GENETIC, SPACING, AND GENOTYPE X SPACING INFLUENCES ON GROWTH OF EUCALYPTUS GRANDIS IN SOUTH FLORIDA

Donald L. Rockwood[1/] and George Meskimen2/

Abstract.--Thirty-three E. grandis progenies in three studies and a related spacing study were used to document genetic, spacing, and genotype x spacing factors for growth up to 2.5 years. Variation among progenies was substantial for total height, diameter, tree volume, and volume/ha. Although progeny comparisons across studies were inconsistent, similarities within studies between traits over ages suggest that early progeny assessment may be possible. Spacing can be modified to alter juvenile yields dramatically, while use of the better progenies, due to the lack of spacing x progeny interaction, will permit yield increases for different cultural systems.

Additional keywords: Biomass, competition, genotype x environment interaction, early progeny assessment, selection.

Eucalyptus grandis Hill ex Maid., widely utilized worldwide (Eldridge, 1978), can be grown in south Florida for pulpwood (Franklin, 1978) or energy (Purdy et al., 1979). Three generations of selection by the USDA Forest Service (FS) have resulted in gains similar to those achieved by other E. grandis breeding programs (van Wyk, 1977; Campinhos and Ikemori, 1977).

Presently, FS E. grandis genetic base populations are planted at 1916 trees/ha and selected and rogued based on 2.5-year measurements. The current seedling orchard provides improved seed for pulpwood plantations established at 1389 trees/ha with an 8-year rotation. Shorter selection cycles and much closer spacings seem possible and appropriate for biomass base populations.

Reported below are results on 1) trait interrelationships among E. grandis progenies at juvenile ages, 2) spacing influences, 3) variation among progenies, and 4) genetic x spacing factors.

METHODS

In July 1979, open-pollinated progenies provided by FS were established near Labelle, Florida, in three biomass studies by the University of Florida (UF). Details of these studies plus the FS base population established in July 1977 near Labelle are presented in Table 1. UF studies were measured variously at .4, .7, 1.4, and 1.7 years for survival, height, and diameter. FS Base was measured for survival and height at .6 years and for survival, height, and dbh at 1.5 and 2.5

1/ Associate Professor, School of Forest Resources and Conservation, University of Florida, Gainesville, FL.
2/ Tree Breeder, USDA Forest Service, Southeastern Forest Experiment Station, Lehigh Acres, FL.
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years. Whole stem volume was estimated by the formula

$$dm3 = .00008333(D^2 H)^{.9525} - .000000055(D^2 H)^{1.2535}$$

first derived by J. Saucier and metricated by T. Lloyd (both USDA Forest Service, personal communication) where D is dbh in mm and H is total height in dm. Data sets were analyzed separately by appropriate analyses of variance and Duncan's Multiple Range Tests. Within data sets, correlation coefficients among traits were obtained using progeny means. Comparison of progenies across tests were based on correlation coefficients also derived from progeny means.

Table 1.--Description of E. *grandis* studies.

Study	No, of Progenies	Planting Densities (trees/ha)	Experimental Design	Plot Type	No. of Reps
UF Nelder	33	40,000 25,000 14,706 8,403 4,444	RCB, Nelder's circles (Design la)	single-tree	8
UF Selection	20	10,000	RCB	25-tree square	3
UF Spacing	49 bulk	20,000 10,000 6,667	CRD	100-tree square	3
FS Base	33 (of 529)	1,916	CRD	single-tree	approx. 60

1/ These progenies common to all studies.

RESULTS AND DISCUSSION

Variation among progenies was appreciable in most studies (Table 2). Survival in FS Base was relatively uniform, while progeny differences for height and stem volume were evident at all measurement ages. Progenies in UF Nelder, when compiled over all five spacings, also differed, and early differences among progenies were evident in UF Selection. Edge effect bias in UF Selection at 1.4 years resulted in elimination of 24 of 57 plots and reduction of precision. Consequently, substantial differences among progeny means, while similar to those in FS Base and UF Nelder, were not statistically significant.

Table 2.--Average, range, coefficient of variation, and significance of progeny means in E. grandis studies.

Study - Trait	Age	n	$\bar{x}$	Range	CV	Significance of Progenies[1/]
FS Base						
Survival - (%)	.6 years	33	98.3	94 - 100	1.7	--
Height - (dm) -	.6 years	33	19.1	16.6 - 20.4	4.2	**
-	1.5 years	33	47.5	41.5 - 52.9	6.7	*
-	2.5 years	33	74.9	63.8 - 84.4	7.6	**
Stem -	1.5 years	33	5.6	4.0 - 8.1	19.6	*
Volume - (dm^3)	2.5 years	33	21.5	12.9 - 31.6	21.9	**
Volume -	1.5 years	33	10.4	7.7 - 14.5	18.4	No
/ha - (m^3)	2.5 years	33	40.9	24.7 - 57.6	21.4	**
UF Nelder						
Height -	.4 years	33	14.8	10.5 - 17.4	8.8	**
(dm) -	.7 years	33	18.1	12.5 - 21.3	8.8	**
-	1.4 years	33	42.4	25.0 - 45.9	9.7	**
Stem -	.7 years	33	.670	.269 - 1.034	21.3	**
Volume - (dm^3)	1.4 years	33	1.88	.41 - 2.73	26.1	**
UF Selection						
Survival - (%)	.4 years	20	91.3	73 - 99	7.0	**
Height -	.4 years	20	16.3	14.6 - 19.1	8.0	**
(dm) -	1.4 years	19	47.0	40.5 - 54.1	8.1	No
Stem - Volume (dm^3)	1.4 years	19	2.37	1.72 - 3.15	15.6	No
Volume - /ha (m^3)	1.4 years	19	21.4	15.3 - 30.6	19.6	No

/ = not calculated, No = non-significant, * and ** = significant at the 5% and 1% levels, respectively.

Progeny differences in each study were consistent with age (Table 3). By age 1.5 years in FS Base, differences appeared to be established. At the closer spacings and higher competition in the OF studies, progeny differences evident as early as .4 years existed at 1.4 years. Correlations among height and volume traits at the same age were strong.

Table 3.--Correlation coefficients among progeny means within each E. grandis study.

	Height 1.5 years	Height 2.5 years	Stem Volume 1.5 years	Stem Volume 2.5 years
FS Base:				
Height - .6 years	.29	.22	.20	.10
- 1.5 years		.90**	.91**	.82**
- 2.5 years			.88**	.93**
Stem Vol. - 1.5 years				.84**
UF Nelder:	1.4 years		.7 years	1.4 years
Height - .7 years	.79**		.92**	.80**
- 1.4 years			.72**	.87**
Stem Vol. - .7 years				.84**
UF Selection:	.4 years	1.4 years	1.4 years	
Survival - .4 years	.05	.14	.30	
Height - .4 years		.77**	.71**	
- 1.4 years			.58**	

*, ** - Significant at the 5 and 1% levels, respectively.

Table 4.--Correlations coefficients among means of 33 progenies common to FS Base and OF Nelder.

	UF Nelder			
	Height		Stem Volume	
FS Base:	.7 years	1.4 years	.7 years	1.4 years
- .6 years	.29	.33	.07	.14
Height - 1.5 years	.26	.38*	.13	.26
- 2.5 years	.20	.41*	.09	.25
Stem - 1.5 years	.09	.28	.01	.18
Volume - 2.5 years	.05	.33	-.02	.19

*Significant at the 5% level.

Progeny performance across the various studies was not consistent. While correlations between height growth of the 33 progenies in FS Base and UF Nelder at 1.4 years were evident, the correlations between height and stem volume and between stem volumes in the two studies were not significant (Table 4). On the basis of the 19 progenies occurring in all three studies, heights at age 1.4 years in the UF studies were correlated with FS Base heights in four of the six possible cases and in one instance 1.4 year height in UF Nelder was correlated with 1.5 year stem volume in FS Base (Table 5). The 19 progenies common to the two UF studies had similar performance at 1.4 year heights only; stem volume correlations were not evident.

Table 5.--Correlation coefficients among means of 19 progenies common to UF Base, UF Nelder, and UF Selection.

		UF Nelder				
		Height			Stem Volume	
FS Base:	Years:	.4	.7	1.4	.7	1.4
Height	- .6 years	.32	.39	.52*	.19	.32
	- 1.5 years	.32	.35	.56*	.22	.50*
	- 2.5 years	.22	.23	.54*	.18	.45
Stem Volume	- 1.5 years	.13	.14	.46*	.08	.39
	- 2.5 years	.03	.02	.43	.01	.34

		UF Selection			
		Height		Stem Vol.	Vol./ha
FS Base:	Years:	.4	1.4	1.4	1.4
Height	- .6 years	.53*	.50*	.31	.26
	- 1.5 years	-.17	-.03	-.47	-.30
	- 2.5 years	-.01	.12	-.26	-.09
Stem Volume	- 1.5 years	-.27	-.03	-.47	-.26
	- 2.5 years	-.16	.06	-.28	-.10

		UF Selection			
		Height		Stem Vol.	Vol./ha
UF Nelder:	Years:	.4	1.4	1.4	1.4
Height	- .4 years	.27	.26	-.02	-.05
	- .7 years	.29	.25	-.01	-.06
	- 1.4 years	.35	.52*	.05	.06
Stem Volume	- .7 years	.21	.22	.00	-.04
	- 1.4 years	.19	.41	-.01	-.03

*Significant at the 5% level.

The lack of consistency of progeny performance may be due to many factors. In view of the degree of similarity in height growth, stem volume inconsistencies may be attributed to the different spacing or competitive regimes in the studies. The relatively wide spacing in FS Base may not create the level of competition through 2.5 years that was present at 1.4 years in UF Selection or at even younger ages in the closer spacings in UF Nelder. Although the two sites are within 8 km of each other, site factors, as have been detected in very limited areas, may cause some genotype x environment interaction. Another possible explanation for progeny instability between FS Base and UF studies may be different seed crop years, but this factor appears minimal because of the lack of correlation just within the UF studies.

The potential for short-term, close-spacing progeny testing for pulpwood rotation systems consequently is not established. Consistency of performance over age within the UF biomass studies gives encouragement for the approach, but longer-term growth data are needed.

Differences among the 33 progenies when grouped by generation identify the progress that has been made by selection and also the same inconsistency in progeny performance discussed earlier. In FS Base, 1.5-year stem volumes of progenies of second and third generation selects compared to progenies of first generation selects averaged 12% and 25% greater, respectively. (These differences may be affected by the inter-genotypic competition introduced by the single-tree plot layout.) However, the same comparisons in UF Nelder for 1.4 year stem volume resulted in differences of only 3% and 7%, suggesting that the selection criteria for pulpwood and biomass cultures are only weakly related.

Spacing had considerable influence on growth in UF Nelder (Tables 6 and 7). Total tree height at .4 and .7 years was greater at the two closest spacings,

Table 6.--Height, stem volume, and volume/ha means for UF Nelder and UF Spacing.

Study-Spacing	Years:	Height			Stem Volume		Volume/ha	
		.4	.7	1.4	.7	1.4	.7	1.4
(trees/ha)		--------dm--------			-----dm^3----		-----m^3----	
UF Nelder -								
40,000		16.5^{a}[1/]	20.6^{a}	41.5^{a}	$.54^{a}$	1.08^{a}	21.6^{a}	43.3^{a}
25,000		15.4^{b}	19.2^{b}	42.5^{a}	$.61^{ab}$	1.43^{ab}	15.3^{b}	35.8^{b}
14,706		14.2^{c}	17.1^{c}	41.8^{a}	$.63^{ab}$	1.61^{b}	8.9^{c}	22.9^{c}
8,404		13.8^{c}	16.5^{c}	41.8^{a}	$.72^{bc}$	2.11^{c}	6.1^{d}	17.7^{d}
4,444		13.9^{c}	16.6^{c}	44.0^{a}	$.84^{c}$	3.15^{d}	3.7^{e}	14.0^{d}
UF Spacing -								
20,000		12.6^{a}	--	43.3^{a}	--	1.89^{a}	--	33.7^{a}
10,000		13.0^{a}	--	43.5^{a}	--	2.42^{b}	--	22.9^{b}
6.667		12.6^{a}	--	42.0^{a}	--	2.72^{c}	--	16.2^{c}

[1/] Meanswithin a trait and study not sharing the same superscript are significantly different at the 5% level.

Table 7.--Summary of F-values resulting from analyses of variance for OF Nelder.

			at Age .7 Years				at Age 1.4 Years			
Source	Approx. df.	Height at Age .4 Years	Height	DBH	Stem Volume	Vol./ha	Height	DBH	Stem Volume	Vol./ha
Reps (R)	7	17.41**	13.91**	9.49**	12.25**	6.02**	4.57**	1.49	2.52**	.88
Spacings (S)	4	9.61**	16.23**	18.26**	4.23**	89.72**	1.61	45.14**	37.93**	56.86**
Progenies (P)	32	3.46**	2.99**	2.37**	2.24**	2.72**	4.98**	3.64**	2.75**	3.42**
R x S	28	4.30**	2.72**	2.87**	4.50**	2.53**	1.99**	1.87**	2.00**	1.38
R x P	224	2.28**	3.85**	1.46**	1.81**	1.53**	1.53**	1.34**	1.45**	1.21*
S x P	128	1.17	1.06	.96	1.10	1.07	1.03	1.09	1.19	1.17
Error	896									
	1319									

* and ** Significant at the 5% and 1% levels, respectively.

but by 1.4 years heights were comparable to all spacings. Diameter was strongly affected by spacing and produced three-fold tree volume differences at 1.4 years. Environmental variation was evident as differences among the eight reps located on the .3 ha area were significant for each trait and age except DBH at 1.4 years. Rep x Spacing and Rep x Progeny interactions were also present.

The absence of progeny by spacing interaction for all traits in OF Nelder (Table 7) is especially notable. For the alternative spacings being considered for biomass plantations, the better performing progenies will apparently do well at any of the spacings. However, because no pulpwood spacings are involved in the examination of interaction, any extrapolation to progeny performance at planting densities less than 4,444 trees/ha is risky.

Volume yields from the four studies mesh in consistent inverse relation to planting density while mean heights are surprisingly uniform (Table 8). These consistent results from different studies, separate sites, different seed crop years, and different planting years suggest that the yields obtained characterize productivity achievable over the vast area of similar sites available in south Florida.

Our results indicate that a thorough genotype x spacing study needs to be initiated in order to characterize definitively the performance of E. *grandis* progenies across the range of spacings to be considered for pulpwood and biomass systems. Such a study, with adequate plot size, buffer, and replication, would involve major commitments of plant material, land, and personnel.

Table 8.--Summary of mean heights and volumes for all E. grandis studies ordered by planting density.

Study	Trees/ha	Age	Height	Volume Total	Volume Per Year
		(yr)	(dm)	m^3/ha	m^3/ha
UF Nelder	40,000	1.4	41.5	43.3	30.9
UF Nelder	25,000	1.4	42.5	35.8	24.6
UF Spacing	20,000	1.4	43.3	33.7	24.1
UF Nelder	14,706	1.4	41.8	22.9	16.4
UF Spacing	10,000	1.4	43.5	22.9	16.4
UF Selection	10,000	1.4	47.0	21.4	15.3
UF Nelder	8,403	1.4	41.8	17.7	12.6
UF Spacing	6,677	1.4	42.0	16.2	11.6
UF Nelder	4,444	1.4	44.0	14.0	10.0
FS Base	1,916	1.5	47.5	10.5	7.0

CONCLUSIONS

Considerable variation for juvenile height and volume growth exists among E. grandis progenies. Progeny differences were consistent over age within each study but were inconsistent over studies possibly due to varying levels of competition and limited time of observation. Short-term, close-spacing systems for progeny evaluation may be possible if longer-term evaluation conforms to present patterns. Close spacings radically affected short-term productivity levels, with the closest spacing resulting in total stem biomass/ha four times larger than that achieved with 1,916 trees/ha. Spacing x progeny interaction appears minor.

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