

ABSTRACT

Handest, Joshua A. Effects of Nutrient Amendments and Genotype on Stand Productivity and Crown Characteristics in Loblolly Pine (*Pinus taeda* L.) (Under the direction of H. Lee Allen and Steven E. McKeand).

Two provenances of loblolly pine, with five open-pollinated families from each were analyzed for differences in height, volume, leaf area, and various crown characteristics. Families from the North Carolina and South Carolina Coastal Plain (ACP) and from the “Lost-Pines” area of Texas (LPT) were included in the study. In addition to studying potential genetic variation, half of the plots received fertilization treatments so that potential nutrient and genotype x environment (GxE) interactions could be assessed. The stands were established in 1993 and height was measured annually until year 3 when both height and diameter at breast height were measured. Leaf area measurements were made in 1999 using the LI-CORE LAI-2000 PCA and destructive and non-destructive sampling of individual branches was done to estimate the crown characteristics

Nutrient additions starting at stand establishment resulted in large gains in juvenile development in height, volume, leaf area, and growth efficiency. Fertilization also dramatically increased foliage and branch biomass at all crown levels, and also contributes to an early shift of foliage from the lower crown to the middle. This is most likely due to early canopy closure. The Atlantic Coastal Plain provenance consistently outperformed the Lost Pine Texas provenance in height, volume, and growth efficiency. The ACP provenance had more foliage, predominately in the middle crown than the LPT provenance, which may explain some of the productivity differences. There was a significant amount of variation in height, volume, leaf area, and growth efficiency between the families of both provenances. Both the vertical distribution and quantity of foliage in

the ACP families may explain some of the variation in volume growth and growth efficiency, though neither show enough of a direct correlation to explain all of it. The crown characteristics studied seem to indicate that distribution of foliage itself is more important in explaining differences among the LPT families.

**Effects of Nutrient Amendments and Genotype on Stand
Productivity and Crown Characteristics in Loblolly Pine
(*Pinus taeda* L.)**

by

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BIOGRAPHY

Joshua Adam Handest was born September 28, 1974, in the city of Warren, Pennsylvania. After graduating high school he moved to Raleigh, North Carolina to pursue a Bachelor of Science degree in Natural Resources and Ecosystem Assessment under the guidance of the Forestry faculty of North Carolina State University. During the summer of 1996 he assisted in a forest inventory of Atlantic white cedar in Dare county, North Carolina. Upon completion of his undergraduate program he was awarded an industry sponsored assistantship to continue his studies at North Carolina State University under H. Lee Allen of the Forest Nutrition Co-op, and Steve McKeand of the Tree Improvement Co-op.

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CHAPTER ONE

Effect of Nutrient Amendments and Genotype on Stand Productivity in Loblolly Pine

(*Pinus taeda* L.)

Introduction

Interest in intensive plantation forestry has grown considerably within the Southern United States in recent years (Allen et al. 1998). This comes as no surprise considering the South's strong agricultural history, and like agriculture, forestry is shifting toward more intensive manipulation of genetic and site resources. Large gains in productivity have already been made in loblolly pine (*Pinus taeda* L.) with up to 35% improvement in volume production possible with second-generation improved stock (Li et al. 1999). The increasing demand for wood products and a shrinking forest land base due to population increases is creating a shift toward more active management of timberland (Allen et al. 1998). Even with limited knowledge of nutrient and water limitations, tremendous gains can be made in productivity once the knowledge is applied (Allen et al. 1990). Agricultural crops are handled in this way; forest crops could be as well.

Leaf area production is one of the more important stand characteristics associated with biomass productivity (Wang and Jarvis 1990). Vose and Allen (1988) and Albaugh et al. (1998) found that silvicultural treatments that accelerate canopy development can have a major impact on stand productivity in loblolly and slash pine (*Pinus elliottii* Engelm, var. *elliottii*) stands. Genetics may also play a significant role in leaf area production since strong family differences have been found in LAI for loblolly pine (Althoff 1994; McCrady and Jokela 1996; Svensson 1996; McCrady and Jokela 1998). McCrady and Jokela (1998) concluded that LAI is important for identifying differences in family performance.

Both stand volume and LAI are strongly affected by genetics and resource availability, however there is a lack of information on genotype by environment (GxE) interactions in these traits. It is important to study potential GxE interactions in LAI in order to better understand the reasons for growth differences in a particular stand (Dalla-Tea and Jokela 1991). Although significant changes in family ranking are rarely found in loblolly pine growth characteristics, certain families have been shown to be more genetically unstable across various site conditions than other families (McKeand et al. 1997). This can be very important in operational deployment, since greater gains will be realized if the more responsive families are allocated to the best sites with the more intensive silvicultural treatments.

In our study, the objectives were to better understand how nutrient additions, genetic (provenance and family) differences, and nutrient x genetic interactions may affect:

- Individual height and volume of loblolly pine.
- Stand level volume.
- Stand level leaf area and its relationship to volume production.

Methods

Site

The study site is located in Scotland County, North Carolina adjacent to the U.S. Forest Service / N.C. State University SETRES (Southeastern Tree Research and Education Site) study and is referred to as SETRES2. The soil is a Wakulla series – (sandy, siliceous, thermic Psammentic Hapludult) very infertile, somewhat excessively drained with a total water holding capacity of 12-14 cm in a 2 m profile. The site receives an average annual rainfall of 1200 mm. Temperatures average 17 °C annually, 26 °C summer, and 9 °C winter.

Study Design

Prior to the establishment of this study the existing 10-year-old loblolly pine stand was carefully removed and the site was disced twice to reduce hardwood sprouting and to prepare the site for planting. A split-split-plot design was used with nutrient treatments as the main plots (fertilized-optimal nutrient additions; control-no nutrient additions), provenance as sub-plots (ACP; LPT), and families within provenance as sub-sub-plots (Figure 1). Open-pollinated families from the North Carolina and South Carolina Coastal Plain (ACP) and from the “Lost-Pines” area of Texas (LPT) were included in the study. Five families from each provenance were randomly selected. Seeds were sown in containers (160cc RL Super Cells) in the greenhouse in June 1993, and seedlings were field-planted in November 1993. Each measured sub-sub-plot consisted of 100 trees planted at 1.5 m by 2 m spacing. Bare-root trees were planted in a 12 m buffer around the main plots. The treatment design was replicated in 10 blocks for a total of 20,000 study trees planted.

The goal of the optimum nutrient treatment was to maintain a sufficient and balanced supply of all nutrients. Foliar nutrient samples were taken in order to determine how much fertilizer was needed each year. Nutrients were applied twice during the first growing season (June and August) and once a year in late March or early April during subsequent years (Table 1). On all plots, vegetation control was conducted with Oust and Roundup applications followed by spot spraying with 2,4-D and Roundup. Further non-crop suppression was conducted mechanically by mowing between 2 m spaced rows annually. Tipmoths (*Rhyacionia sp.*) were controlled in the first two growing seasons with periodic insecticide sprays.

All trees were measured annually for height (h) and starting in year 3 for diameter at breast height (dbh). Dead trees were considered as missing in the analysis.

Individual tree stem wood volume was calculated as:

$$V = 0.00748 + (0.0000353 \times \text{dbh}^2 \times h)$$

where V was total outside bark volume in cubic meters (Shelton et al. 1984). Tree volumes were summed on a plot basis to calculate per hectare volume. Annual volume increment for the fifth growing season was estimated by subtracting the year-4 volume from year-5 volume.

Canopy leaf area index (LAI) was estimated using the LICOR 2000 Plant Canopy Analyzer. All sensor rings were used and a 90° lens mask was used in order to sample only within each plot and to keep the operator out of the measurements. The measurements were taken in January and March of 1999 in order to sample only the foliage produced during the 1998 growing season. Eight sample points were taken in each family plot. These eight samples were averaged to give a LAI estimate. For analysis the average of the January and March data was used. Growth efficiency (GE) was calculated on a plot basis as the ratio of stand volume production (year 4-5 volume increment) per unit of leaf area (LAI from LICOR).

Statistical Analysis

Analyses of variance on plot means were conducted for average 5-year height, average 5-year individual tree volume, 5th year stand volume increment, LAI, and GE to determine the significance of nutrient additions, genetic effects and interactions using the following model:

$$Y_{ijkl} = \mu + \beta_i + \tau_j + \beta\tau_{ij} + \delta_k + \beta\delta_{ik} + \tau\delta_{jk} + \beta\tau\delta_{ijk} + \psi_{l(k)} + \beta\psi_{il(k)} + \tau\psi_{jl(k)} + \epsilon_{ijkl}$$

β_i : block df = 9

τ_j : treatment df = 1

$\beta\tau_{ij}$: block x treatment df = 9

δ_k : provenance df = 1

$\beta\delta_{ik}$: block x provenance df = 9

$\tau\delta_{jk}$: treatment x provenance df = 1

$\beta\tau\delta_{ijk}$: block x treatment x provenance df = 9

$\psi_{l(k)}$: family(provenance) df = 4

$\beta\psi_{il(k)}$: block x family(provenance) df = 36

$\tau\psi_{jl(k)}$: treatment x family(provenance) df = 4

ϵ_{ijkl} : error (block x treatment x provenance x family(provenance)) df = 36

Block effects and family within provenance effects were treated as random effects while nutrient treatment and provenance were considered fixed. Plot mean analysis of variance were done using the PROC GLM procedure and estimates of variance components using PROC MIXED and the restricted maximum likelihood method of the statistical software package from SAS[®] Institute Inc., Cary, NC (SAS 1988, 1996). Waller-Duncan's k-ratio test was used to determine significant differences and ranking at the family level. F-tests for all analyses were considered significant at the $P < 0.10$ level.

Results

Fertilizer Response

Nutrient additions had a strong positive effect on growth. Cumulative height has increasingly diverged (Type A response) due to fertilization with 21%, 46%, 43%, 43%, and 50% more growth in fertilized plots for years one, two, three, four, and five respectively (313 cm average height in control, 468 cm in fertilized at year five)(Figure 2). At age 5 mean stem volume was 167 % greater in the fertilized plots as compared with the controls (47.1 vs. 28.2 m³ha⁻¹) and fifth year volume increment was 393 % greater (16.9 vs. 4.3 m³ha⁻¹yr⁻¹). There was a 282% (0.67 to 1.89) increase in mean stand leaf area due to fertilization, and volume production was strongly

correlated with LAI ($R^2 = 0.9$)(Figure 3). Growth Efficiency (GE) was significantly increased by 38% with nutrient amendments (6.5 m^3 per unit of LAI for control, 9.0 for fertilized). Survival was very good at 93% after the first five growing seasons with no treatment or genetic effects.

Amelioration of nutrient deficiency has also increased stand uniformity. The within-plot coefficients of variation for fifth-year height averaged 20.1% for the control plots and 10.2% for the fertilized plots. The standard deviations for height were also greater (73.3 cm for the control plots as compared to 50.7 cm for the taller fertilized plots).

Provenance and Family Variation

The ACP provenance showed superior height growth and leaf area production over LPT across both treatments (Table 2a and 2b). There were significant differences in plot volume but not in volume increment or GE (Table 3). No significant provenance by treatment interactions were detected for height, volume, volume increment, or GE (Table 3).

Families within provenance showed significant differences in height, volume, volume increment, LAI, and GE (Table 3) in both ACP and LPT provenances (Waller-Duncan's k-ratio tests). The range of mean volume increments for the ACP families was 3.7 to $5.5 \text{ m}^3\text{ha}^{-1}\text{yr}^{-1}$ in the control plots and 14.7 to $19.2 \text{ m}^3\text{ha}^{-1}\text{yr}^{-1}$ in the fertilized plots. The LPT families significantly differed only in the fertilized (15.0 to $17.5 \text{ m}^3\text{ha}^{-1}\text{yr}^{-1}$) plots. The only detectable GxE found at the family level was for volume, and this was predominately within the ACP families. There was no significant rank change but some families grew better in response to nutrient additions for volume production within the ACP provenance.

The LPT family means differed significantly for LAI in both the control (from 0.53 to 0.66) and fertilized (from 1.70 to 1.99). The ACP families only differed in the fertilized treatments (from

1.74 to 2.06) with no significant family difference detected in the control plots. It should be noted that the variation among families for the ACP provenance for LAI is due to one family, the poorest performer, 9-1046.

GE differed significant by family in all of the treatment/provenance combinations. A 20% difference in GE was found between the lowest and highest LPT families (6.9 to 8.3) and a 29% difference in ACP (6.9 to 8.9). No significant rank changes were found in either provenance.

There does not appear to be any correlation between volume increment and LAI at the family level. When looking at all families, the ones with higher levels of LAI also had greater volume production (Figure 4). However, the correlation between the ACP families seems to be driven only by one family (Figure 5). No correlation can be seen between the LPT families (Figure 6).

Discussion

The LPT provenance is considered resistant to drought stress (van Buijtenen 1978) and outperformed other Carolina provenances in survival and consequently stand volume on Sandhills sites (Jett 1992). Such observations have lead to wide scale planting of Texas provenances in the Sandhills. Because of the care taken in the study, seedling survival was not a problem and three of the five ACP families outperformed all of the LPT families.

Nutrient applications have resulted in marked growth increases. Starting fertilization at the time of planting resulted in a 393% increase in 5th year volume increment and a 282% increase in 5th year LAI. In the neighboring nutrition and irrigation study (SETRES) the primary limit to productivity on the sandy, well-drained site was found to be nutrition (Albaugh et al. 1998). After four years of nutrient amendments starting in an 8-yr-old stand, loblolly pine at SETRES showed a 152% increase in stem volume increment and a 101% increase in LAI in the fertilized stands

compared with the non-fertilized stands. When compared to the SETRES site, trees in this study have been able to take advantage of the additional resources during the relatively rapid juvenile growth period to produce greater gains. Since large differences in stand development are possible in young stands it is unlikely that the percentage differences will be maintained, however, these data would suggest that it is more beneficial to start fertilizer applications near stand establishment.

The 38% increase in stand growth efficiency due to fertilization was substantially higher than the 20% increase in GE reported by Albaugh et al. (1998) at SETRES 1. Some reasons for the increase in GE include greater photosynthetic efficiency associated with higher nutrients and greater allocation to above ground tissues. Murthy et al. (1996) found that fertilization can increase photosynthesis rates by 26% in a single cohort of foliage for loblolly pine. Retzlaff et al. (2001) examined possible differences in standing biomass allocation on the same site as this study and found no difference in percentage of standing biomass and carbon allocation treatments. The addition of nutrients has led to an early shift of foliage from the lower third into the middle third of the crown (Chapter 2). This redistribution of foliage could be affecting photosynthetic rates by altering light interception through the canopy.

Along similar lines, the differences in GE at the family level could be due to genetic differences in foliar photosynthetic rates or biomass allocation. No significant differences have yet been found between families in standing biomass and carbon allocation (Retzlaff et al. 2001). Again, foliage distribution could be a major factor in the family differences by affecting light interception. McCrady and Jokela (1996) found that a nonuniform vertical foliage distribution was present in the best performing families of loblolly. In Chapter 2 it was found that the families in both ACP and LPT provenances varied in their vertical distribution of foliage with the higher volume producing families tended to have more of their foliage in the mid or lower crown.

Regardless of the reasons, the largest volume growth will occur in those families with both high LAI and high GE. With differences in growth characteristics among families across the board and no interaction across the fertilization treatment for LAI and GE, deployment decisions can be easily made.

Although the ACP families as a whole out performed the LPT families, there is one exception that is worth noting. ACP family 9-1046 performed consistently worse than the other ACP families across all growth traits, often performing near the average values of the LPT families (Table 2a and 2b). These families are considered a random variable for analysis and were selected as such, though no particular family was chosen from the poorest performing families within either provenance. These results show that a large variation can still be found within a small sample of the population of families.

Even with the tremendous differences in productivity between the fertilized and control plots there were no rank changes at the provenance or family level in any trait. Given the extreme in nutrient treatments and provenance, the lack of provenance x treatment interaction indicates the high stability of open-pollinated loblolly pine families across a range of nutrient conditions and reinforces the practice of planting the best genetic stock on the best sites. This stability may not be observed with additional resource limitations. It should be noted that there was a narrower range of provenance differences in the fifth year volume increment and LAI in the fertilized stands. The ACP provenance was 23% and 18% greater than the LPT provenance in volume increment and LAI respectively for the control plots, but only 10% and 7% greater in the fertilized plots.

This study is still young and has only recently reached an age where results may reflect those found in a mature stand. Productivity measurements will continue to be taken to see if the trends

that were reported here will continue beyond the juvenile period of growth. Specifically it will be interesting to see how within stand competition will affect the performance of the two provenances. As these stands develop competition for limited soil resources in the non-fertilized plots and light resources in the fertilized stands will become stronger.

Conclusions

- No survival differences have yet developed between provenances.
- Nutrient additions starting at stand establishment resulted in large gains in juvenile development in all growth traits including growth efficiency.
- The Atlantic Coastal Plain provenance consistently outperformed the Lost Pine Texas provenance.
- Families varied significantly in height, volume, leaf area index, and growth efficiency.
- Little GxE with no rank change makes deployment selection simple.

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Figure 1: Experimental layout of Block 1.

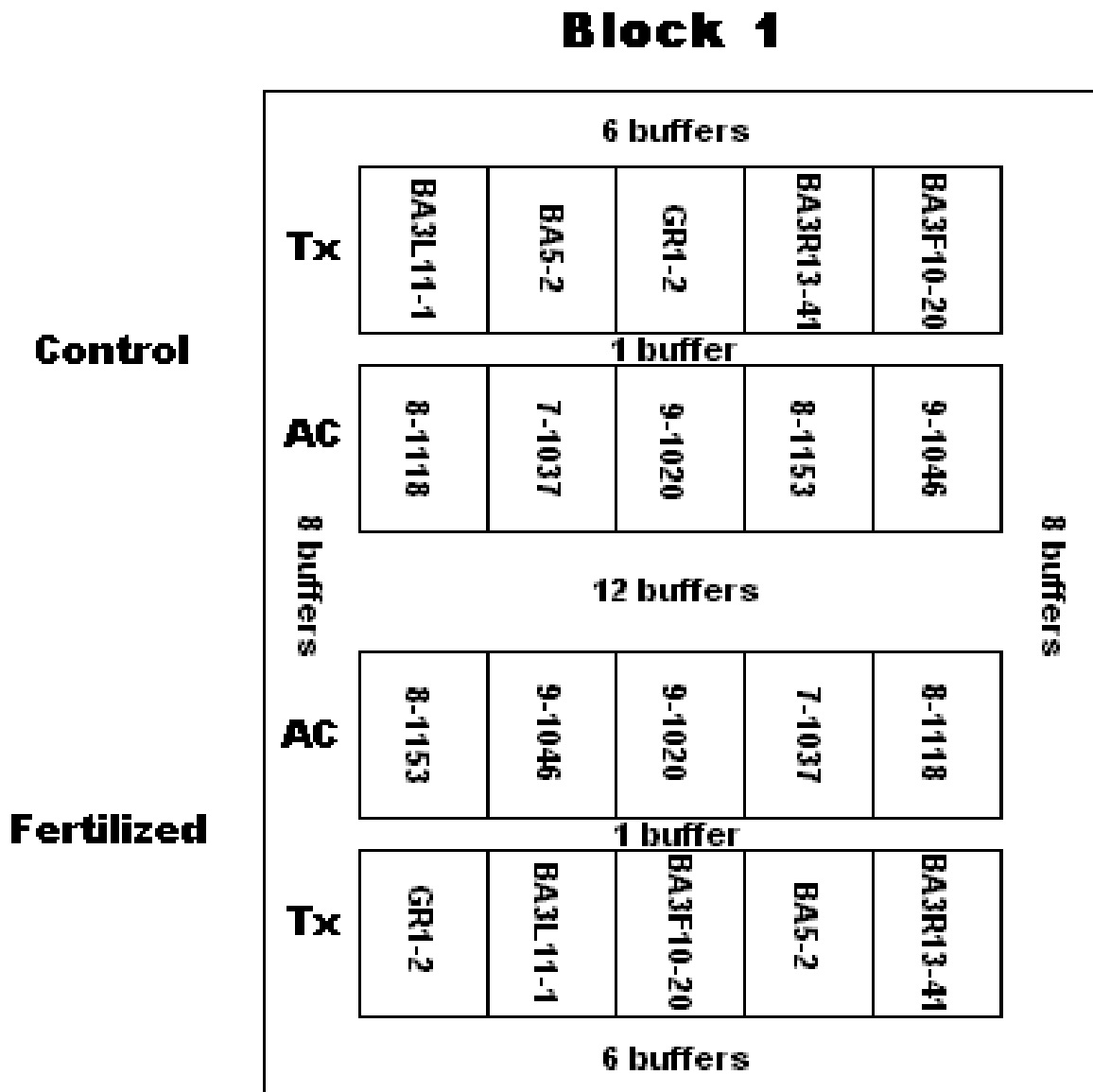


Figure 2: Treatment and provenance cumulative height means years 0-5.

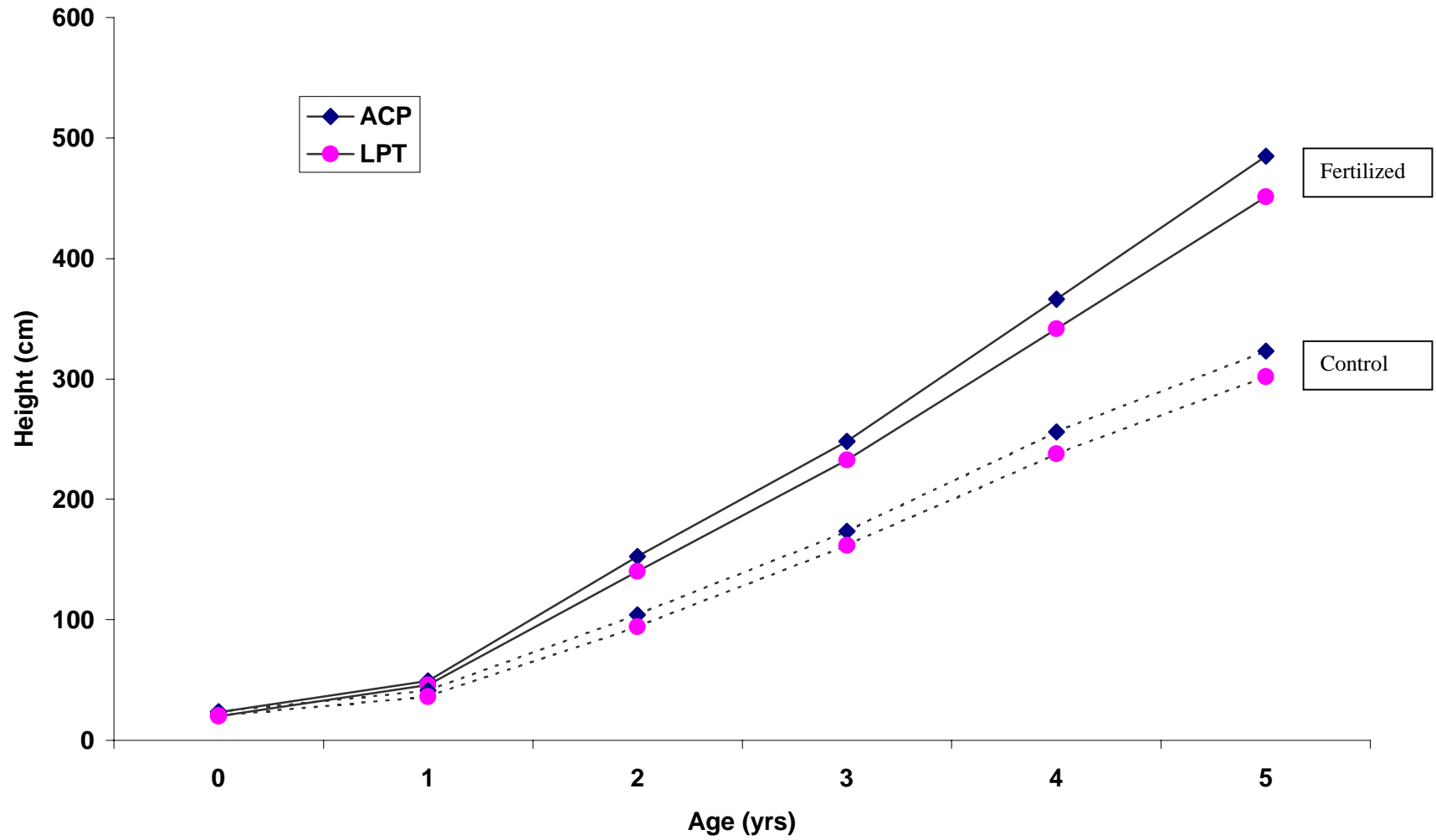


Figure 3: 1998-99 volume increment vs 1998 cohort LAI by treatment. (Data point = plot mean)

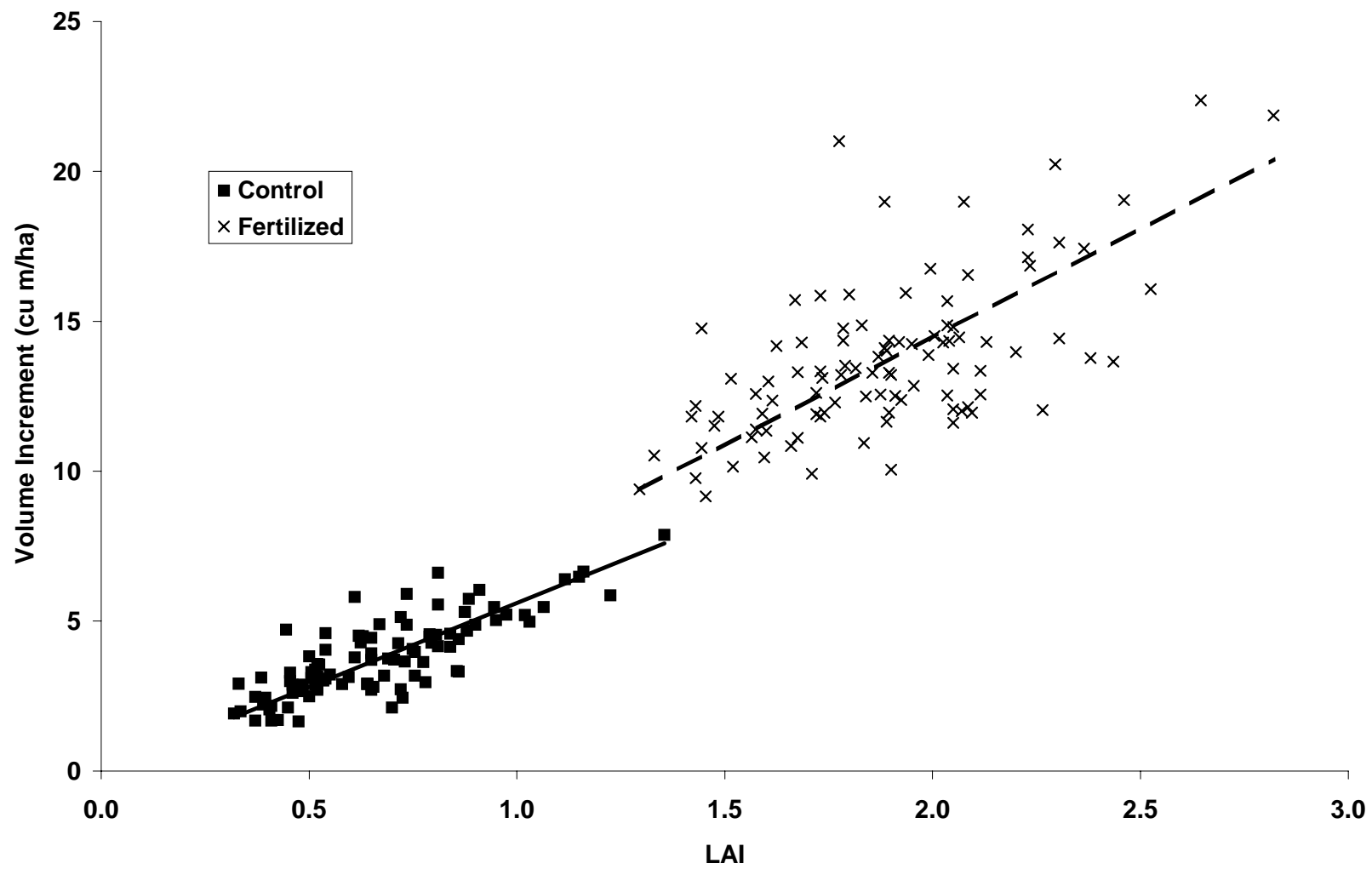


Figure 4: 1998-99 volume increment vs 1998 cohort LAI by provenance. (Data point = family mean)

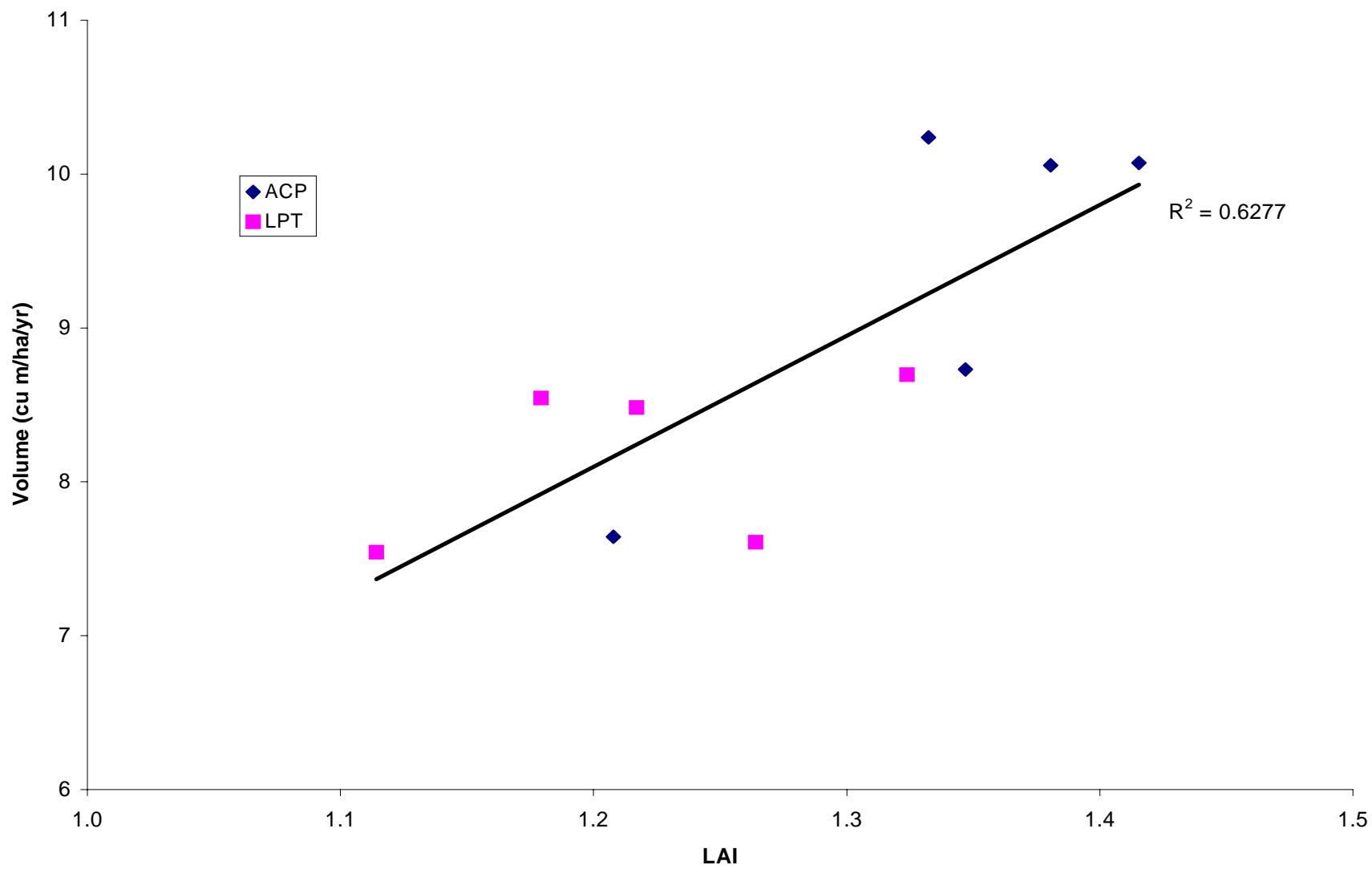


Figure 5: 1998-99 volume increment vs 1998 cohort LAI by family (ACP). (Data point = family mean)

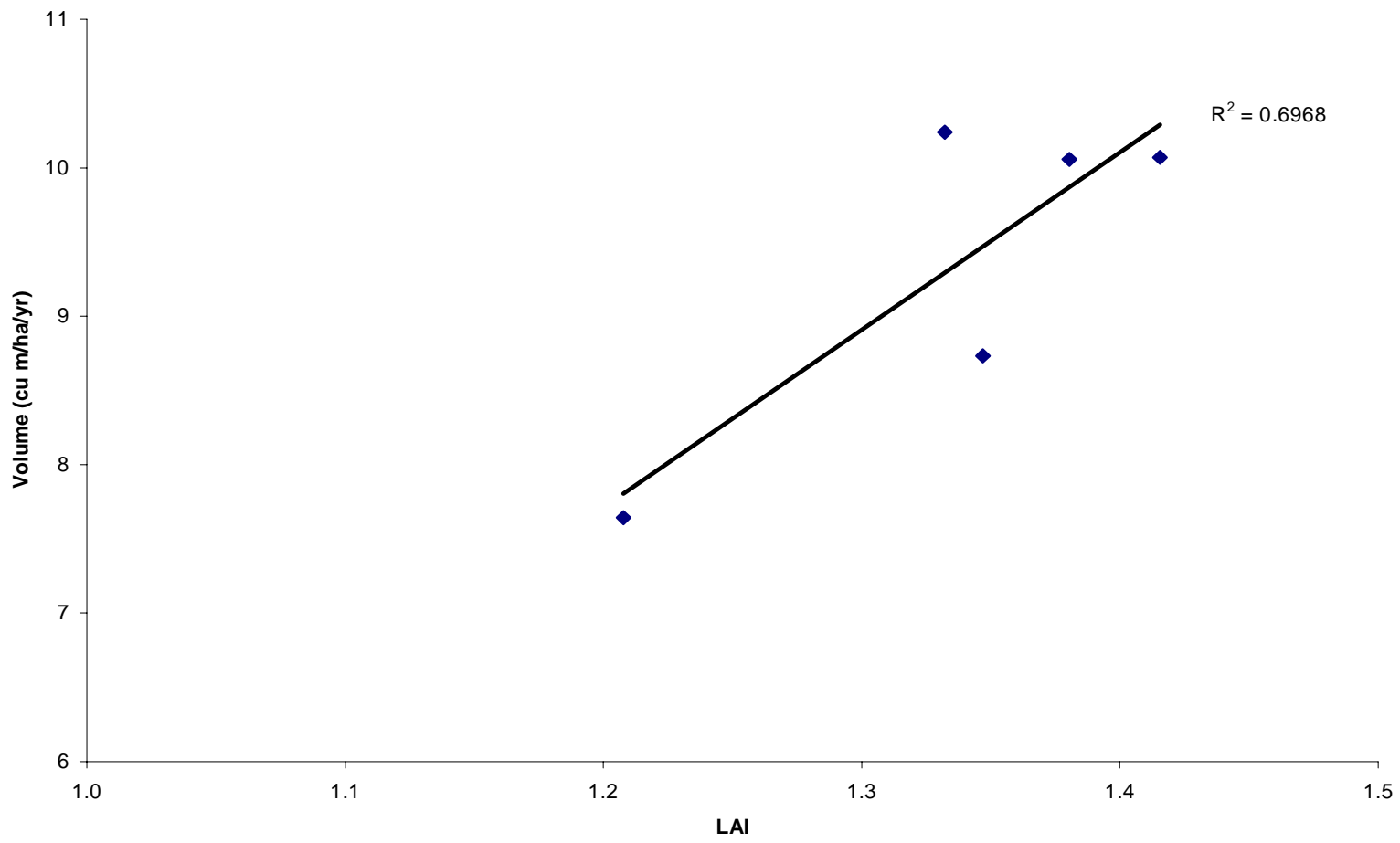


Figure 6: 1998-99 volume increment vs 1998 cohort LAI by family (LPT). (Data point = family mean)

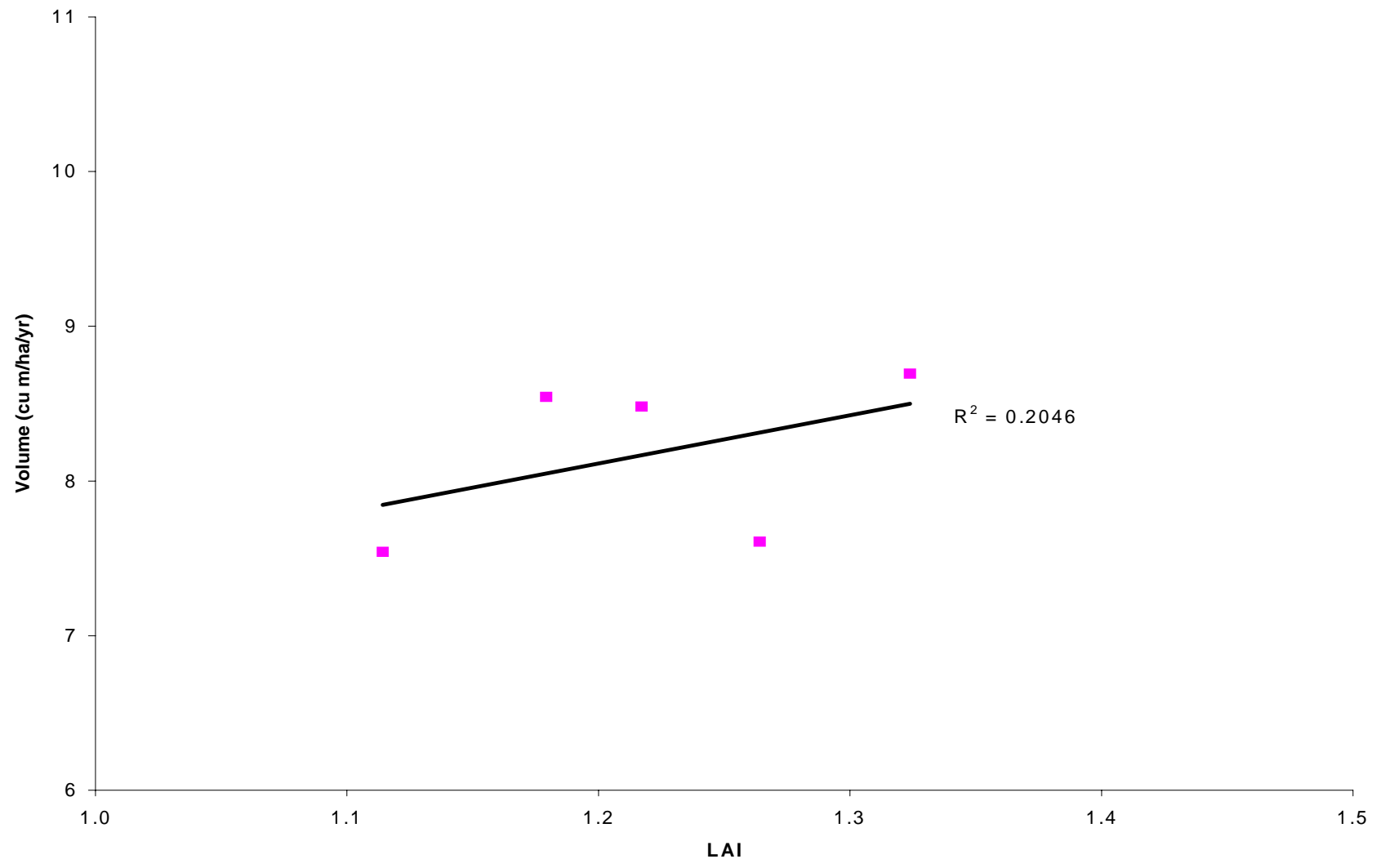


Table 1: Annual nutrient applications on fertilized plots through March 1999.

Fertilizer Applications (pounds/acre)							
Date	Fertilizer	N	P	K	Ca	Mg	S
Jun-94	10-10-10	23	10	19	0	0	< .4
Aug-94	10-10-10	23	10	19	0	0	< .4
Mar-95	12-6-6 + Micros*	37	8	15	0	0	0
Apr-96	Urea + TSP + KMagS	50	5	25	2.5	15	36
Apr-97	Urea + TSP + Mg	80	8	0	0	16	10
Apr-98	Urea + Mg	80	0	0	0	15	10
Mar-99	Urea + DAP + Boron**	85	8.4	0	0	0	11
Total through 1999		378	49.4	78	0.5	46	67

* Micronutrients: 0.5 B, 2.0 Cu, 5.0 Fe, 5.0 Mn, 2.0 Zn

** Micronutrients: 1.2 B

Table 2a: Least square means and standard errors for height, volume, and annual volume increment.

		Ht.(cm)			Vol.(cu m/ha)			5th year Vol. Increment (cu m/ha/yr)		
		Control	Fertilized	Std error	Control	Fertilized	Std error	Control	Fertilized	Std error
<u>Provenance:</u>	ACP	324	486	0.087	28.9	48.7	0.958	4.8	17.8	0.719
	LPT	302	450	0.087	27.5	45.5	0.959	3.9	16.1	0.720
<u>Family:</u>	7-1037	337	504	0.081	29.2	49.9	1.076	5.3	19.2	0.678
	8-1118	325	488	"	29.9	52.4	"	5.0	19.2	"
	8-1153	335	507	"	29.7	51.5	"	5.5	19.2	"
	9-1020	317	474	"	27.8	46.6	"	4.3	16.7	"
	9-1046	305	458	"	27.6	43.3	"	3.7	14.7	"
	BA3F10-2	300	447	0.111	27.2	44.0	1.631	3.6	15.0	0.967
	BA3L11-1	313	450	"	28.0	47.1	"	4.1	16.7	"
	BA3R13-4	300	445	"	27.9	45.6	"	4.1	16.2	"
	BA5-2	307	468	"	27.9	47.5	"	3.9	17.5	"
	GR1-2	292	445	"	26.5	43.6	"	3.5	15.1	"
<u>Total Average:</u>		313	468	0.070	28.2	47.1	0.877	4.3	16.9	0.579

Table 2b: Least square means and standard errors for leaf area index and growth efficiency.

	LAI			GE*		
	Control	Fertilized	Std error	Control	Fertilized	Std error
Provenanc ACP	0.72	1.95	0.072	6.6	9.2	0.363
LPT	0.61	1.82	0.072	6.4	8.9	0.363
Family:						
7-1037	0.75	2.01	0.072	7.1	9.6	0.320
8-1118	0.78	2.06	"	6.4	9.4	"
8-1153	0.71	1.96	"	7.9	9.9	"
9-1020	0.72	1.98	"	6.1	8.5	"
9-1046	0.67	1.74	"	5.4	8.5	"
BA3F10-2	0.66	1.87	0.084	5.6	8.2	0.481
BA3L11-1	0.59	1.77	"	7.1	9.5	"
BA3R13-4	0.65	1.79	"	6.4	9.1	"
BA5-2	0.64	1.99	"	6.0	8.8	"
GR1-2	0.53	1.70	"	6.8	8.9	"
Total Average:	0.67	1.89	0.065	6.5	9.0	0.305

*GE is the year 5 volume increment per unit of LAI.

Table 3. Significance levels for main effects and interactions tested in the analysis of variance for fifth year height, volume, volume increment, leaf area index, and growth efficiency.

Source	Ht.	Vol.	Vol. Inc.	LAI	GE
Treatment	.0001	.0001	.0001	.0001	.0003
Provenance	.0098	.0994	.1088	.0396	.6344
Trt x Prov	.1604	.2663	.3647	.7162	.7993
Family (P)	.0021	.0602	.0388	.0674	.0006
Trt x Fam(P)	.7670	.0344	.0860	.3849	.5733

CHAPTER TWO

Effects of Nutrient Amendments and Genotype on Crown Characteristics of Loblolly Pine

(*Pinus taeda* L.)

Introduction

Intensive plantation forestry has grown considerably within the Southern United States in recent years (Allen et al. 1998). Large gains in productivity have already been made in loblolly pine (*Pinus taeda* L.) with up to 35% improvement in volume production possible with second-generation improved stock (Li et al. 1999). The increasing demand for wood products and a shrinking forest land base due to population increases is creating a shift toward more active management of timberland (Allen et al. 1998). Even with limited knowledge of nutrient and water limitations, tremendous gains can be made in productivity once the knowledge is applied (Allen et al. 1990). Agricultural crops are handled in this way; forest crops could be as well.

One of the concepts that foresters have taken from agriculture in the past 15 years is the idea of a “crop ideotype”. The definition of a plant ideotype given by Donald (1968) is a biological model that will produce a higher quality or quantity of product than normal cultivars or wild plants. Through manipulation of tree morphology and physiology, it should be possible to establish a tree ideotype that will successfully acquire and make the most efficient use of site resources (Dickmann 1985). Also, different ideotype models could be developed for various situations since forest stands grown for different purposes (e.g. pulp, sawtimber) may require different resources. By following several models (different plant ideotypes) based on data from *in situ* studies there would be enough genetic variation to provide further refinements toward several goals. In this way a particular ideotype may be paired with specific deployment options.

Some of the characteristics that have been suggested for a conifer ideotype tree are straight stems with little taper and thin bark, clear, sound wood with rapid height and diameter growth, slow growing branches that are smaller in length and diameter, large leaf area per unit of branchwood, and long narrow live crown (Karki and Tigerstedt 1985). Genetic control over biomass partitioning has been shown to exist in lodgepole pine (*Pinus contorta* ssp. *latifolia*) (Wu and Yeh 1997), slash pine (*Pinus elliottii* var. *elliottii*) (Van Buijtenen 1978), and loblolly pine (Svensson 1996). Choosing a genetic line based on a specific crop ideotype that matches desired product goals could lead to a refinement in the selection process, and could provide higher yield than simply picking the “biggest tree”. It is necessary to identify which characteristics are most valuable in distinguishing a highly desirable ideotype.

To facilitate this goal, our objectives were to better understand how nutrient additions, genetic (provenance and family) differences, and nutrient x genetic interactions may affect:

- Foliage and branch biomass.
- Vertical distribution of foliage within the crown.
- Density of foliage with the crown.

Methods

Site

The study site is located in Scotland County, North Carolina adjacent to the U.S. Forest Service / N.C. State University SETRES (Southeastern Tree Research and Education Site) study and is referred to as SETRES2. The soil is a Wakulla series – (sandy, siliceous, thermic Psammentic Hapludult) very infertile, somewhat excessively drained with a total water holding capacity of 12-14 cm in a 2 m profile. The site receives an average annual rainfall of 1200 mm. Temperatures average 17 °C annually, 26 °C summer, and 9 °C winter.

Study Design

Prior to the establishment of this study the existing 10-year-old loblolly pine stand was carefully removed and the site was disced twice to reduce hardwood sprouting and to prepare the site for planting. A split-split-plot design was used with nutrient treatments as the main plots (fertilized-optimal nutrient additions; control-no nutrient additions), provenance as sub-plots (ACP; LPT), and families within provenance as sub-sub-plots (Figure 1). Open-pollinated families from the North Carolina and South Carolina Coastal Plain (ACP) and from the “Lost-Pines” area of Texas (LPT) were included in the study. Five families from each provenance were used. Seeds were sown in containers (160cc RL Super Cells) in the greenhouse in June 1993, and seedlings were field-planted in November 1993. Each measured sub-sub-plot consisted of 100 trees planted at 1.5 m by 2 m spacing. Bare-root trees were planted in a 12 m buffer around the main plots. The treatment design was replicated in 10 blocks for a total of 20,000 study trees planted.

The goal of the optimum nutrient treatment was to maintain a sufficient and balanced supply of all nutrients. Nutrients were applied twice during the first growing season (June and August) and once a year in late March or early April during subsequent years (Table 1). On all plots, vegetation control was conducted with Oust and Roundup applications followed by spot spraying with 2,4-D and Roundup. Further non-crop suppression was conducted mechanically by mowing between 2 m spaced rows annually. Tipmoths (*Rhyacionia* sp.) were controlled in the first two growing seasons with periodic insecticide sprays.

Whole crown characteristics were estimated using a two step approach (Gillespie et al. 1994). First, equations for foliage and branch biomass of individual branches were developed using data from destructively harvested branches collected during January 1999. A total of 180 individual branches were collected; generally one branch from each plot in the study. To make the sampling

easier, the branches were removed from one of the two trees per plot whose branch diameters were measured as described below. Three branches were randomly selected from three crown positions (upper, middle, and lower) per family/treatment. Only one branch was removed from each selected tree to minimize any future effects on growth. The foliage was removed from each branch, oven dried, and weighed. A regression model was used to relate branch wood and foliar biomass to branch diameter and the distance from the top of the tree.

The branch diameter and distance from the top of the tree for every branch was measured on two average trees per plot for a total of 369 trees. The branch regressions were then applied to these data in order to get an estimate of whole tree foliage and branch wood biomass for each of the measured trees. Average trees had heights within 12cm of the plot mean and DBHs within 7mm of the plot mean. These deviation criteria were chosen because they were the smallest possible while still allowing for at least two trees to be represented in each plot.

The live crown length was considered to be the total distance from the lowest living branch to the top of the tree. The crown was divided into upper, middle, and lower crown by dividing the live crown length of each tree into three equal sections. The foliage of all the branches that lay within each section was summed up to get the foliage totals for each. Foliage density was calculated by dividing the foliar biomass by the live crown.

Since a larger tree tends to have a larger crown it was important to look at trees of comparable size in order to differentiate true differences in specific crown characteristics. To do this, total tree branch biomass, total tree foliage biomass, and live crown length were also analyzed as a ratio of tree height.

Statistical Analysis

The branch regression model was developed using a backward elimination stepwise regression method in the PROC GLM procedure of the statistical software package from SAS[®] Institute Inc., Cary, NC (SAS 1988, 1996). The final form of the regression was:

$$Y_i = \mu + X_i^2 + Z_i^2 + Z_i + X_i^2 Z_i + X_i^2 \tau_j + X_i \tau_j + X_i^2 \psi_{l(k)} + \epsilon_{ijl}$$

Y_i : estimated branch foliage biomass

X_i : branch diameter

Z_i : distance from the top of tree

τ_j : nutrient treatment

$\psi_{l(k)}$: family(provenance)

ϵ_{ijl} : error

This model was then used to estimate the biomass of each branch on two trees per plot as mentioned above. Analyses of variance were done with the same model that was used in the previous chapter (Chapter 1, *Statistical Analysis*) to determine the significance of nutrient additions, genetic effects and interactions on the crown characteristics on a plot mean basis. Block effects and family within provenance effects were treated as random effects while nutrient treatment and provenance were considered fixed. Plot mean analysis of variance were done using the PROC GLM procedure and estimates of variance components using PROC MIXED and the restricted maximum likelihood method. Waller-Duncan's k-ratio test was used to determine significant differences and ranking at the family level. F-tests for all analyses were considered significant at the $P < 0.10$ level.

Results

Fertilizer Response

Nutrient additions had a strong effect on most crown characteristics (Tables 2b-6b). Live crown length increased by 41% (282 to 397 cm) and foliar biomass increased by 141% (700 to 1688 g). There was an increase in branch biomass of 177% (638 to 1769g) and the total number of branches of 12% (33 to 37 per tree). There were significant treatment differences in the ratio of branch biomass and foliar biomass to height but there was no significant difference for live crown length ratio (Table 3a). Large increases in the amount of foliage were found in the upper, middle, and lower crown positions (Table 4a), however this extra biomass was not evenly distributed. The percentage of foliar biomass located within the upper third was not changed by fertilizer addition. However, the mid crown had a slight increase in foliage and the lower crown showed a significant decrease (Table 5a). Foliage density was also increased by 72% (2.5 to 4.3 g/cm) (Table 3) with a 91% (1.1 to 2.1 g/cm) increase in the upper, 86% (3.5 to 6.5 g/cm) in the middle, and 43% (3.0 to 4.3 g/cm) in the lower crown (Table 6a). Branch biomass increased by 140% (18.7 to 44.9 g)(Table 2a).

Provenance and Family Variation

Provenance and family effects on foliar biomass were much less pronounced than nutrient effects. The ACP provenance showed a slight increase in total foliar biomass due to an increase in the amount of foliage within the middle crown. Since no significant difference in live crown length was found, this increase in mid crown resulted in a greater foliage density in that crown level. No significant differences were detected between the LTP and ACP provenances for foliar biomass or density in the upper or lower crown. Vertical distribution did not differ by provenance. The ACP trees averaged two fewer branches per tree but averaged 12% more branch biomass. There

was a significant difference in the live crown length/height ratio though none was detected for branch biomass/height nor foliar biomass/height.

Some provenance by treatment interaction was detected in live crown length and mid crown foliage biomass. The live crown length for the ACP provenance increased by 45% (282cm to 408cm) due to fertilization compared with a 37% (282cm to 385cm) increase for the LPT provenance. For mid crown foliage biomass the LPT provenance increased by 169% (300g to 806g) due to fertilization while the ACP provenance increased by 164% (349g to 920g). There was no rank change for either trait.

Families within the provenances showed significant differences in many of the crown characteristics (Table 2b-6b). Live crown length, foliar biomass in mid and lower crown, percentage of foliage in the upper and lower crown, total foliage density, and density within the mid and lower crown all varied between families. There was a significant difference in the foliar biomass/height ratio. Differences were not detected for the branch biomass/height nor live crown length/height ratios. For the ACP provenance, if a family was ranked high in one crown trait it tended to rank similarly in the others. This was not the same in the LPT provenance. Family 8-1153 was consistently one of the highest producer of foliage in mid and lower crown with high foliage density. Conversely, family 9-1046 had the lowest numbers in the same. Family BA3L11-1 of the Lost Pines provenance was one of the higher foliage biomass producers in its mid and lower crown while BA3R13-4 was among the lowest ranked in both crown positions. Branch number and biomass was not significant at the family level.

Some significant family by treatment interaction was detected in total crown foliage biomass (Table 2b). The response in foliage biomass to nutrient amendments for ACP families ranged from and increase of 113% (family 8-1118; 741g to 1580g) to 160% (9-1049; 633g to 1645g).

There was an even greater range of responses among the LPT families which ranged from increases of 98% (GR1-2; 741g to 1467g) to 224% (BA3R13-4; 451g to 1460g). The only significant rank change was among the LPT families and this was primarily due to family GR1-2.

Discussion

Nutrient amendments had strong positive effects on volume, leaf area, and growth efficiency (Table 7). It comes as no surprise that these same effects can be seen in individual crown characteristics. Clearly the increases in live crown length and foliage density allows for greater amounts of light to be intercepted resulting in greater volume production. The change in vertical distribution of foliage from the lower into the middle crown in fertilized plots may be due to a denser canopy and crown closure (Gillespie et al. 1994; Sampson and Allen 1998; Vose et al. 1994; Xu and Harrington 1998). Within the control plots the crowns were still quite sparse with canopy closure several years away. There was a greater increase in branch biomass than foliage biomass due to fertilization, which agrees with similar findings in Albaugh et al. (1998). This demonstrates the importance of a support structure to the increase in leaf area. The strong difference in the branch biomass/height and foliage biomass/height ratios show that the fertilized trees are able to support more leaves for trees of the same height, which allows for the dramatic differences in volume production.

The ACP provenance consistently outperformed the LPT provenance across both treatments in volume production (Table 7). The ACP provenance showed similar dominance in the crown characteristics with the strongest increase in amounts of foliage within the middle third of the crown. The two provenances had similar amounts of foliage and branch biomass for trees of the same height; though the LPT provenance spread it out over a slightly longer live crown. This would suggest that the differences in crown biomass at this level are due to the ACP provenance producing larger trees. The distribution and density of foliage in the mid crown may contribute to

the larger size of the ACP over LPT families. The additional foliage carried by the ACP provenance was supported by fewer, larger branches as compared with the LPT provenance. This could result in lumber with larger knots that may be less desirable. The presence of a small GxE at the provenance level suggests that the ACP provenance may utilize additional available resources to produce foliage within the mid-crown position. This GxE effect in the crown did not equate to a similar response in volume. No significant provenance by treatment interactions were detected in height, volume, or growth efficiency (Chapter 1).

It was previously shown that these families varied significantly in volume production and growth efficiency (Chapter 1). Significant differences were also found in many of the crown characteristics. Though the relatively small sample of families from each provenance does not allow for reliable heritability tests, they still give a good indication of some of the variability that can be found. The best and worst performing families in fifth year volume increment and growth efficiency were 8-1153 and 9-1046 respectively. Family 8-1153 had significantly higher absolute amounts of foliage biomass in the mid and lower crown (41% more than 9-1046 in lower 2/3). Also, family 8-1153 was able to support a greater amount of foliage than 9-1046 for trees of equal size. This can help explain the better volume performance but does not explain the differences in growth efficiency. Family 8-1153 did have a significantly different way of holding its foliage within the crown. Family 8-1153 had 39% of its total crown foliage located in the lower third of the crown (9-1046 had 33%), had the highest density of foliage within mid crown, and was one of the highest ranking families in crown length. Family 9-1046 on the other hand had 20% total foliage in the upper third (8-1153 had 12%), had the lowest mid crown foliage density, and the shortest live crown. McCrady and Jokela (1996) found that the best performing loblolly pine families had nonuniformly distributed foliage skewed toward the middle third of the crown. It is possible that at the family level, a stronger distribution of foliage into the middle and lower

canopy has allowed family 8-1153 to increase its light interception efficiency, thereby increasing the amount of volume it would be able to produce with the same amount of foliage.

The reasons for the differing performances of the Lost Pines families were not as clear but showed similar results. Family BA3L11-1 seemed to match the best ACP family in performance trends. It was one of the top ranked in volume and growth efficiency with most of its foliage in the middle to lower crown (16.5% up / 49% mid / 34.5% low), and had one of the highest foliage biomass/height ratio. The remaining families did not follow this same strategy however. Family BA3F10-2 (14% / 43% / 43%) was one of the poorest in volume production and growth efficiency. It also had very low foliage biomass and density within the middle crown but had the highest of the same in the lower crown and high foliage/height ratio. GR1-2 (17% / 51.5% / 31.5%), another poor performer in volume was ranked highly in middle crown characteristics but low in the lower ones. It could be concluded that in order to receive the apparent benefits of a fuller deep crown, it is necessary to have proper distribution within the lower two-thirds. The performance of family BA3R13-4 (13.5% / 51.5% / 35%) seems to reinforce that distribution may be more important than total biomass at the family level. Though it is ranked lowest in foliage biomass and density in the lower and middle crown positions, it is one of the top ranked volume producers. What foliage it does have is concentrated into its lower two thirds with most in the mid-crown.

Conclusions

- Annual fertilization from planting dramatically increases foliage and branch biomass at all crown levels. It also contributes to an early shift of foliage from the lower crown to the middle. This is most likely due to early canopy closure.

- The ACP provenance had more foliage, predominately in the middle crown than the LPT provenance. This may help to explain the superior volume production seen in previous findings.
- Both the vertical distribution and quantity of foliage in the ACP families may explain some of the variation in volume growth and growth efficiency, though neither show enough of a direct correlation to explain all of it. The crown characteristics studied seem to indicate that distribution of foliage itself is more important in explaining differences among the LPT families.

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Figure 1: Experimental layout of Block 1.

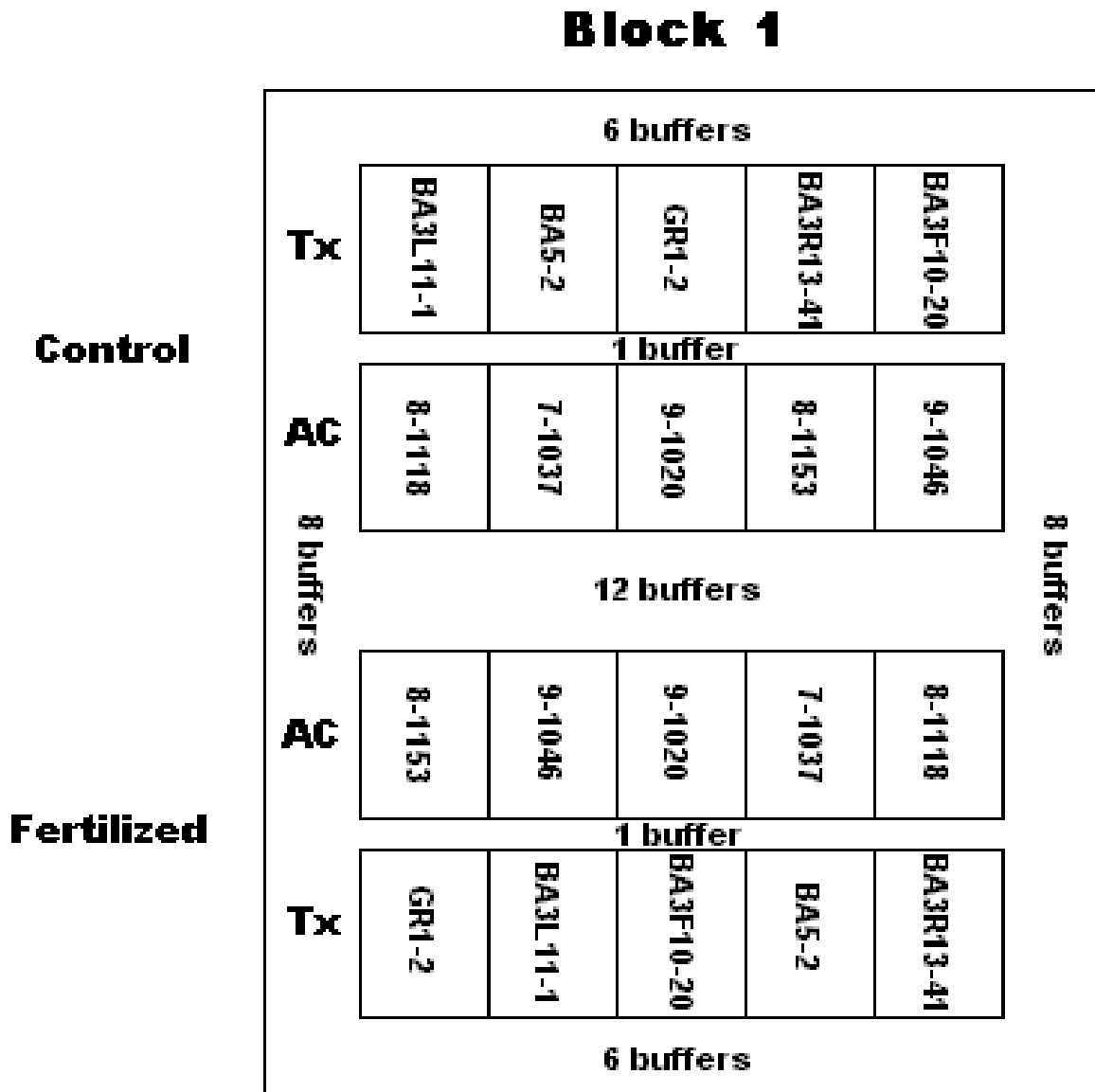


Table 1: Annual nutrient applications on fertilized plots through March 1999.

Fertilizer Applications (pounds/acre)							
Date	Fertilizer	N	P	K	Ca	Mg	S
Jun-94	10-10-10	23	10	19	0	0	< .4
Aug-94	10-10-10	23	10	19	0	0	< .4
Mar-95	12-6-6 + Micros*	37	8	15	0	0	0
Apr-96	Urea + TSP + KMagS	50	5	25	2.5	15	36
Apr-97	Urea + TSP + Mg	80	8	0	0	16	10
Apr-98	Urea + Mg	80	0	0	0	15	10
Mar-99	Urea + DAP + Boron**	85	8.4	0	0	0	11
Total through 1999		378	49.4	78	0.5	46	67

* Micronutrients: 0.5 B, 2.0 Cu, 5.0 Fe, 5.0 Mn, 2.0 Zn

** Micronutrients: 1.2 B

Table 2a: Least square means and standard errors for live crown length, number of branches, total branch biomass, and total foliage biomass.

	LCL			Total Branches			Branch biomass			Foliage biomass		
	Control	Fertilized	Std error	Control	Fertilized	Std error	Control	Fertilized	Std error	Control	Fertilized	Std error
Provenanc ACP	282	408	10.533	32.1	36.1	1.075	674	1911	5.023	750	1760	70.933
LPT	282	385	10.415	34.6	37.5	1.076	602	1622	5.112	649	1613	66.310
Family: 7-1037	298 a	430 a	11.231	33.6 a	38.2 a	1.157	645 a	2067 a	5.112	739 bc	1786 ab	73.044
8-1118	279 abc	395 bc	"	32.6 a	35.9 a	"	630 a	1609 a	"	741 bc	1580 b	"
8-1153	293 ab	427 ab	"	32.2 a	36.3 a	"	837 a	2367 a	"	862 a	2063 a	"
9-1020	272 bc	398 abc	"	29.5 a	35.5 a	"	711 a	1813 a	"	775 ab	1723 ab	"
9-1046	268 c	392 c	"	32.8 a	34.8 a	"	545 a	1699 a	"	633 c	1645 b	"
BA3F10-2	268 a	379 a	12.539	31.6 b	38.0 a	1.240	644 a	1666 a	5.057	670 ab	1738 ab	101.820
BA3L11-1	285 a	371 a	"	35.9 ab	38.6 a	"	605 a	1637 a	"	756 a	1755 a	"
BA3R13-4	270 a	394 a	"	35.2 ab	37.3 a	"	539 a	1789 a	"	451 c	1460 b	"
BA5-2	288 a	384 a	"	33.1 ab	35.8 a	"	622 a	1416 a	"	633 b	1658 ab	"
GR1-2	301 a	398 a	"	37.7 a	37.7 a	"	603a	1582 a	"	741 a	1467 ab	"
Total Average:	282	397	9.286	33.4	36.8	0.943	638	1769	3.625	700	1688	53.452

Note: Families with like notation (a,b,c) are not significantly different.

Table 2b: Statistical summary (probability > F) of significance test for Table 2a.

	LCL	Tot Br	Br Bio	Fol Bio
Trt	0.0001	0.0123	0.0001	0.0001
Prov	0.4187	0.0096	0.0878	0.0767
Fam(P)	0.0128	0.1451	0.1424	0.1048
TxP	0.0030	0.1926	0.1171	0.1621
TxF	0.8769	0.8175	0.3067	0.0655

Table 3a: Least square means and standard errors for ratio of live crown length, total branch biomass, and total foliage biomass to height.

	LCL / Ht			Branch biomass / Ht			Foliage biomass / Ht		
	Control	Fertilized	Std error	Control	Fertilized	Std error	Control	Fertilized	Std error
Provenance: ACP	0.840	0.829	0.018	2.00	3.85	0.204	2.25	3.58	0.149
LPT	0.891	0.847	0.018	1.89	3.55	0.203	2.05	3.55	0.148
Family: 7-1037	0.837 a	0.846 a	0.020	1.81 ab	4.05 a	0.225	2.09 b	3.53 a	0.150
8-1118	0.82 a	0.799 a	"	1.86 ab	3.24 a	"	2.2 ab	3.22 a	"
8-1153	0.843 a	0.822 a	"	2.42 a	4.51 a	"	2.51 a	3.97 a	"
9-1020	0.839 a	0.824 a	"	2.15 ab	3.74 a	"	2.5 ab	3.57 a	"
9-1046	0.859 a	0.853 a	"	1.76 b	3.69 a	"	2.04 b	3.59 a	"
BA3F10-2	0.879 a	0.855 a	0.022	2.08 a	3.74 a	0.261	2.20 ab	3.91 a	0.220
BA3L11-1	0.865 a	0.817 a	"	1.83 a	3.59 a	"	2.30 a	3.86 a	"
BA3R13-4	0.857 a	0.862 a	"	1.69 a	3.89 a	"	1.43 c	3.18 b	"
BA5-2	0.894 a	0.823 a	"	1.90 a	3.04 a	"	1.95 b	3.57 ab	"
GR1-2	0.97 a	0.877 a	"	1.94 a	3.46 a	"	2.41 a	3.23 b	"
Total Average:	0.865	0.838	0.015	1.95	3.70	0.174	2.15	3.56	0.112

Note: Families with like notation (a,b,c) are not significantly different.

Table 3b: Statistical summary (probability > F) of significance test for Table 3a.

	LCL / Ht	Br Bio / Ht	Fol Bio / Ht
Trt	0.1739	0.0001	0.0001
Prov	<u>0.0699</u>	0.2254	0.5070
Fam(P)	0.1912	0.2134	<u>0.0557</u>
TxP	0.2303	0.4169	0.3934
TxF	0.6128	0.2770	0.2201

Table 4a: Least square means and standard errors for foliage biomass within the upper, middle, and lower thirds of the crown.

	Upper 1/3 Foliage			Middle 1/3 Foliage			Lower 1/3 Foliage		
	Control	Fertilized	Std error	Control	Fertilized	Std error	Control	Fertilized	Std error
Provenance: ACP	108	295	25.495	349	920	34.474	293	544	41.327
LPT	93	267	25.398	300	806	34.011	256	540	38.006
Family:									
7-1037	73 c	302 a	28.227	352 ab	898 a	39.035	314 ab	586 ab	42.583
8-1118	150 a	255 a	"	338 ab	905 a	"	252 bc	420 b	"
8-1153	93 bc	284 a	"	403 a	1072 a	"	366 a	708 a	"
9-1020	109 b	274 a	"	362 a	921 a	"	304 abc	528 ab	"
9-1046	115 b	363 a	"	289 b	807 a	"	229 c	476 b	"
BA3F10-2	79 c	276 a	30.868	273 bc	755 a	45.838	318 a	706 a	61.779
BA3L11-1	115 ab	325 a	"	383 a	823 a	"	257 b	608 ab	"
BA3R13-4	58 c	200 a	"	219 c	800 a	"	174 c	460 bc	"
BA5-2	85 bc	289 a	"	295 b	806 a	"	253 b	563 abc	"
GR1-2	129 a	248 a	"	331 ab	844 a	"	280 ab	376 c	"
Total Average:	101	281	22.578	325	864	26.724	275	542	28.083

Note: Families with like notation (a,b,c) are not significantly different.

Table 4b: Statistical summary (probability > F) of significance test for Table 4a.

	Up Fol	Mid Fol	Low Fol
Trt	0.0001	0.0001	0.0001
Prov	0.4349	0.0258	0.5804
Fam(P)	0.2613	<u>0.0891</u>	<u>0.0630</u>
TxP	0.4060	0.0347	0.9018
TxF	0.5660	0.6377	0.1129

Table 5a: Least square means and standard errors for percentage of total tree foliage located within the upper, middle, and lower thirds of the crown.

	Upper 1/3 % of total			Middle 1/3 % of total			Lower 1/3 % of total		
	Control	Fertilized	Std error	Control	Fertilized	Std error	Control	Fertilized	Std error
Provenance: ACP	15	17	1.621	46	52	1.693	39	32	2.208
LPT	14	16	1.552	46	50	1.617	40	33	2.122
Family: 7-1037	10 c	17 a	1.773	47 a	50 a	2.040	43 a	34 a	2.362
8-1118	21 a	16 a	"	45 a	57 a	"	34 a	28 a	"
8-1153	11 bc	13 a	"	47 a	51 a	"	42 a	36 a	"
9-1020	14 b	16 a	"	47 a	53 a	"	39 a	31 a	"
9-1046	18 a	22 a	"	45 a	48 a	"	37 a	30 a	"
BA3F10-2	12 b	16 a	2.290	41 b	44 c	2.647	47 a	39 a	3.026
BA3L11-1	15 ab	18 a	"	51 a	46 c	"	34 b	36 ab	"
BA3R13-4	13 ab	14 a	"	49 a	54 ab	"	38 b	32 ab	"
BA5-2	12 b	18 a	"	47 ab	49 bc	"	41 ab	33 ab	"
GR1-2	18 a	16 a	"	45 ab	58 a	"	38 b	26 b	"
Total Average:	14	17	1.248	46	51	1.166	39	32	1.662

Note: Families with like notation (a,b,c) are not significantly different.

Table 5b: Statistical summary (probability > F) of significance test for Table 5a.

	Up %	Mid %	Low %
Trt	0.1503	<u>0.0960</u>	0.0051
Prov	0.8352	0.7007	0.8856
Fam(P)	<u>0.0888</u>	0.4383	0.0081
TxP	0.8726	0.4722	0.4898
TxF	0.3359	<u>0.0809</u>	0.8281

Table 6a: Least square means and standard errors for vertical foliage density within the upper, middle, and lower thirds of the crown.

	Upper 1/3 Fol Density			Middle 1/3 Fol Density			Lower 1/3 Fol Density		
	g/cm			g/cm			g/cm		
	Control	Fertilized	Std error	Control	Fertilized	Std error	Control	Fertilized	Std error
Provenance: ACP	1.17	2.08	0.186	3.71	6.72	0.234	3.19	4.13	0.341
LPT	0.96	2.03	0.179	3.19	6.24	0.226	2.80	4.38	0.322
Family: 7-1037	0.74 d	2.05 a	0.208	3.55 ab	6.20 a	0.261	3.20 a	4.26 a	0.367
8-1118	1.63 a	1.79 a	"	3.65 ab	6.95 a	"	2.88 a	3.44 a	"
8-1153	0.97 cd	1.86 a	"	4.18 a	7.40 a	"	3.79 a	5.12 a	"
9-1020	1.18 bc	1.99 a	"	4.01 a	6.96 a	"	3.41 a	4.08 a	"
9-1046	1.31 b	2.73 a	"	3.17 b	6.09 a	"	2.7 a	3.73 a	"
BA3F10-2	0.85 bc	2.16 ab	0.264	3.06 bc	5.98 a	0.335	3.59 a	5.68 a	0.492
BA3L11-1	1.18 ab	2.49 a	"	4.06 a	6.57 a	"	2.73 b	5.15 ab	"
BA3R13-4	0.62 c	1.46 b	"	2.40 c	5.98 a	"	2.01 c	3.69 bc	"
BA5-2	0.85 bc	2.23 ab	"	3.10 b	6.32 a	"	2.63 b	4.56 abc	"
GR1-2	1.34 a	1.82 ab	"	3.36 b	6.33 a	"	2.93 ab	2.92 c	"
Total Average:	1.07	2.06	0.146	3.46	6.48	0.162	3.00	4.25	0.252

Note: Families with like notation (a,b,c,d) are not significantly different.

Table 6b: Statistical summary (probability > F) of significance test for Table 6a.

	Up Den	Mid Den	Low Den
Trt	0.0001	0.0001	0.0001
Prov	0.6822	0.0465	0.7305
Fam(P)	0.2260	0.0450	0.0417
TxP	0.9097	0.2713	0.2457
TxF	0.1509	0.7116	0.3872

Table 7: Least square means for annual volume increment, leaf area index, and growth efficiency from Chapter 1.

		5th year Vol. Growth		LAI		GE*	
		m ³ /ha/yr					
		Control	Fertilized	Control	Fertilized	Control	Fertilized
Provenance	ACP	4.8	17.8	0.72	1.95	6.6	9.2
	LPT	3.9	16.1	0.61	1.82	6.4	8.9
Family:	7-1037	5.3	19.2	0.75	2.01	7.1	9.6
	8-1118	5.0	19.2	0.78	2.06	6.4	9.4
	8-1153	5.5	19.2	0.71	1.96	7.9	9.9
	9-1020	4.3	16.7	0.72	1.98	6.1	8.5
	9-1046	3.7	14.7	0.67	1.74	5.4	8.5
	BA3F10-2	3.6	15.0	0.66	1.87	5.6	8.2
	BA3L11-1	4.1	16.7	0.59	1.77	7.1	9.5
	BA3R13-1	4.1	16.2	0.65	1.79	6.4	9.1
	BA5-2	3.9	17.5	0.64	1.99	6.0	8.8
	GR1-2	3.5	15.1	0.53	1.70	6.8	8.9
Total Average:		4.3	16.9	0.67	1.89	6.5	9.0

*GE is the year 5 volume increment per unit of LAI.