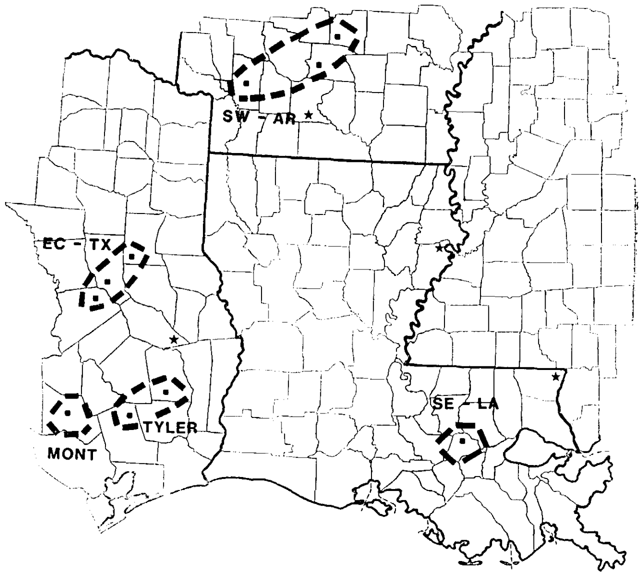

Figure 1. — Location of test sites (stars), selected seed sources (squares) and provenance boundaries (dashed lines).

Measurements were taken in December 1985, after 12 growing seasons in the field. Total height was measured to the nearest 0.1 meter and diameter outside bark was measured to the nearest millimeter at 1.37 meters from the ground. Individual tree volumes were determined using the following relationship:

$$\text{volume (dm}^3) = 0.02618D^2H$$

Where D is diameter in cm and H is height in m.

Increment cores were extracted from bark to bark through the pith with a 4.3 mm increment borer at 1.37 meters from the ground at age 13 from the Zavalla site and age 12 from the other three sites. Specific gravities were determined on each core using the maximum moisture content method (Smith, 1954).

Geographic variation in survival, height, diameter, volume and specific gravity was characterized for each planting location separately and for all locations combined using the General Linear Models (GLM) procedure in the Statistical Analysis System (SAS) (SAS Institute,

Table 1. — Formulas used to estimate genetic gain for different selection methods. Where σ^2_{E}, $\sigma^2_{R(L)F(P)}$, $\sigma_{LF(P)}$, $\sigma^2_{(F)P}$ are the variance components for the error, replication (location) * family (provenance), location * family (provenance) and family (provenance) terms, respectively; r, n and l are the number of replications per location, average number of trees per plot and number of locations, respectively.

$$\text{Mass Selection} = i_M * \frac{4\sigma^2_{F(P)}}{\sqrt{\sigma^2_E + \sigma^2_{R(L)F(P)} + \sigma^2_{LF(P)} + \sigma^2_{F(P)}}}$$

$$\text{Family selection} = i_F * \frac{\sigma^2_{F(P)}}{\sqrt{\frac{\sigma^2_E}{rnl} + \frac{\sigma^2_{R(L)F(P)}}{rl} + \frac{\sigma^2_{LF(P)}}{l} + \sigma^2_{F(P)}}}$$

$$\text{Within family selection} = i_{I/F} * \frac{3\sigma^2_{F(P)}}{\sqrt{\sigma^2_E + \sigma^2_{R(L)F(P)} + \sigma^2_{LF(P)}}}$$

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[3]) Texas Forest Service unpublished data.

Table 2. — Summary of 12-year green ash measurements for the five traits included in the study by location and for the combined analysis.

Location	Survival (percent)		Height (m)		Diameter (cm)		Volume (dm^3)		Specific Gravity	
	Mean	S.D.[1]	Mean	S.D.	Mean	S.D	Mean	S.D.	Mean	S.D.
	(range)[2]		(range)		(range)		(range)		(range)	
Bogalusa,	97.8	14.8	7.2	2.2	5.8	2.1	8.3	8.1	.552	.048
LA	(87.5 - 100)		(5.6 - 8.3)		(4.4 - 7.2)		(3.5 - 14.5)		(.496 - .609)	
Camden,	99.5	6.9	9.7	1.3	7.1	1.3	13.5	6.4	.544	.038
AR	(93.7 - 100)		(8.5 - 10.6)		(5.9 - 8.0)		(8.3 - 18.4)		(.505 - .586)	
Zavalla,	95.2	21.3	9.4	1.6	9.5	2.2	23.7	13.9	.564	.039
TX	(81.2 - 100)		(7.8 - 10.4)		(7.4 - 10.8)		(12.2 - 33.4)		(.506 - .610)	
Rodney	91.3	28.1	14.5	3.3	10.6	3.6	48.2	43.2	.506	.041
Island,	(79.1 - 100)		(11.8 - 16.8)		(7.7 - 14.4)		(20.7 - 98.8)		(.460 - .562)	
MS										
Combined	96.0	19.7	10.1	3.4	8.2	3.0	23.4	27.8	.542	.047
	(90.6 - 100)		(8.8 - 11.0)		(6.9 - 9.1)		(15.1 - 36.8)		(.497 - .589)	

1) S.D. = standard deviation

2) Range of family means

1985). Survival was analyzed using the arcsin square-root transformation. Dead trees were assigned a zero volume to reflect survival differences. For analyses involving diameter, height and specific gravity, dead trees were treated as missing observations. The provenance effect was fixed while locations, replications and families were considered random effects. When exact F-tests were lacking, approximate F-tests were calculated (Satterthwaite, 1946). All tests of significance were conducted at the five percent probability level. Initial analysis indicated heterogeneous variances among locations for volume; therefore, a logarithmic transformation of the form: $x = \log_{10}(x + 1)$ was employed. All analyses were carried out on plot means and a between-within plot analysis was used to estimate within-plot error.

Expected genetic gains were calculated for mass selection and combined family and within-family selection. For mass selection, the nine best trees from the combined analysis were chosen resulting in a selection intensity (i_M) equal to 2.91. For combined selection, the best tree in each of the best nine families was chosen resulting in selection intensities of $i_F = 1.06$ for family selection and $i_{I/F} = 2.49$ for within-family selection. The gain formulas are shown in *table 1*.

Baradat (1976) defined a coefficient of genetic prediction (CGP) between two traits as follows:

$$CGP = \frac{Cov_{A(xy)}}{P_{(x)} \cdot P_{(Y)}}$$

Where $Cov_{A(xy)}$ = additive genetic covariance between X and Y; $P_{(x)}$ and $P_{(Y)}$ = phenotypic standard deviation of X and Y, respectively.

The coefficient of genetic prediction can predict the effect of selection for trait x on the average breeding value of trait y. When the phenotypic mean of trait x is shifted one standard deviation, the breeding value of trait y in the selected population is shifted by an amount equivalent to the CGP multiplied by the phenotypic standard deviation of trait y.

A 4 × 4 matrix of CGP values for the measured traits was generated. The necessary cross-product sums of squares were generated with the MANOVA statement the GLM procedure. Narrow-sense family heritabilities were obtained from the diagonal of the matrix of CGP values.

The methods of Kung and Clausen (1984) and Clausen (1984) were employed to graphically develop seed movement guidelines. Mean family height at each location was expressed as a standard deviation from the plantation average. The PROC RSQUARE procedure of the Statistical Analysis System (SAS Institute, 1985) was used to develop contour plots depicting height as a function of latitude and longitude. For the individual and combined data sets, these values were regressed on linear, quadratic, cubic and interaction functions of seed source latitude and longitude.

A second type of regression analysis to determine the effect of latitude and longitude upon seed movement was performed for the combined location data. The PROC RSQUARE procedure was used to regress family height means from each location on seed source latitude, planting latitude, their quadratic and cubic terms and all possible cross-product terms. The same regression was completed replacing latitude with longitude. For both regression approaches, the best models were determined with the aid of the R^2 statistic and sequential F-tests which tested the significance of the contribution of each additional term to the model. Linear terms had to be included as a basic part of each model.

Results and Discussion

Analysis of Variance

A summary of 12-year measurements for the study locations is given in *Table 2*. The consistently high survival values reflected both excellent test maintenance and the adaptability of green ash. The best growth occurred at Rodney Island which was an excellent hardwood site; the poorest performance was at the Bogalusa test on a site more suited for pine growth.

Significant differences exised among provenances for height and specific gravity but not survival, diameter or volume. Provenance effects for the latter three traits, while not significant at the five percent level, were significant at the ten percent level. Because the approximate F-tests used for testing the provenance effect are conser-

Table 3. — Twelve-year green ash provenance height (m) means for the individual and combined analyses[1]).

Combined		Camden		Zavalla		Rodney Island	
Prov.	Mean	Prov.	Mean	Prov.	Mean	Prov.	Mean
SW AR	10.79	SW AR	10.23	SW AR	10.06	SE LA	15.93
Tyler	10.71	Tyler	10.10	SE LA	9.56	Tyler	15.80
SE LA	10.51	EC TX	9.48	Tyler	9.56	SW AR	14.83
Mont.	9.67	SE LA	9.45	EC TX	9.48	Mont.	13.85
EC TX	9.47	Mont.	9.22	Mont.	8.79	EC TX	12.51
Mean = 10.1		Mean = 9.7		Mean = 9.4		Mean = 14.5	

[1]) The Bogalusa plantation was excluded because a significant difference among provenances was not found for height.

Table 4. — Provenance and family within provenance variance components from the combined analysis for twelve-year green ash data.

Trait	Provenance Variance Component	% of Total	Family (Provenance) Variance Component	% of Total
Height	.2586	73.6	.0927	26.4
Diameter	.2506	65.5	.1318	34.5
Volume	.0036	61.1	.0023	38.9
Specific[1] Gravity	.2870	56.4	.2220	43.6

[1]) Divide by 1000 for correct variance components.

vative, these values may be larger than would be obtained with exact F-tests. Survival was uniformly high; therefore, green ash appears to be widely adapted in the Western Gulf region. The best provenances for height growth were located in southwest Arkansas, southeast Louisiana and southeast Texas (*Table 3*). Green ash populations from the species' western fringe consistently exhibited poor growth. The southwest Arkansas provenance was the only seed source exhibiting both superior growth rate and high specific gravity.

Significant family within provenance differences existed for all traits except survival. The best nine families in the combined analysis for height, diameter, volume and specific gravity exhibited 8.9%, 10.9%, 57.3% and 8.6% superiority, respectively, over the combined analysis means for these traits. The majority of variation among families, however, was due to provenances as shown in Table 4. Therefore, the largest initial gains should be expected from provenance selection combined with family within provenance selection.

Table 5. — Family and individual tree heritability estimates for twelve-year-old green ash measurements.

Trait	Individual h^2	S.E.	Family h^2	S.E.
Height	.09	.05	.56	.29
Diameter	.11	.05	.56	.29
Volume	.06	.03	.57	.29
Specific Gravity	.57	.18	.89	.28

Table 6. — Expected genetic gains from different selection methods (combined analysis).

Method of Selection	Height (m)	Diameter (cm)	Log_{10} Volume	Specific Gravity
Mass Selection	.550	.703	.068	.065
Combined Selection				
Family	.241	.288	.038	.014
Within-Family	.357	.457	.044	.045
Total	.598	.745	.082	.059

Significant location × family-within-provenance interactions existed for specific gravity and diameter. Most of the important rank changes for both traits occurred among families of the Montgomery or east-central Texas provenance. These seed sources should be excluded from plantation programs because of their slow growth and apparent instability when planted under different environmental conditions. The practice of multiple location testing should be continued due to the potential for genotype × environment interactions.

Family heritabilities for height, diameter and volume were moderate while the heritability for specific gravity was high (*Table 5*). These values were comparable to heritability values reported by Stauder and Lowe (1983). Individual tree heritabilities for all traits except specific gravity were much smaller than family heritabilities.

Comparison of expected genetic gains revealed that combined family and within family selection produced the greatest gains for all traits except specific gravity (*Table 6*). Expected gains from combined selecttion were 5.9%, 9.0%, 7.0% and 10.8%, respectively, for height, diameter, volume and specific gravity. Although expected gain in specific gravity from mass selection was greater than combined selection (0.065 versus 0.059), combined selection would be more desirable because it results in less relatedness among progeny derived from a hypothetical seed orchard.

Table 7. — Family coefficients of genetic prediction from the combined analysis[1]).

	Height	Diameter	Volume	Specific Gravity
Height	.56	.41	.48	.00
Diameter	--	.56	.56	-.28
Volume	--	--	.57	-.07
Specific Gravity	--	--	--	.89

1) Values along main diagonal are family heritabilities.

The relative efficiency of direct versus indirect selection was examined by comparing coefficients of genetic prediction (CGP's) with the corresponding family heritabilities on the main diagonal of *Table 7*. CGP's between height, diameter and volume were nearly as large as family heritabilities for these traits. In all cases, direct selection was most efficient; however, improvement for the other traits should be expected when direct selection is applied to height, diameter or volume.

The CGP between specific gravity and height indicated no relationship between the two traits. A weak negative relationship between diameter or volume and specific gravity suggested that gains in dry wood weight due to selection for faster diameter or volume growth would be partially offset by a reduction in wood density. Index selection for dry wood weight could provide one solution to this problem. Alternatively, because height was not negatively correlated with specific gravity, selection for height would increase the breeding value for volume while avoiding a decline in specific gravity.

Seed Movement Guidelines

Based on the analysis of variance, several generalizations were possible concerning seed movement guidelines for green ash in the Western Gulf region. First, survival was consistently high making selection for adaptability unnecessary. Second, seed collection for superior height, diameter and volume growth should be limited to the southwest Arkansas, Tyler, Texas, or southeast Louisiana provenances. These regions consistently proved superior for all growth traits. In addition, the southwest Arkansas provenance possessed high wood density. The Montgomery and east-central Texas provenances should be avoided because of poor growth. Finally, despite statistically significant location × provenance interactions for height, diameter and volume, the best sources for these traits may be planted anywhere in the Western Gulf region without losses due to depressed growth rate.

Regression Analysis

The Bogalusa test was not included because a significant difference between provenances for height was not found. Provenance height means for three of the test sites and the combined analysis are given in *Table 3*. The height growth regression equations and response surfaces were extremely varied among planting locations (*Table 8* and *Figure 2*). If the zero deviation line was accepted for determination of acceptable seed sources, then *Figure 2a* suggested that the best sources for Camden were located in southwest Arkansas, western Louisiana and eastern Texas. The east-central Texas and southeast Louisiana provenances were located near the zero deviation boundary and Montgomery was clearly below it. Thus, the results for this plot were consistent with the results of the analysis of variance (*Table 3*).

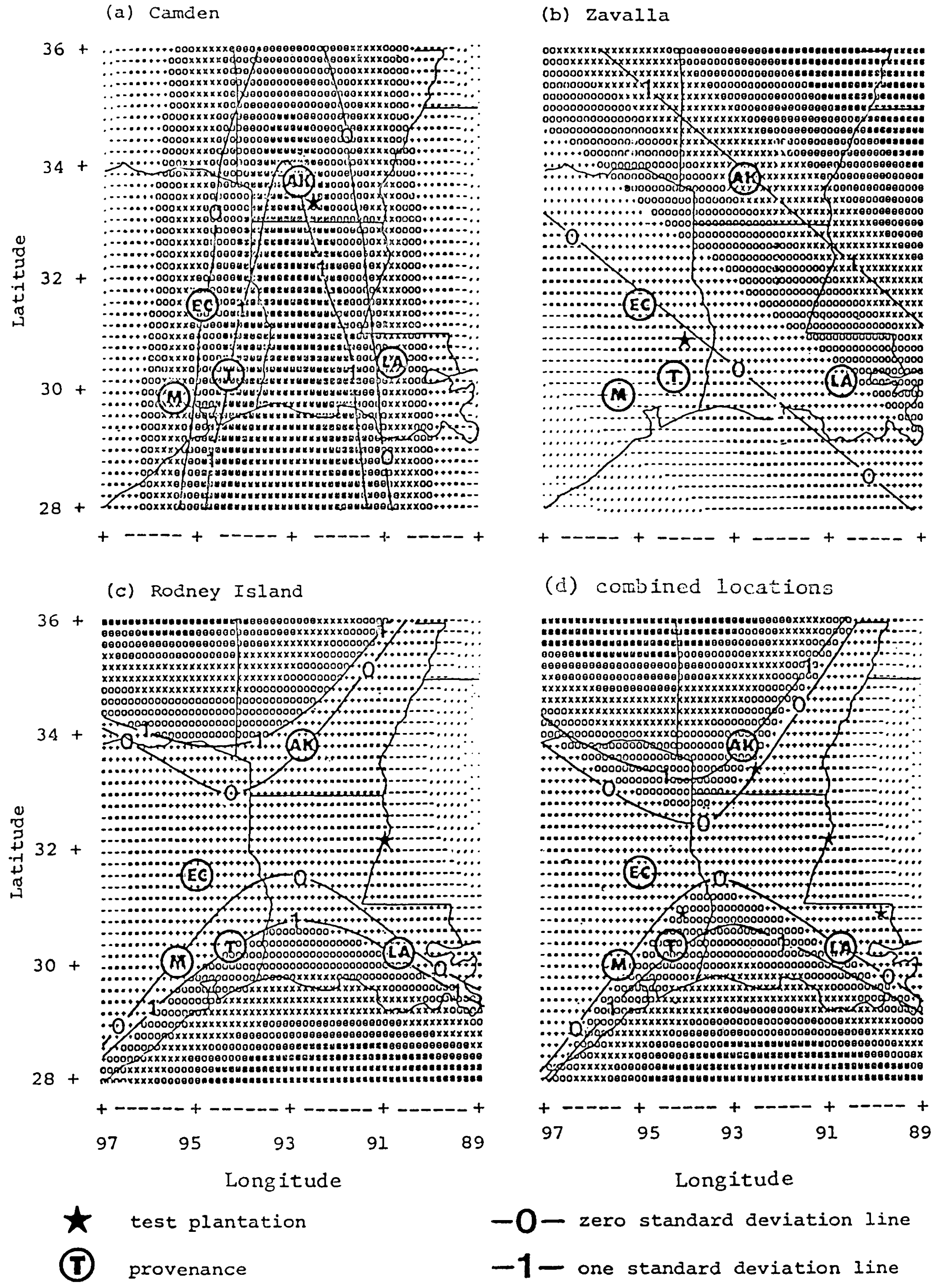
Figure 2b was less successful in predicting the best sources for the Zavalla plantation. The contour plot indicated that height performance increased by moving northeast and correctly predicted that southwest Arkansas would be best at Zavalla. *Table 3* showed that the Tyler and southeast Louisiana provenances had equal height at Zavalla. However, the contour plot implied that the southeast Louisiana provenance performed better than the Tyler, Texas, provenance. This model contained only linear terms; thus it could not adequately account for the variation observed in *Table 3*. Additional higher-order terms did not significantly increase the sum of squares accounted for by the model.

The regression model for the Rodney Island site produced a saddle-shaped plot (*Figure 2c*). The analysis of variance indicated that the southeast Louisiana and Tyler, Texas, provenances were best at this location. The

Table 8. — Regression models describing variation in twelve-year height as a function of seed source latitude and longitude.

Location	R^2	Model[1]
Camden, AR	.50	$Ht = -4119.0 - .23*LAT + 88.70*LONG - .47*LONG^2$
Zavalla, TX	.42	$Ht = 9.35 + .29*LAT - .19*LONG$
Rodney Island, MS	.83	$Ht = -2060.4 - 43.0*LAT + 65.0*LONG - .38*LONG^2 + .09*LAT^2 + .006*LAT*LONG^2$
Combined	.41	$Ht = -1859.1 - 42.75*LAT + 58.91*LONG - .36*LONG^2 + .45*LAT^2 + .0015*LAT*LONG^2$

1) LAT = seed source latitude; LONG = seed source longitude


(a) Camden

(b) Zavalla

(c) Rodney Island

(d) combined locations

Figure 2. — Height contour plots based on seed source latitude and longitude for: (a) Camden, (b) Zavalla, (c) Rodney Island and combined locations. The zero standard deviation line represents average plantation height for twelve-year-old green ash. Areas with predicted height performance of one standard deviation above plantation mean height are shown by the one standard deviation line.

contour plot supported this result and correctly reflected the differences among the Montgomery, Texas, east-central Texas and southwest Arkansas provenances.

The combined location plot (*Figure 2d*) quite accurately reflected the differences among provenance means in *Table 3*. The best provenances were from southwest Arkansas, Tyler, Texas, and southeast Louisiana. Due to the absence of an important provenance × environment interaction, the combined location plot represented the relative performance of Western Gulf green ash sources regardless of their planting location.

The contour plot procedure should adequately predict the relative performance of sampled provenances and correctly predict the performance of seed sources not sampled. This criteria requires adequate seed source sampling and assumes genetic potential can be related to

Table 9. — Regression models describing variation in twelve-year height as a function of seed source and plantation latitude or longitude.

Trait	R^2	Model[1]
Height	.27	$Y = 7229.4 + .01*PLAT - 670.52*SLAT + 20.69*SLAT^2 - .21*SLAT^3$
Height	.29	$Y = -1841.7 + .008*PLONG + 39.7*SLONG - .21*SLONG^2$

[1] PLAT = plantation latitude; SLAT = seed source latitude; PLONG = plantation longitude; SLONG = seed source longitude.

predictable environmental gradients. The plots for height in this study generally reflected the results of the analysis of variance which were correlated with the complexity of the models. The height model for the Zavalla test contained only linear terms and was inadequate to account for the large variation that occurred on a relatively small geographic scale. The plots for Camden, Rodney Island and the combined locations illustrated how increased complexity could account for subtle variations in relative performances among test environments. For example, the rank of the east-central Texas provenance changed from third at Camden to fifth at Rodney Island and in the combined data set. In the latter two plots, the inferior performance of the provenance resulted in prediction of minimal performance for other sources of the same latitude. As a result of this increased complexity, the contribution of two higher-order terms became significant and the long ridge evident in the Candem plot became modified to the more complex saddle-shaped surfaces in the Rodney Island and combined locations plots (*Figure 2*).

Greater model complexity may produce misleading results. In the plots that exhibited a saddle-shaped surface, the poor performances of the east-central Texas and Montgomery, Texas, provenances resulted in the prediction of regions of equally poor performance in central Mississippi (e.g., *Figure 2c*). This occurred because of the inherent symmetry of the quadratic models used in the regressions. Such effects demonstrated that extrapolation outside the area defined by the sampled provenances should be avoided. Symmetry effects may also produce misleading results within the range of sampled sources if sampling is not evenly distributed.

The problems discussed here could be avoided by either more intensive and evenly distributed sampling or more widespread sampling of provenances. Clausen (1984) successfully used this procedure by sampling over 20 provenances spanning 20 degrees of latitude and 30 degrees of longitude compared to the five provenances spanning four degrees of latitude and five degrees of longitude in this study. For studies smaller in scope, smaller-scale yield variations become more important; thus, sampling of provenances must be intense and evenly distributed in

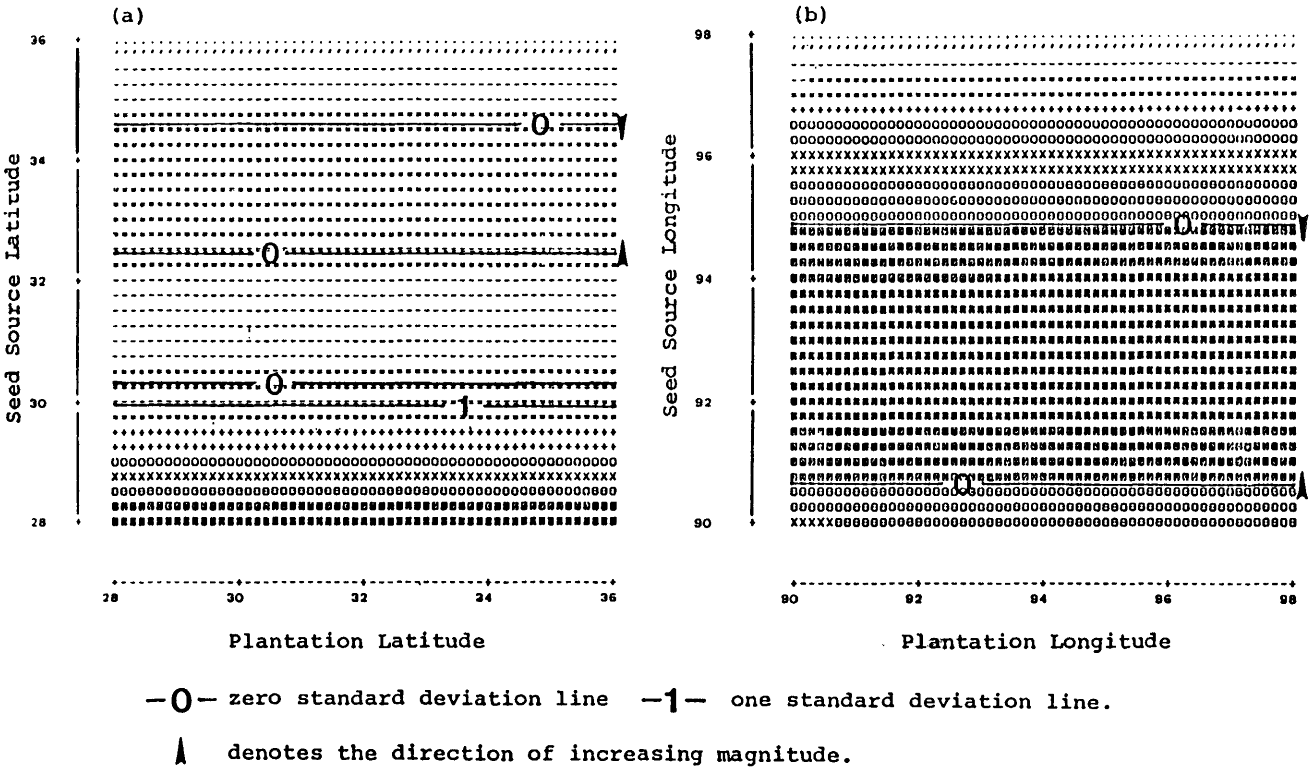


Figure 3. — Height response surface for (a) seed source latitude and plantation latitude and (b) seed source longitude and plantation longitude. The zero standard deviation line represents average plantation height for twelve-year-old green ash. Areas with predicted height performance of one standard deviation above plantation mean height are shown by the one standard deviation line.

order to adequately model the variation. In the present study, sampling of provenances from central Louisiana and Mississippi would have increased the validity of interpolation between the sampled regions.

Table 9 presents the regression models describing height deviations as either functions of seed source and plantation latitude or longitude. The height contour plot based on seed source and plantation latitude exhibited two maxima (*Figure 3a*). The contours varied only with respect to seed source latitude; thus, the optimum seed sources were the same for all plantation latitudes. Using the zero-deviation line as the selection criterion, the optimum seed sources existed between 32.5° N and 34.5° N and south of 30.5° N.

The height contour plot based on seed source and plantation longitude was similar to the latitude plot because plantation longitude did not affect the shape of the contours (*Figure 3b*). The plot possessed a single maximum area located between 91.5° W and 94° W longitude. The zero-deviation line extended the range of acceptable sources from 90.5° W to 95° W longitude, an area containing the Tyler, Texas, southwest Arkansas and southeast Louisiana provenances.

When the optimal range of seed source latitudes was superimposed on the optimal range of seed source longitudes, two regions were defined from which seed sources consistently performed above test location means. One region was centered in southern Arkansas and encompassed the southwest Arkansas provenance. The second was centered in southern Louisiana and contained the southeast Louisiana and Tyler, Texas, provenances. Both the east-central Texas and Montgomery, Texas, provenances were located outside the optimum seed collection zones.

Summary

Genetic variation in survival, height, diameter, volume and specific gravity among provenances and half-sib families within provenances for 12-year green ash plantations was examined. Seed movement guidelines were developed with the results of the analysis of variances and the aid of contour plot regression techniques. The results of this study indicated:

1. Significant differences existed among provenances for height and specific gravity but not survival, diameter or volume. The best provenances for height growth were located in southwest Arkansas, southeast Louisiana and southeast Texas. Green ash populations from the fringe of the species range consistently exhibited poor growth and should be excluded from commercial plantations. The southwest Arkansas provenance was the only seed source exhibiting both superior growth rate and high specific gravity. Significant family-within-provenance differences existed for all traits except survival.

2. Significant location × provenance interactions occurred for height, diameter and volume; however, the same sources tended to perform best at all test locations. Significant location × family-within-provenance interactions existed for specific gravity and diameter. Most of the important rank changes for both traits occurred among families of the Montgomery, Texas, and east-central Texas provenances. The practice of multiple location testing should be continued due to the potential for GxE interactions at both the family and provenance levels.

3. Height, diameter, and volume were under moderate genetic control while specific gravity was strongly genetically controlled ($h^2 = 0.56$, 0.56, 0.57 and 0.89, respectively). Expected genetic gains were 5.9%, 9.0%, 7.0% and 10.8%, respectively for the combined analysis. Comparison of expected gains from mass selection and combined family and within-family selection indicated the latter to be more efficient.

4. Coefficients of genetic prediction between height, diameter and volume were nearly as large as family heritabilities for these traits. In all cases, direct selection was most efficient; however, a moderate degree of improvement for the other traits should be expected when direct selection was applied to height, diameter or volume. The coefficient of genetic prediction between specific gravity and height indicated no relationship between the two traits. A weak negative relationship between diameter or volume and specific gravity suggested that gains in dry wood weight due to selection for faster diameter or volume growth would be partially offset by a reduction in wood density.

5. Regressions of yield deviations on seed source latitude and longitude accurately predicted the performances of provenances sampled in the study. The contour plots showed the locations of the optimum seed sources for the individual locations and the combined location data. However, an uneven distribution of provenances sampled made interpolation between sampled provenances questionable.

6. The regressions of yield deviations on seed source and plantation latitude or longitude located the optimum latitudes and longitudes for seed collection for all traits. The location of the best sources did not vary with plantation latitudes or longitudes which reflected the lack of important GxE interactions. When the optimum latitudes and longitudes were superimposed, optimal regions for seed collection were defined which corresponded both to the results of the analysis of variance and to the regressions of seed source latitude and longitude.

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Provenance Variation in Eucalyptus Tereticornis in a Field Trial within the Northern Guinea Savanna Zone of Nigeria

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Abstract

A trial involving 11 provenances of *Eucalyptus tereticornis* Sm. was established in one location within the Northern Guinea Savanna zone of Nigeria in 1969. Assessments of their total height and diameter were carried out at ages three, five and six years.

Very highly significant differences were found in the total height of the provenances at ages three and six years while such differences were only significant at the 10% level at age five. Differences in the diameter of the provenancs were not significant until after their sixth year of growth.

The N. Laura, Queensland provenance exhibited the best growth rate. The two provenances from Papua New Guinea (Port Moresby and an unknown source) and the Mysore, India provenance jointly had the least growth rate.

Key words: Eucalyptus tereticornis, provenances, height, diameter, ages, selection.

Introduction

Eucalyptus tereticornis Sm. is a member of the red gum group, members of which are for the most part trees of the savanna woodland. Although members of this group are not generally tall and straight, *E. tereticornis* is the tallest species in the group, with a long stem of relatively good form. It is one of the two most important commercial species of the group, the other being *E. camaldulensis* which is closely related and exhibits very similar properties and characteristics (Davidson, 1981). It produces very strong, hard, heavy and durable timbers which are used in heavy construction, building scantlings, mining timbers and posts (Hall *et al.*, 1970). It is widely used for poles and fuelwood in India.

Eucalyptus tereticornis occurs naturally along the east coast of Australia with an occurence in Papua New Guinea. It extends from latitudes 10° S to 38° S (Quadri, 1981). It has an altitudinal range from near sea level to 909 m in northern Queensland and up to 1818 m in Papua New Guinea. Because of its wide geographic distribution, it covers a wide climatic range, ranging from monsoonal with distinct wet and dry seasons in Papua New Guinea, to a predominantly summer rainfall with a very dry winter in Queensland, to an equal distribution of rainfall between winter and summer in southern New South Wales to a dry summer and wet winter in Victoria (Davidson, 1981). The annual rainfall of its area of natural occurrence ranges from 635 mm to 1524 mm (Hall *et al.*, 1970).

In using *Eucalyptus tereticornis* as an exotic species, it is necessary to know the nature and magnitude of provenance variation associated with the large geographic distribution of the species. This will ensure that the correct seed source will be used to obtain maximum yield of dry fibre which is the goal when the anticipated use is for energy and chemicals (Dost, 1983). Such knowledge will also help in the selection of the right materials for breeding work.

Eucalyptus tereticornis has long been recognized as one of the fast-growing exotic tree species that can be used for afforestation programmes in the savanna region of Nigeria (Kemp, 1969). Because of this and the likelihood of great genetic diversity associated with geographic location a provenance trial involving the species was established in 1969 at Afaka, a location within the Northern Guinea Savanna region of the country. Data on the growth rates of the provenances represented in this trial were collected in 1972, 1974 and 1975, that is at ages three, five and six years respectively.

The aim of this paper is to show the patterns and magnitudes of intraspecific variation in growth in *Eucalyptus tereticornis* grown at Afaka, Nigeria. It is also intended to identify the most suitable provenance of the species for use in afforestation programmes in this part of Nigeria.

Materials and Methods

Eleven seed sources of *Eucalyptus tereticornis* were represented in the study. A brief description of these sources is presented in *Table 1.* Although northern New South Wales, Australia may be one of the most promising regions for provenance selection of this species (F.A.O., 1976), it was not represented in the trial while eight of the provenances tried came from Queensland. This probably arose because of earlier experience with other exotic tree species grown in Nigeria that trees from areas with predominantly summer rainfall do better in the country than those from areas of predominantly winter rainfall.

Information on the mother trees for three of the seedlots shows that two of them came from one mother tree each while one came from five mother trees. There is. however, no information on the number of mother trees for the remaining eight seedlots. It is suspected that none