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GENETIC AND SPACING EFFECTS ON LOBLOLLY PINE PLANTATION DEVELOPMENT THROUGH AGE 17

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Abstract—Eight North Carolina families and a Mississippi-Alabama commercial check of loblolly pine (*Pinus taeda* L.) were planted at three spacings (5x5, 8x8, and 10x10 feet) in east Mississippi. Results for ages 5, 9, 13, and 17 years indicated that spacing effects occurred by age 5 for d.b.h. and height and by age 9 for survival, stand volume, and periodic annual increment (PAI) in volume. D.b.h. decreased as spacing decreased. Height was temporarily stimulated as trees began to compete with each other. Density-related mortality began between ages 5 and 9 for the 5x5 and between ages 9 and 13 for the 8x8 and 10x10. Peak PAI occurred during these same periods. The 5x5 spacing had the greatest stand volume at ages 9 and 13, but by age 17, the 8x8 and 5x5 spacings were similar. Family effects were detected by age 5 for d.b.h., height, stand volume, and PAI. Survival differences among families became significant by age 13. Family NC1 consistently ranked highest in stand volume at all ages, and it had 27 percent more volume per acre than the local check at age 17. The primary contributor to family differences for stand volume was survival. Family-by-spacing interactions were seldom significant.

INTRODUCTION

Selections of a spacing and genetic source of seedlings are two of the most important decisions that must be made during establishment of forest plantations. These decisions will predetermine future timing of silvicultural treatments, productivity of the plantation, and quality of harvested wood.

Numerous spacing studies with loblolly pine (*Pinus taeda* L.) have been established to evaluate and model density effects on growth (Smith and Strub 1991). Unfortunately, most of the studies do not have a family component to examine genetic effects. Also, many of the reports have been for measurements taken at young ages. A recent paper by Sharma and others (2002) provides information for measurements taken through age 16 for spacings ranging from 4x4 feet to 12x12 feet. However, the study used only one source of genetic material. A paper by Matyas and Varga (2000) provided 25-year data for spacing trials of Scots pine (*Pinus sylvestris* L.) established with grafted clones. Those authors showed that spacing affected early phases of stand development and allocation rates to different parts of the tree. Genetic effects could not be traced, however, because of large within-clone variation and a small number of replications.

The present study was designed to investigate how initial spacing and family "types" affect loblolly pine stand development. Such an investigation requires large, adequately replicated plots containing families of predetermined growth types that are grown under various spacings without thinning and measured through the periods of crown closure and self thinning. Results to age 5 (prior to crown closure) were reported by Land and others (1991) at the Sixth Biennial Southern Silvicultural Research Conference. This paper examines stand development from age 5 to age 17.

METHODS

Eight open-pollinated families from North Carolina that were pre-selected for differences in growth rate and crown size (from earlier progeny tests in North Carolina) (Land and others 1991) were planted at three spacings in east-central Mississippi and compared with a local unselected check for stand development through age 17. Spacings were 5x5 feet, 8x8 feet, and 10x10 feet. Families NC1 and NC8 had the type "fast growth and small crown", families NC4 and NC7 were typed as "fast growth and large crown", families NC3 and NC6 were "slow growth and small crown" types, and families NC2 and NC5 were classified as "slow growth and large crown" types. The check was a mixture of seeds from trees in Lowndes and Kemper Counties of east-central Mississippi and Fayette and Pickens Counties in west-central Alabama. Containerized seedlings of the nine genetic sources were provided by Weyerhaeuser Company.

The study was established in early 1985 as a randomized complete block design with treatments arranged in split-split plots and repeated on two adjacent sites: one an old field and the other a cutover-and-site-prepared area. There were four replications on each of the two sites. Each replication was split into three spacing plots of equal acreage. Each spacing plot was split into a "mixture" subplot and a "single-family" subplot of genetic deployments. However, the mixture subplots were not included in the analyses and results for this paper. Therefore, the analyses reported here used a split-plot design with nine single-family subplots within each spacing main plot of each replication. Each single-family subplot had a single or double border row around an interior set of measurement trees that covered the same acreage (40 feet x 40 feet, or 0.0367 acres) in all spacings. Thus, a single-family subplot contained 16 measurement trees at 10x10-foot spacing, 25 measurement trees at 8x8-foot spacing, and 64 measurement trees at 5x5-foot spacing.

Survival, d.b.h., and height were measured at ages 5, 9, 13, and 17 years. Stem volume in total cubic feet outside bark was estimated for each tree by the following equation provided by Dr. Tom Matney at Mississippi State University for old-field loblolly pine:

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$$\text{Volume} = 0.00250 \times \text{d.b.h.}^2 \times \text{ht.} \quad (1)$$

Single-family subplot values for survival, d.b.h., height, and stand volume per acre were calculated for each of the 4 years. Dominant height (co-dominant and dominant trees only) was also calculated at ages 9, 13, and 17 years. Eighteen of the 216 subplots had to be discarded at age 17 because bark-beetle-caused mortality was greater than 20 percent in those plots. Periodic annual increment (PAI) in stand volume was calculated for each subplot for the four periods, 0-5 years, 5-9 years, 9-13 years, and 13-17 years. Subplot values were used in analyses of variance based on a mixed-effects model, where spacings and families were treated as fixed effects and replications and planting sites were considered random effects. A full analysis with all sources of variation was conducted first for each trait at each age. If higher-order interactions were not significant, they were pooled with the error term for a final analysis. The Tukey-Kramer procedure was used for all pairwise comparisons among spacing means and among family means (SAS Institute Inc. 1999).

RESULTS AND DISCUSSION

Spacing Effects

Spacing effects on survival—Differences among spacings in survival were not significant at age 5, but they had become significant by age 9 (table 1). The 5x5 spacing was significantly lower in survival than the wider two spacings at age 9, and by ages 13 and 17 all three spacings were significantly different from each other (table 2). Crown closure and self thinning started between ages 5 and 9 in the 5x5 spacing and between ages 9 and 13 in the 8x8 and 10x10 spacings. There was a decline of 1 percent per year in survival before age 5, 2 percent per year during the period of crown closure and initiation of self thinning, and 2.5 percent to 4.5 percent per year in the 4-year periods after the initiation of self thinning. As a result, the 5x5 spacing had 53 percent survival at age 17, the 8x8 had 70 percent, and the 10x10 had 74 percent (reflecting differences in the length of time since initiation of self thinning).

Spacing effects on stem diameter—Close spacings resulted in smaller d.b.h. than wide spacings at the same age. These spacing effects were already significant at age 5 (table 1), before the onset of self thinning. The early difference was due to the 5x5 spacing, which had a significantly smaller d.b.h. than the two wider spacings at age 5 (table 3). By age 9 and thereafter, all three spacings were significantly different from each other. At age 17 the mean tree d.b.h. in the 5x5 spacing was 5.9 inches, while the 8x8 and 10x10 spacings had d.b.h.s of 8.0 and 9.3 inches, respectively.

Spacing effects on tree height—Mean height (all trees) differed significantly among spacings at all 4 ages (table 1), but the spacing with the tallest trees differed for the different ages (table 4). Height growth was temporarily stimulated at the time of crown closure. Trees were tallest in the 5x5 spacing at age 5, equally tall in the 5x5 and 8x8 spacings at age 9, tallest in the 8x8 at age 13, and equally tall in the 8x8 and 10x10 spacings at age 17. The difference between the tallest and shortest spacings for mean heights at a given age increased from approximately 1.5 feet at ages 5 and 9 to 4.5 feet at age 17. All living trees were included in the means, so part of the decline in rank of the closer spacings at the older ages could be due to the inclusion of the intermediate and overtopped crown classes. This possibility was supported by analyses of dominant heights (co-dominant and dominant trees only). Those analyses showed the same trends as seen in table 4, except that the spacing means were 1.0 to 1.5 feet taller than for all trees, and the difference between the tallest and shortest means was reduced to 3.5 feet at age 17. The rankings and significance of differences among spacing means remained the same for dominant height as for height of all trees. Thus, part of the temporary stimulation effect on height is a "real" effect (rather than a confounded effect from inclusion of intermediate and overtopped trees). By age 17 and thereafter, however, the shortest trees will be in the 5x5 spacing, and the tallest trees will be in the 10x10 spacing.

Table 1—F-test significance of sources of variation for five traits across four ages in a 17-year-old loblolly pine spacing and genetics trial

Source of variation	d.f.	Survival age =				DBH age =				Height age =				Stand volume age =				Volume PAI age =			
		5	9	13	17	5	9	13	17	5	9	13	17	5	9	13	17	5	9	13	17
Locs [=L]	1	ns	ns	ns	ns	**	**	ns	ns	**	**	ns	**	**	**	ns	ns	**	*	ns	ns
Reps/L[R(L)]	6	**	**	**	**	**	ns	**	*	**	*	*	*	**	*	**	ns	**	**	**	**
Spacings[=S]	2	ns	**	**	**	**	**	**	**	**	*	**	**	ns	**	**	**	ns	**	**	**
S x L	2	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	**	ns	ns	ns	**	ns	ns	ns
S x R(L)	12	*	ns	ns	ns	ns	**	*	*	*	**	**	**	**	ns	ns	ns	**	ns	ns	ns
Families[=F]	8	ns	ns	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
F x L	8	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
F x R(L)	48	*	ns	*	ns	ns	ns	*	**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns
F x S	16	*	ns	ns	*	ns	ns	ns	**	ns	ns	ns	ns	*	ns	ns	ns	*	ns	**	ns
Pooled error	112[a]																				

PAI = periodic annual increment; ns = non-significant; * = significant at 0.05 probability; ** = significant at 0.01 probability.
[a] Or 94 at age 17.

Table 2—Spacing and family effects on survival at four ages in a 17-year-old loblolly pine study

Effects	Survival at four ages (years)			
	5	9	13	17
	percent			
Study mean	94.5	87.7	77.4	66.4
Spacing:				
5x5 feet	94 A	85 b	71 C	53 c
8x8 feet	95 A	88 a	79 B	70 b
10x10 feet	94 A	90 a	82 A	74 a
Family:				
Local check	95 a	88 A	76 bc	61 CD
NC fast growth & small crown:				
NC1	95 a	92 A	88 a	78 A
NC8	92 a	84 A	73 c	61 CD
NC fast growth & large crown:				
NC4	96 a	91 A	82 ab	68 BCD
NC7	95 a	88 A	78 bc	68 BC
NC slow growth & mall crown:				
NC3	95 a	84 A	71 c	60 D
NC6	95 a	87 A	76 bc	63 BCD
NC slow growth & large crown:				
NC2	94 a	87 A	75 bc	64 BCD
NC5	94 a	88 A	77 bc	70 AB

Means followed by the same letter (and case) within a column are not significantly different at the 0.05 level. The family mean with a single underline is the largest mean at that age, and the family mean with a double underline is the smallest mean at that age.

Table 3—Spacing and family effects on mean diameter (d.b.h.) at four ages in a 17-year-old loblolly pine study

Effects	D.b.h. at four ages (years)			
	5	9	13	17
	inches			
Study mean	2.47	5.29	6.86	7.82
Spacing:				
5x5 feet	2.37 B	4.23 c	5.21 C	5.92 c
8x8 feet	2.50 A	5.53 b	7.16 B	8.03 b
10x10 feet	2.54 A	6.11 a	8.22 A	9.34 a
Family:				
Local check	2.41 c	5.30 AB	6.89 ab	7.92 AB
NC fast growth & small crown:				
NC1	2.64 a	5.36 AB	6.77 b	7.63 B
NC8	2.44 bc	5.34 AB	7.09 a	8.02 A
NC fast growth & large crown:				
NC4	2.61 ab	5.43 A	6.88 ab	7.74 AB
NC7	2.45 abc	5.33 AB	6.97 ab	7.77 AB
NC slow growth & small crown:				
NC3	2.46 ab	5.31 AB	6.88 ab	7.81 AB
NC6	2.51 ab	5.26 ABC	6.71 b	7.56 B
NC slow growth & large crown:				
NC2	2.45 abc	5.19 BC	6.87 ab	7.82 AB
NC5	2.26 c	5.10 C	6.72 b	7.60 B

Means followed by the same letter (and case) within a column are not significantly different at the 0.05 level. The family mean with a single underline is the largest mean at that age, and the family mean with a double underline is the smallest mean at that age.

Table 4—Spacing and family effects on mean height (all crown classes included) at four ages in a 17-year-old loblolly pine study

Effects	Four ages (years)			
	5	9	13	17
	height in feet			
Study Mean	15.0	33.1	50.3	60.5
Spacing:				
5x5 feet	15.9 A	33.5 a	48.6 C	57.4 b
8x8 feet	14.7 B	33.3 ab	52.0 A	61.8 a
10x10 feet	14.3 B	32.5 b	50.5 B	62.1 a
Family:				
Local Check	14.2 de	31.3 D	48.0 e	57.2 C
NC Fast Growth & Small Crown:				
NC1	16.1 a	34.6 A	51.4 a	61.7 A
NC8	15.0 cd	33.3 B	51.2 ab	61.9 A
NC Fast Growth & Large Crown:				
NC4	15.9 ab	34.6 A	51.7 a	61.0 A
NC7	15.0 cd	33.4 B	51.8 a	62.0 A
NC Slow Growth & Small Crown:				
NC3	14.8 cd	33.0 BC	50.1 bc	60.1 AB
NC6	14.8 cd	32.4 BCD	48.7 de	58.7 BC
NC Slow Growth & Large Crown:				
NC2	15.2 bc	33.4 B	50.6 abc	61.2 A
NC5	13.8 e	31.9 CD	49.8 cd	60.5 AB

Means followed by the same letter (and case) within a column are not significantly different at the 0.05 level. The family mean with a single underline is the largest mean at that age, and the family mean with a double underline is the smallest mean at that age.

Spacing effects on stand volume—Significant differences among spacings for stand volume were first detected at age 9 and remained significant through age 17 (table 1). However, the differences were greatest at ages 9 and 13 and had declined by age 17. At age 9, the 10x10 spacing had only half the volume of the 5x5, and the 8x8 was intermediate (table 5). By age 17, the 5x5 spacing had apparently reached carrying capacity for the site and the 8x8 had caught up, so that these two spacings were no longer different in stand volume. Volume for the 10x10 spacing was still significantly less than the other two, but it was closing on them and was 91 percent of the 5x5 volume. The reader is cautioned to remember that the same equation was used to calculate volumes in all spacings, so no accounting for differences in stem taper was provided. The spacing differences in actual volume may be larger than reported here.

Spacing effects and stand volume growth rate—Periodic annual increments (PAI) in stand volume differed significantly among spacings in the 5-to-9 age period, the 9-to-13 age period, and the 13-to-17 age period (table 1). However, the spacing with the greatest PAI differed for each of these periods (table 6). The 5x5 spacing had the greatest growth rate in cubic feet per acre per year during the 5-to-9 age period, the 8x8 had the greatest rate in the 9-to-13 age period, and the 10x10 had the greatest rate during the 13-to-17 age period. The peak (maximum) PAI occurred between ages 5 and 9 years for the 5x5 spacing and between ages 9 and 13 years for the 8x8 and 10x10 spacings. Based on the PAIs in the adjourning periods, the peak rate of growth probably occurred at ages 8-9 in the 5x5, ages 10-11 in the 8x8, and ages 12-13 in the 10x10. These peak values correspond with onset of self thinning in the different spacings.

Genetic Effects

Genetic effects on survival—Family differences in survival were first detected as significant at age 13 (table 1), which was when self thinning had begun in all spacings. Family NC1 (fast growth and small crown) had the highest survival at ages 13 and 17 (88 percent and 78 percent, respectively) (table 2). Family NC3 (slow growth and small crown) had the lowest survival at ages 13 and 17 (71 percent and 60 percent, respectively). The local check was among the lower ranking families for survival and was not significantly different from NC3. Since the families were competing only with themselves in the single-family subplots, the family differences must be due to differences in self-thinning rates rather than family differences in crown position and overtopping (as might occur in a mixture of families). This will be studied in subsequent analyses and is not included here.

Genetic effects on stem diameter—Family differences in mean tree d.b.h. were highly significant at age 5 and all ages thereafter (table 1). However, the rankings of the families changed radically between age 5 and age 17 (table 3), partly as a result of the family differences in survival that

Table 5—Spacing and family effects on stand volume (cubic feet per acre outside bark) at four ages in a 17-year-old loblolly pine study

Effects	Stand volume at four ages (years)			
	5	9	13	17
	cubic feet per acre			
Study Mean	237	1757	3729	4779
Spacing:				
5x5 feet	427 A	2390 a	4325 A	4953 a
8x8 feet	175 A	1619 b	3695 B	4883 a
10x10 feet	110 A	1262 c	3167 C	4509 b
Family:				
Local Check	216 cd	1669 BC	3516 d	4364 CD
NC Fast Growth & Small Crown:				
NC1	282 a	1933 A	4218 a	5550 A
NC8	234 bc	1792 AB	3835 bc	4861 BC
NC Fast Growth & Large Crown:				
NC4	270 ab	1954 A	4049 ab	4914 B
NC7	234 bc	1827 AB	3994 ab	5129 AB
NC Slow Growth & Small Crown:				
NC3	239 abc	1679 BC	3402 d	4335 CD
NC6	234 bc	1672 BC	3393 d	4246 D
NC Slow Growth & Large Crown:				
NC2	240 abc	1689 BC	3617 cd	4769 BCD
NC5	186 d	1597 C	3538 cd	4869 BC

Means followed by the same letter (and case) within a column are not significantly different at the 0.05 level. The family mean with a single underline is the largest mean at that age, and the family mean with a double underline is the smallest mean at that age.

Table 6—Spacing and family effects on periodic annual growth (PAI) in stand volume (cubic feet per acre per year) at four ages in a 17-year-old loblolly pine study

Effects	Periodic annual growth at four ages (years)			
	0–5	5–9	9–13	13–17
	cubic feet per acre per year			
Study Mean	47.5	379.9	493.0	260.7
Spacing:				
5x5 feet	85.5 A	490.6 a	483.9 B	150.2 c
8x8 feet	34.9 A	361.2 b	518.9 A	286.4 b
10x10 feet	22.0 A	287.9 c	476.2 B	332.4 a
Family:				
Local Check	43.2 cd	363.3 BC	461.7 cd	208.6 B
NC Fast Growth & Small Crown:				
NC1	56.4 a	412.7 A	571.2 a	329.4 A
NC8	46.9 bc	389.4 ABC	510.6 abc	242.3 AB
NC Fast Growth & Large Crown:				
NC4	54.0 ab	421.1 A	523.8 abc	218.0 B
NC7	46.8 bc	398.3 AB	541.7 ab	281.9 AB
NC Slow Growth & Small Crown:				
NC3	47.9 abc	360.0 C	430.6 d	233.2 B
NC6	46.7 bc	359.5 C	430.4 d	207.6 B
NC Slow Growth & Large Crown:				
NC2	48.0 abc	362.2 BC	482.1 bcd	282.2 AB
NC5	37.3 d	352.6 C	485.2 bcd	303.5 AB

Means followed by the same letter (and case) within a column are not significantly different at the 0.05 level. The family mean with a single underline is the largest mean at that age, and the family mean with a double underline is the smallest mean at that age.

caused density-related effects on diameter growth. An example was family NC1, which had the largest mean d.b.h. at age 5 (rank 1 of 9) and one of the smallest mean d.b.h. values at age 17 (rank 7 of 9). This family had the highest survival at age 17. Family NC8, which was the other fast-growth and small-crown family with NC1, exhibited the opposite change in rank. It was near the lower end of family means for d.b.h. at age 5 (rank 7 of 9) and at the top for family mean d.b.h. at age 17. It had the next-to-lowest survival at age 17. The local check acted much like NC8. It had the next-to-smallest mean d.b.h. at age 5 and next-to-largest mean d.b.h. at age 17. It was tied with NC8 for next-to-lowest survival at age 17.

Genetic effects on tree height—Differences among families in mean tree height (all trees) were highly significant at age 5 and all ages thereafter (table 1). Family ranks for height did not change as greatly between age 5 and age 17 as they did for d.b.h. (table 4). Dominant heights gave similar rankings and significance tests for family means, except that the dominant heights were taller than the mean heights by 1.0 feet at ages 9 and 13 and by 1.5 feet at age 17. Family NC1 had the tallest mean height at age 5 (16.1 feet) and was near the tallest at age 17 (61.7 feet = rank 3 of 9). The local check was next to the shortest in height at age 5 (14.2 feet), and it was the shortest of all families at age 17 (57.2 feet). Two families did increase in family rank from age 5 to age 17. Families NC7 and NC8 had middle ranks for height at age 5 (ranks 4 and 5 of 9), but they were tallest at age 17 (ranks 1 and 2, respectively). Both of these families were pre-selected for fast growth, but NC7 was classified as large crown and NC8 as small crown. Thus, 3 of the 4 "fast growth" families were the tallest 3 in rank at age 17. The pre-selections for fast growth (in height), based on 12-year performance in North Carolina progeny tests, were effective for performance through age 17 in Mississippi.

Genetic effects on stand volume—Family differences in stand volume were highly significant at all ages from 5 years through 17 years (table 1). Family NC1 consistently ranked highest in volume (rank 1 at ages 5, 13, and 17, and rank 2 at age 9) from the time of crown closure through the early stages of self thinning (table 5). By age 17 this family had 5,550 cubic feet per acre as compared with the check's value of 4,364 cubic feet per acre, or a realized gain of 27 percent. Family NC6 was in the lower half of the families for stand volume at age 5 (rank 6 of 9) and had the lowest volume of 4,246 cubic feet per acre at age 17 (3 percent below the check). Family ranks at age 5 were not always indicative of family performance at age 17 for stand volume, however. Family NC5 had the lowest stand volume at ages 5 and 9, but it had increased to rank 4 of 9 by age 17 and was not significantly different from the second-ranked family. The most important contributing factor to the family differences in stand volume was survival. Family NC1 ranked number 1 for survival and number 1 for stand volume at age 17, family NC6 ranked number 6 for survival and number 9 for volume, and the check ranked number 8 for survival and number 7 for volume. The families classified as "fast growth" in prior progeny tests (NC1, NC4, NC7, and NC8) generally had greater stand volumes at age 17 than those classified as "slow growth", but crown-size classification was only important in the "slow growth" class. The two families classified for slow growth and small crown size (NC3 and NC6) had the two lowest family values for 17-year stand volume.

Genetic effects on stand volume growth rate—Differences among families for periodic annual increments (PAI) in stand volume were highly significant for the 5 periods 0-5 years, 5-9 years, 9-13 years, and 13-17 years (table 1). Family rankings changed for some families from before age 9 to after age 9 (the onset of self thinning), and not for others (table 6). Family NC5 increased from the lowest growth rate before age 9 to the next to highest growth rate in the 13-17-year period. It is a slow starter but a good survivor. It was pre-selected for slow growth and large crown size. Family NC1 was an example of a family that did not change between the two periods. It consistently had the fastest or next-to-fastest growth rate before and after age 9. This family is a fast starter and a good survivor. It was pre-selected for fast growth and small crown size. The local check also did not change much from before age 9 to after age 9. It was next to lowest in stand growth rate for the 0-5 age period and for the 13-17 age period. It was a slow starter and a poor survivor.

Family-by-Spacing Interactions

Family-by-spacing interactions were usually not significant (table 1). Interactions for survival were detected at ages 5 and 17, but the differences were so small at age 5 that they had little practical meaning. By age 17 there were some minor changes in family ranks for survival among spacings, but the major contributor to the interaction was a greater spread in family means for the 8x8 and 10x10 spacings than for the 5x5 spacing. The only significant interaction found for stem diameter was at age 17, and this interaction was mainly due to a larger spread in family means at the wider spacings than at the 5x5 spacing. There were no family-by-spacing interactions for mean tree height at any age. The only age at which an interaction was detected for stand volume was age 5. This interaction was due to a wider spread in family means at the 5x5 spacing than at the other two spacings. Interactions were significant for PAI in stand volume during the first 5-year period and also during the period of onset of self thinning between ages 9 and 13 years. Both interactions were due to changes in spread of family means in the different spacings. For the first 5 years the greatest spread was in the 5x5 spacing, but for the 9- to 13-year period the greatest spread was in the 8x8 spacing. Family ranks changed little between spacings.

SUMMARY AND CONCLUSIONS

Spacing effects were seen on tree diameter and height before the onset of self thinning. Self thinning began around age 8-9 years in the 5x5 spacing, 10-11 years in the 8x8 spacing, and 12-13 years in the 10x10 spacing, as indicated by both the development of significant differences between spacings in survival and the timing of peak PAI values for annual growth in stand volume. Thus, differences among spacings in mean d.b.h. and height were already significant at age 5, but differences in survival and stand volume were not detected until age 9. D.b.h. was reduced by close spacing at age 5, and this difference between spacings got larger with increasing age. However, mean tree height (all living trees included) was only temporarily stimulated by close spacing, so that the 5x5 spacing was tallest at age 5, the 8x8 was tallest at age 13, and the 10x10 was tallest at age 17. Part of the decline in mean height after crown closure may be from the inclusion of increased numbers of intermediate and overtopped trees in the height mean. The 5x5 spacing reached peak PAI for growth in stand volume around age 8-9 years and was approximately at carrying capacity for cumulative stand volume at age 17. The 8x8 spacing reached peak PAI around age 10-11 years and was approaching the same carrying capacity as the 5x5 spacing by age 17, so that these two spacings were no longer significantly different for stand volume at that age. The 10x10 spacing reached peak PAI around age 12-13 years, and the cumulative volume for this spacing at age 17 was 91 percent of the 5x5 value and closing on that value. By age 20, the three spacings might not differ in stand volume.

Genetic effects, averaged over spacings, were detected for all traits at all ages, with the exception of survival at ages 5 and 9. The ability to detect these effects was enhanced by the pre-selection of family "types" and the treatment of these families as fixed effects in the analyses of variance. "Fast-growth" families produced the most volume per acre at age 17, and "slow growth with small crown" families produced the least volume. The local check was next to lowest in volume per acre at age 17, indicating that selection in North Carolina progeny tests provided realized gains in plantings in Mississippi. The greatest contributor to family differences in stand development was survival. Family NC1 ranked at the top for survival and stand volume throughout the 17-year life of the stand, while NC6 ranked near the bottom (rank 6 of 9) for survival and had the lowest volume per acre at age 17. Family differences in survival caused differences in density-related stand characteristics and resulted in changes in family ranks for the periods before and after onset of self thinning. The family NC1 had the largest mean d.b.h. at age 5 and one of the smallest mean d.b.h. values at age 17, because the family's high survival caused a greater density effect than for other families with lower survival. Both rapid early growth and the ability to tolerate competition (maintain high survival after crown closure) are needed to maximize stand volume production. This combination occurs in family NC1.

Spacing-by-family interaction effects should not represent a major concern for tree improvement programs. Interactions were seldom detected, and most of those interactions were due to changes in spread between family means at the different spacings rather than changes in rank. However, information about the interactions might be used in decisions about spacings for progeny tests, so that the largest spreads among family means can be generated to increase selection efficiency. From an operational standpoint the changes in spread among families can be used to enhance yield by matching families with pre-determined spacings and rotation lengths.

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