SLASH PINE IMPROVED PLANTING STOCK-VEGETATION CONTROL STUDY: RESULTS THROUGH AGE 21

Plantation Management Research Cooperative

Warnell School of Forest Resources
University of Georgia
Athens, Georgia 30602

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By: Michael B. Kane, W. Michael Harrison and Dehai Zhao

EXECUTIVE SUMMARY

A designed experimental study using block plots was established in 1986 and 1987 at multiple locations in the Coastal Plain region of Georgia and northern Florida on cutover sites with the objective of evaluating the impacts of first generation genetic improvement, complete competition control, and the combination of genetic improvement and complete vegetation control on yields and quality of slash pine plantations. Genetic treatments were 1) unimproved stock, 2) first generation half-sib, improved stock planted in single family blocks, and 3) first generation half-sib, improved stock planted in mixtures of families. The two levels of competition control examined were either none other than that provided by the operational site preparation or complete and sustained control during the life of the study. Results through age 21 years for the 15 installations active throughout the entire assessment period are reported. All of these installations were located in the Lower Coastal Plain. Detailed results are presented for tree and stand attributes at age 21 as well as growth increment during the age 15 to 18-year and 18 to 21-year periods. These results were examined with those previously reported for younger age periods to evaluate treatment effects on temporal growth patterns.

A mixed model approach was used to analyze the age 21 measurements for this study and the 3-year periodic increment for the age 15 to 18 and 18 to 21 year periods. Installation and all installation related interactions were treated as random factors and competition control and genetics were treated as fixed factors. Treatment effects were considered statistically significant at alpha=0.05.

At age 21, both genetic improvement and competition control significantly increased slash pine plantation productivity. Although no significant genetic treatment by competition control treatment interaction was detected by the statistical analyses conducted for tree and stand attributes at age 21 years, there was a pronounced trend at later ages for stand basal area, volume, and weight to be markedly greater in stands with both genetically improved stock and complete competition control than that expected from the performance of genetically improved stands not receiving complete competition control and unimproved stands receiving complete competition control. This trend suggests that responses, especially at later ages, may be more than additive.

Deployment of improved, first generation stock in single family blocks or family mixtures yielded similar plantation performance.

At age 21, total o.b. green weight was 89, 96, 97, and 115 tons/acre for the genetically unimproved planting without complete competition control, the unimproved planting with complete competition control, the genetically improved planting without complete competition control, and the improved planting with complete competition control treatments, respectively. The response to improved genetic stock across competition control treatments averaged 12 tons per acre (13%). The response to complete competition control across genetic treatments was 16 tons per acre (17%). Genetically improved trees had significantly greater dominant height as compared with unimproved trees. Differences in mean dbh between unimproved and improved stock were not significant. Complete competition control significantly increased average dominant height and dbh. Range, skewness, and kurtosis of the dbh distribution were not significantly affected by treatment. Complete competition control accelerated stand development as indicated by significantly lower trees per acre (537 vs 579) and higher stand density index (288 vs 267) on complete competition control plots as compared with operational site preparation only plots. Similarly, the stand density index for genetically improved plantings (284) was significantly greater that that of unimproved plantings (266).

Treatments had different effects on tree health and quality. Genetic improvement significantly improved tree health. The incidence of trees with fusiform stem galls was lower for improved plantings (11%) than unimproved plantings (19%). Tree quality attributes (percentages of defect-free trees, forked trees, trees with crook or sweep) were similar for improved and unimproved

plantings. As compared with stands without complete competition control, stand receiving complete competition control had a greater percentage of trees with fusiform rust stem galls (17 vs 11%), forks (4 vs 2%), crook or sweep (70 vs 63%) and a lesser percentage of trees without defects (23 vs 32%). No significant interactions between genetic treatment and competition control treatment were observed for tree health and quality attributes.

Temporal patterns in response differed somewhat between genetic improvement alone, complete competition control alone, and the combination of genetic improvement and complete competition control. Responses to complete competition control alone reached a greater magnitude and tended to peak at earlier ages as compared to responses from genetic improvement alone. Absolute cumulative responses to genetically improved plantings in mean dominant height, basal area per acre and tons per acre reached a plateau by about ages 15 to 18. Absolute cumulative responses to competition control peaked at 6, 9, 9, and 15 years for mean dbh, mean dominant height, basal area per acre, and tons per acre, respectively. Responses after age 9 to the genetic improvement and complete competition control combination were of greater magnitude than that expected from the responses to the individual treatments. Response to the improved genetics-complete competition control combination for mean dbh, mean dominant height, basal area per acre, and tons per acre peaked at ages 6, 18, 12, and 18 years, respectively.

Periodic annual responses in mean dbh, mean dominant height and basal area per acre to the individual treatments and their combination peaked during the ages of 1 to 3 years, 4 to 6 years and 4 to 6 years, respectively. Periodic annual responses in tons per acre peaked during the ages 4 to 6 years with the exception that periodic response to genetically improved planting peaked during ages 16 to 18 years.

The response patterns observed in this study can inform development of models for predicting responses from genetic improvement and vegetation management. Dominant height gains from genetic improvement alone followed a Type B response pattern (maximum response reached and maintained); absolute gains in dominant height reached their maximum by about age 15 and were thereafter maintained. Responses to complete competition control alone followed a Type C response pattern (response declines after reaching maximum); absolute gains in dominant height reached their maximum by about age 9 and thereafter showed a slight decline. Basal area response patterns for the individual treatments are similar to those for dominant height. The improved genetic-complete competition control combination exhibited a Type B response for dominant height and Type C response for basal area through age 21.

The growth patterns reported are for nonthinned stands. By age 21, intra-specific competition was present and nutrient limitations were likely limiting stand productivity at most locations. At age 21, genetically improved plantings with complete competition control averaged 140 ft^2/acre of basal area, 298 stand density index (75% of maximum SDI), 17 feet average live crown length, and 0.29 live crown ratio.

These updated results confirm earlier findings that 1) gains from first generation, improved stock in block plots were within the range of gains estimated from progeny trial results; 2) single family and mixed block plots show similar productivity patterns suggesting flexibility in deployment strategies for this type of genetic stock; and 3) effective competition control provides consistent, substantial and persistent productivity gains. The latest results indicate that the response to the combination of genetically improved plantings and complete competition control at later ages tends to be more than that expected based on the individual responses from genetic improvement and complete competition control.

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1. INTRODUCTON

Numerous studies have shown that control of competing vegetation can significantly increase productivity of slash pine plantations in the Lower Coastal Plain of Florida and Georgia (Lauer and Glover, 1998; Oppenheimer et al., 1989; Yeiser and Ezell, 2004; Zhao et al., 2008, 2009;). This has led to implementation of vegetation management regimes in commercial slash pine plantations that include mechanical site preparation treatments and herbicide applications at different periods of the rotation (Fox et al., 2007; Shepard et al., 2004).

Another widely used regeneration practice is planting genetically-improved seedlings. From the mid-1970s to the mid-1990s, seed from first generation rogued slash pine seed orchards affiliated with the University of Florida's Cooperative Forest Genetics Research Program (CFGRP) was used to establish many commercial plantations (White and Byram, 2004). Estimates of genetic gains from this material were based largely on results from progeny tests and there was some uncertainty about how genetic gains from progeny trials would predict actual gains in commercial plantings. This concern resulted from the fact that progeny trials at the time were typically designed with single family row plots and were often managed with cultural treatments such as mowing and fertilization that may or may not be done in operational plantations. It was thought that the single family row test design and the specific cultural treatments used could lead to estimates of genetic gain that would not be achieved in block plot plantings of single families or mixtures of families grown under different site and cultural conditions. Additionally, block plot data is needed for developing growth and yield systems that provide breakdowns of stand structure (diameter and height distributions) in addition to total yield.

In response to the above uncertainties, the Plantation Management Research Cooperative (PMRC) designed and installed a regional field study in 1986-87 with the following objectives:

(1) Evaluate the impact of first generation genetic improvement on yields in block plot plantings,

(2) Determine the relative performance of improved single family plantings and improved mixed family plantings, and

(3) Assess the impact on yields and possible interactions of combining genetic improvement and complete and sustained vegetation control

Results through age 21 for 15 slash pine installations active throughout the study period and located in the Lower Coastal Plain of Florida and Georgia are presented in this report. This document complements an earlier PMRC report on the results of this study through age 15 (Logan and Shiver, 2003).

2. METHODS

A designed study examining impacts of slash pine genetic improvement, complete competition control and the combination of genetic improvement and complete competition control was established at 19 locations in the Coastal Plain (Lower Coastal Plain and Upper Coastal Plain) of Georgia and northern Florida. All installations were established on cut-over sites. Two locations were planted during the 1986 planting season and 17 locations were planted in 1987. By age 21, 15 installations were active and subject to measurement and analysis. Unless otherwise noted, results reported in this publication are based on data from the 15 installations active at age 21. All of the installations active at age 21 were located in the Lower Coastal Plain. CRIFF B, C, and D soils are found at six, one, and four installations, respectively. Soils information is not available on the remaining four installations. Note that CRIFF B, C, and D soils may be somewhat to very poorly drained. CRIFF B soils do not have a spodic horizon and the argillic horizon, if present, is at greater than 20 inch depth. CRIFF C and D soils have spodic horizons and are typically somewhat poorly to very poorly drained but may be moderately well drained. CRIFF C soils have an argillic horizon as well as a spodic horizon.

Genetically-improved families to examine were identified by polling the PMRC membership to determine the top ten families for each cooperator. The six top-ranked families were tentatively scheduled for inclusion in the study. The families were then checked by personnel of the University of Florida Cooperative Forest Genetics Research Program. They compared their family rankings with those provided by the PMRC cooperators and paid particular attention to disease resistance in recommending families. Once the families were approved, seeds were obtained from rogued, first generation, open-pollinated seed orchards owned by PMRC cooperators. Families chosen for the study are identified in Table 1.

Table 1. University of Florida Cooperative Forest Genetics Research Program identification for improved first generation families in the PMRC Slash Pine Improved Planting Stock-Vegetation Control Study.

Coastal Plain Slash Pine Families
106-56
6-56
35-60
56-56
261-56
187-57

Unimproved seed was obtained from International Forest Seed Company. This unimproved seed was obtained in the same region encompassed by the study from areas other than seed orchards or seed production areas. The unimproved seed lot was independent of any check lots used by tree improvement cooperatives.

Bulk lot improved stock was obtained by mixing equal amounts of seed from the six selected families. The seedlings were grown at the Union Camp Corporation nursery at Belleville, Ga. A portion of the seed from each family was kept separate and grown in separate nursery beds for the single family plantings.

Eight plots were included at each study installation:

(1) Unimproved stock, no vegetation control (UINC),
(2) Unimproved stock, complete vegetation control (UICC),
(3) Bulk lot improved stock, no vegetation control (BLNC),
(4) Bulk lot improved stock, complete vegetation control (BLCC),
(5) Replicate plot of one of the first four treatments,
(6) Single family improved stock, no vegetation control (SFNC),
(7) Single family improved stock, complete control (SFCC), and
(8) Replicate plot of one of the single family treatments.

Six of the eight plots per installation were randomly assigned to one of the six 2 x 3 factorial treatment combinations. Additionally, one of treatments 1-4(#5) and one of treatments 6-7(#8) were randomly assigned to the remaining two plots at each installation and served as replicate plots. Only one single family was assigned to an installation and the assignments were made at random. Therefore, each family was planted on two to three installations on average. Each treatment plot was 0.4 ac in size and contained a centrally located 0.2 ac measurement plot.

Most locations had some mechanical site preparation as the operational treatment that was applied to all plots. The operational site preparation treatment usually included bedding. The two levels of competition control were either none other than that provided by the operational site preparation treatment applied by the cooperator prior to planting, or complete and sustained control of all competing vegetation during the life of the study. No herbaceous weed control was applied on the no competition control plots. Complete control was achieved and maintained by killing woody vegetation prior to planting with prescribed herbicides, by spraying sulfometuron

methyl in early spring of each of the first three growing seasons, and by directed sprays of glyphosate as needed during the growing season throughout the study period.
Seedlings were hand-lifted and planted during the dormant season at a density of 700-750 trees per acre. Fertilization at a particular installation was at the discretion of the cooperator. If fertilized, all plots at an installation received the same treatment. No thinnings were performed.

At three years of age and at three year intervals thereafter, every third pine tree on the measurement plot was measured for total height (ft) to the nearest foot and every tree was measured for dbh to the nearest 0.1 inch and checked for stem cankers caused by fusiform rust (*Cronartium quercum* f. sp. *fusiforme*) . Beginning at age 15 years and at all subsequent evaluations, height-to-live-crown measurements were taken on height measurement trees and a quality code was assigned to all measurement trees. The quality codes were: defect- free (sawtimber potential), fork, crook or sweep, canker, or broken top.

The tree height data were used to develop height-diameter regression equations for each plot to estimate the heights of the unmeasured trees. The following height-diameter relationship was fit to each plot at each measurement age:

$$LH = b_0 + b_1 D^{-1}$$

where LH=natural log of height (ft), D=diameter (0.1 in.), and b_0 and b_1= parameter estimates from sample data.

Dbh range, skewness and kurtosis were calculated on each plot to evaluate how treatments affect the diameter distribution. Skewness is a measure of the asymmetry of the distribution. A normal distribution has a skewness value of zero. Negative skewness indicates a distribution with a longer left tail; positive skewness indicates a longer right tail. Kurtosis is a measure of peakedness of the distribution. A greater kurtosis value indicates a more peaked distribution.

Total (outside bark) and merchantable (4.5 inch minimum dbh and 3 inch top diameter ob) tree volumes and weights were estimated using total and merchantable volume and weight equations developed by Pienaar, *et al.* (1987). Chip-n-saw yields were calculated to a 6-inch top for defect-free trees having dbh greater or equal to 7.5 inches. Pulpwood yields were calculated for trees with dbh from 4.5 to 7.5 inches, merchantable portions of degraded trees, and tops of chip-n-saw trees.

Stand density index (SDI) and relative spacing (RS) were calculated for each plot to assess the impact of treatment on stand density. Stand density index (SDI) is defined as the relationship between the number of trees per acre and the average tree size. In fully-stocked, even-aged stands, the relationship between the number of trees per acre and the quadratic mean dbh (D_q) should appear linear in logarithmic coordinates. This implies a theoretical, limiting number of trees for a given D_q. Reineke (1933) observed this relationship for a variety of species and determined the slope of the limiting line was approximately -1.6. Therefore, SDI can be calculated as:

$$SDI = TPA\left(\frac{D_q}{10}\right)^{1.6}$$

Relative spacing (RS) is defined as the ratio between the average distance between trees and the average dominant height of a stand:

$$RS = \frac{\sqrt{43560 / TPA}}{HD}$$

For the statistical analyses to test for treatment effects, installations were treated as random factors of the experiment since region-wide recommendations were the objective of the study. The replication within an installation represented an attempt to quantify the within-location error. A mixed model approach was used for the analysis because it allows for the mixed effects and unbalanced nature of this design. Installation and all installation interactions were treated as random factors and genetic treatment and competition control treatment were treated as fixed factors. Genetic treatment was either unimproved, improved bulk lot (mixture of improved familes) or improved single family. The two levels of competition control were either none, other than that provided by the operational site preparation, or complete control. Main effects of genetic treatments were calculated by averaging across both vegetation control treatments and main vegetation control effects were determined by averaging across all genetics treatments. To obtain the correct degrees of freedom (df) for this analysis, the Satterthwaite option in SAS®'s PROC MIXED procedure was used. Unlike traditional analysis of variance, the degrees of freedom may not necessarily be an integer. Tukey's studentized range test was used to conduct pair-wise comparisons of least square means to detect differences between individual treatment level means. Least square means are the estimated marginal means over a balanced population, allowing for the unbalanced nature of the experiment. Unless otherwise indicated, the α=0.05 significance level was used for identifying statistically significant effects.

The age 21 statistical analyses were completed separately on the following dependent variables: average dbh, range in dbh, skewness and kurtosis statistics of the dbh distribution, average dominant height, basal area per acre, total and merchantable stem volume, total and merchantable stem green weight, pulpwood weight, chip-n-saw weight, surviving trees per acre, percent fusiform rust infection, percentage of defect-free trees, percentage of forked trees, percentage of trees with crook or sweep, stand density index, relative spacing, average live crown length and average live crown ratio. No transformations were done on percentage data. Least square mean values are reported in tables. Arithmetic means are presented in graphs.

Tree (mean dbh, dominant height) and stand (per acre basal are, total green weight, number of surviving trees, stand density index, and relative spacing) attributes were graphed over age to further evaluate temporal patterns of productivity and stand development for the genetic and competition control main effects and two contrasting combinations of genetic and competition control treatments, namely the unimproved genetics without complete competition control combination and the improved single family and complete competition control combination.

In an effort to identify statistically significant treatment effects on periodic growth, increments in mean dbh, mean dominant height, and per acre basal area and total and merchantable volume and weight for the periods from age 15 to 18 and from age 18 to 21 years were calculated and analyzed using the mixed model approach. The results from these analyses were combined with those reported by Logan and Shiver (2003) on treatment effects on growth increment during the periods from age 6 to 9, age 9 to 12, and age 12 to 15 years to understand temporal patterns of statistically significant treatment effects through age 21 years. Note that the results after age 15 contain only the 15 installations that were active through age 21 while the results prior to age 15 included measurements from all installations active at each measurement up to a total of 19 installations.

Mean cumulative and periodic annual dbh, dominant height, basal area per acre, and total green tons per acre increment responses to genetic improvement, complete vegetation control and their combination were calculated and described to isolate individual treatment and combined treatment effects throughout the 21-year assessment period. Given the lack of significant differences in tree and stand attributes observed between the improved single family and improved mixed family treatments, means of these treatments were averaged to represent the genetically improved plantings. Cumulative response to the genetically improved plantings, in the absence of complete competition control, was calculated by subtracting the mean for genetically improved plantings without complete competition control from the mean for the unimproved planting without complete competition control at each measurement age. Cumulative response to complete competition control, in the absence of genetic improvement, was calculated by subtracting the mean for unimproved plantings without complete competition control from the mean for unimproved plantings with complete competition control at each measurement age. Cumulative response to the treatment combination was calculated by subtracting the mean for the unimproved plantings without competition control from the mean for the improved plantings with complete competition control at each measurement age. Periodic annual responses were calculated by subtracting responses observed at the beginning of a three year measurement interval from responses at the end of the interval and dividing by three.

Observed cumulative patterns of dominant height and per acre basal area responses to genetic improvement alone, complete competition alone, and the genetic improvement – complete competition control combination were characterized using the following convention: Type A, response magnitude increases with age; Type B, response maximum is attained and maintained; Type C, response peaks and diminishes somewhat with time; Type D, response peaks and with time diminishes to zero or negative.

3. AGE 21 RESULTS

3.1 Average DBH

Competition control significantly increased average dbh an average of 0.67 inches across all levels of genetic stock (Table 2). There were no significant effects of genetic treatments or interactions between genetics and competition control on average dbh. Least square means of average dbh by treatment are presented in Table 3 and arithmetic means are presented in Figure 1.

Table 2. Test of fixed effects for average dbh (in.) of slash pine at age 21.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	26.9	0.33	0.7219
Competition Control	1	14.2	55.63	<0.0001
Genetics* Competition Control	2	67.0	0.02	0.9754

Table 3. Summary of least squares means for average dbh (in.) of slash pine at age 21.

	No Control	Complete Control	Average
Unimproved	5.97	6.66	6.31
Bulk Lot	5.97	6.64	6.31
Single Family	6.05	6.70	6.37
Average	6.00	6.67	6.33

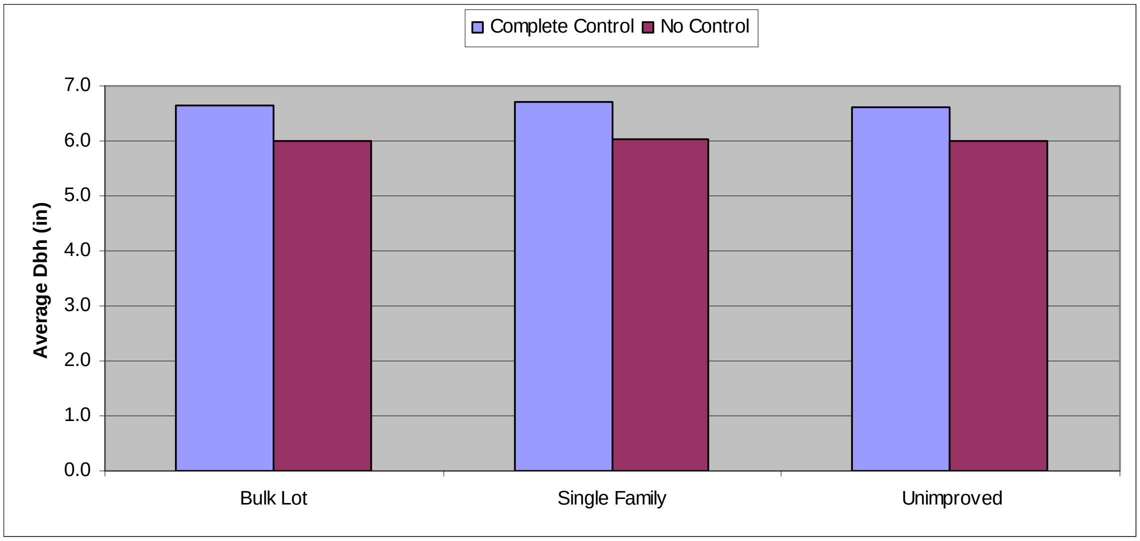

Figure 1. Mean dbh by treatment for 21-yr-old slash pine.

3.2 Range, Skewness, and Kurtosis of the DBH Distribution

Dbh range, skewness and kurtosis did not differ significantly by treatment. The strongest evidence (P=0.16) of any treatment effect was in kurtosis among genetic entries. Least squares mean kurtosis for unimproved plantings, improved bulk lot plantings, and improved family plantings were 0.02, -0.15, and 0.06, respectively.

3.3 Average Dominant Height

Both genetics and competition control main effects on average dominant height were significant and there was an absence of significant genetic x competition control interaction (Table 4). While there was no significant difference between single family and bulk lot plantings, these treatments increased dominant height by 2.9 ft and 2.8 ft over unimproved stock, respectively (Table 4 and Figure 2). Competition control increased average dominant height an average of 3.5 ft at age 21 across all genetic treatments.

Table 4. Test of fixed effects for average dominant height (ft) of slash pine at age 21.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	26.3	5.19	0.0126
Competition Control	1	14.2	21.75	0.0004
Genetics* Competition Control	2	65.6	0.05	0.9532

Table 5. Summary of least squares means for average dominant height (ft) of slash pine at age 21.

	No Control	Complete Control	Average
Unimproved	51.6	54.8	53.2
Bulk Lot	54.1	57.9	56.0
Single Family	54.3	58.0	56.1
Average	53.4	56.9	55.2

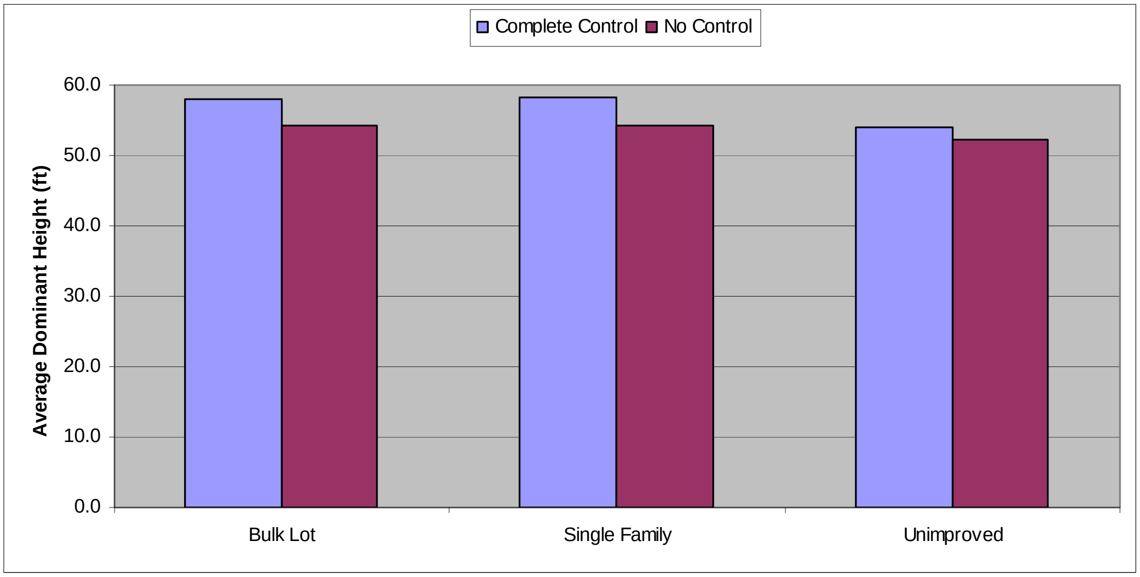

Figure 2. Mean dominant height by treatment for 21-yr-old slash pine.

3.4 Basal Area per Acre

Genetic and competition control treatments significantly affected basal area per acre (Table 6). The interaction between competition control and genetic stock was not significant. Competition control significantly increased basal area an average 14.3 ft^2/ac across all levels of genetic stock (Table 7) while basal area per acre increased from 122 ft^2/ac for unimproved plantings to about 130 ft^2/ac for improved plantings across competition control treatments. Single family and bulk lot plantings with improved stock had nearly identical basal areas per acre. Least square means of basal area per acre for the different treatment combinations are presented in Table 7 and arithmetic means are provided in Figure 3.

Although the genetic treatment by competition control treatment interaction was not statistically significant, the basal area per acre appeared greater for genetically improved plantings with complete vegetation control as compared to that expected from the performance of improved plantings without complete completion control and of unimproved plantings with complete competition control relative to that of unimproved plantings without complete competition control.

Table 6. Test of fixed effects for basal area (ft^2/ac) of slash pine at age 21.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	48.7	4.59	0.0149
Competition Control	1	14.0	12.22	0.0036
Genetics* Competition Control	2	49.5	1.33	0.2729

Table 7. Summary of least squares means for basal area (ft^2/ac) of slash pine at age 21.

	No Control	Complete Control	Average
Unimproved	118.2	126.2	122.2
Bulk Lot	122.6	140.4	131.5
Single Family	122.0	139.4	130.7
Average	121.0	135.3	128.2

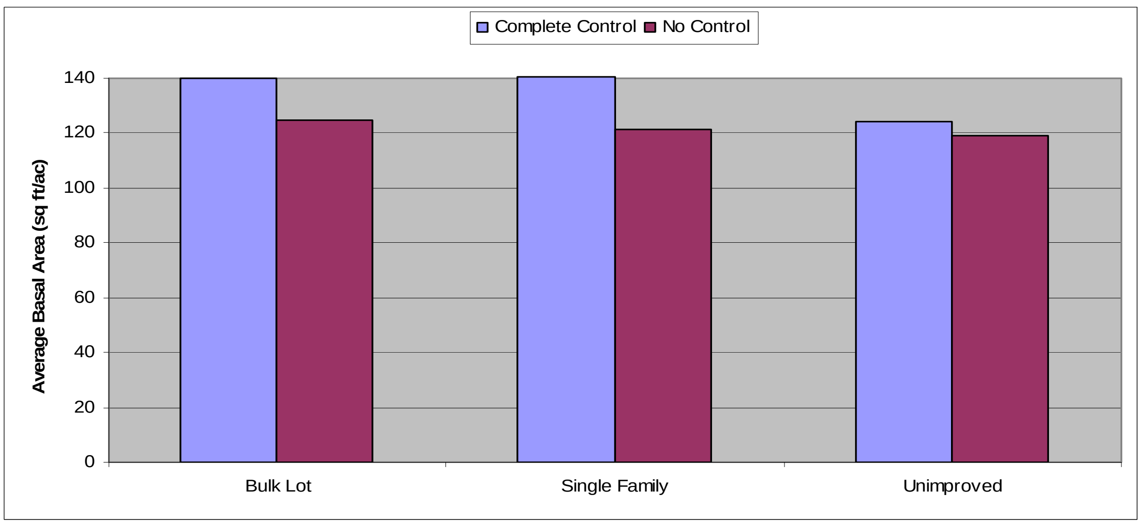

Figure 3. Basal area per acre by treatment for 21-yr-old slash pine.

3.5 Total Volume per Acre

Genetic and competition control treatments significantly affected total volume per acre (Table 8). There was no significant interaction between genetics and competition control. Total volume was greater with improved than unimproved stock (Table 9, Figure 4) and statistically similar for improved bulk lot and improved single family plantings. Across competition control levels, total volume was 3080 ft^3/ac for unimproved stock and averaged 3456 ft^3/ac for improved treatments, a gain of 376 ft^3/ac (12.2%) relative to unimproved stock. Complete competition control increased yield an average 519 ft^3/ac (16.9%) across all genetic treatments.

Although the genetic treatment by competition control treatment interaction was not statistically significant, the total volume per acre appeared greater for genetically improved plantings with complete vegetation control as compared to that expected from the performance of improved plantings without complete completion control and of unimproved plantings with complete competition control relative to that of unimproved plantings without complete competition control.

Table 8. Test of fixed effects for total volume (ft^3/ac) of slash pine at age 21.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	47.7	7.18	0.0019
Competition Control	1	14.2	21.26	0.0004
Genetics* Competition Control	2	49.4	1.37	0.2629

Table 9. Summary of least squares means for total volume (ft^3/ac) of slash pine at age 21.

	No Control	Complete Control	Average
Unimproved	2931	3229	3080
Bulk Lot	3146	3792	3469
Single Family	3137	3748	3442
Average	3071	3590	3331

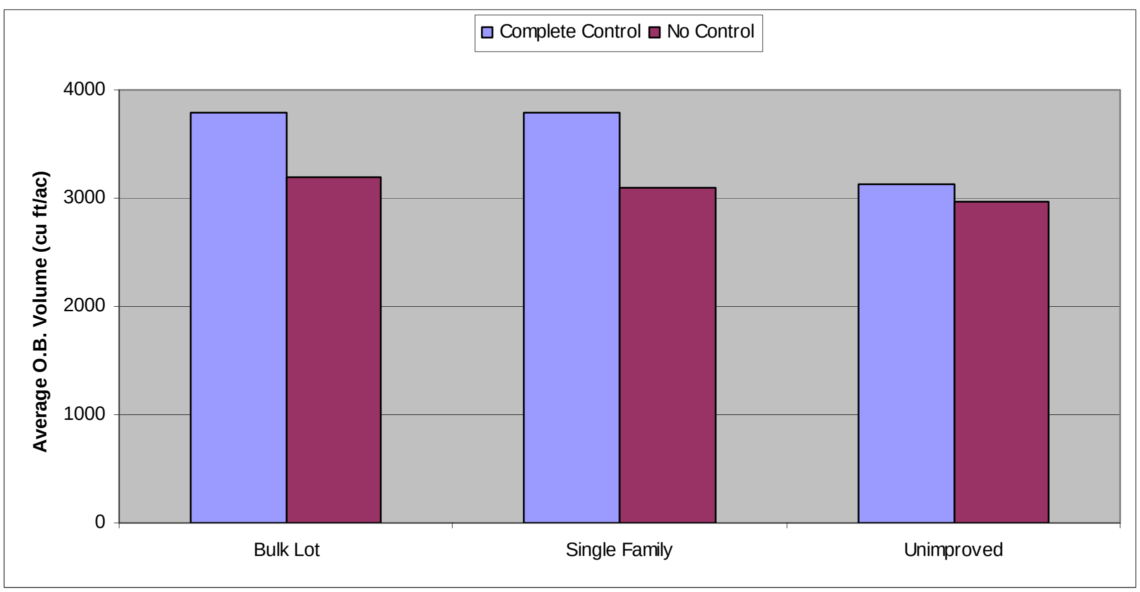

Figure 4. Total volume per acre by treatment for 21-yr-old slash pine.

3.6 Merchantable Volume

Results for merchantable volume (3-in. top) are essentially the same as for total volume with significant genetic and competition control effects and the lack of significant interactions (Table 10). Merchantable volume was greater with improved than unimproved stock (Table 11, Figure 5) and statistically similar for improved bulk lot and improved single family plantings. Across competition control levels, merchantable volume was 2857 ft^3/ac for unimproved stock and averaged 3226 ft^3/ac for the improved stock treatments, a gain of 369 ft^3/ac (13%) relative to unimproved stock. Complete competition control increased yield an average 584 ft^3/ac (21%) across all genetic treatments.

Although the genetic treatment by competition control treatment interaction was not statistically significant, the merchantable volume per acre appeared greater for genetically improved plantings with complete vegetation control as compared to that expected from the performance of improved plantings without complete completion control and of unimproved plantings with complete competition control relative to that of unimproved plantings without complete competition control.

Table 10. Test of fixed effects for merchantable volume (o.b. to a 3-in. top o.b. (ft^3/ac) of slash pine at age 21.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	88.2	6.66	0.0020
Competition Control	1	14.2	25.93	0.0002
Genetics* Competition Control	2	86.2	1.29	0.2799

Table 11. Summary of least squares means for merchantable volume o.b. to a 3-in. top o.b. (ft^3/ac) of slash pine at age 21.

	No Control	Complete Control	Average
Unimproved	2674	3041	2857
Bulk Lot	2877	3587	3232
Single Family	2882	3556	3219
Average	2811	3395	3103

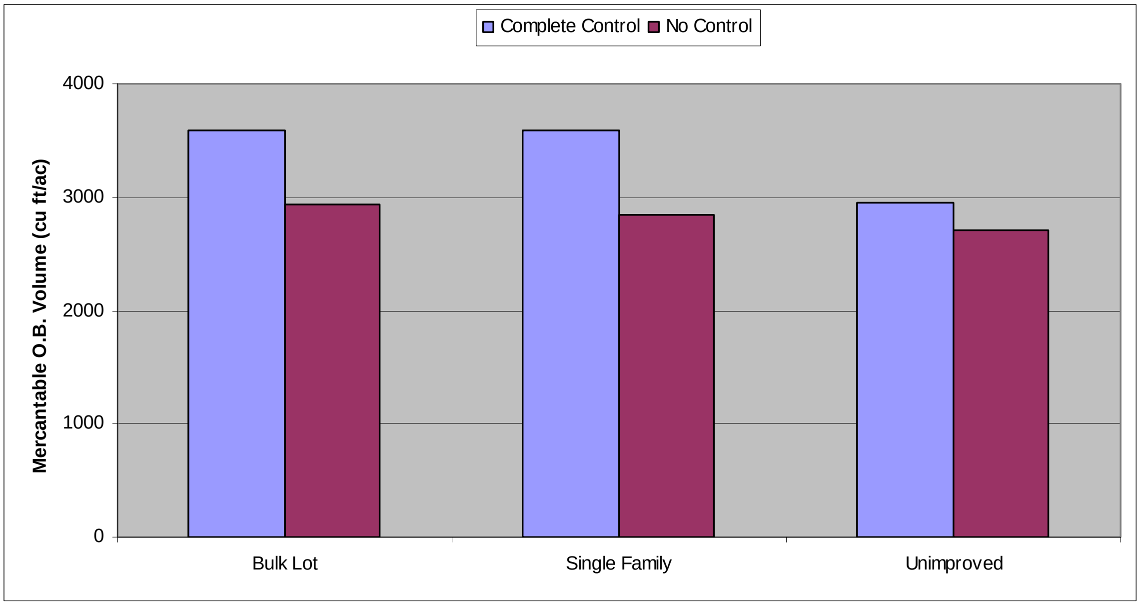

Figure 5. Merchantable volume (3-in. top) per acre by treatment for 21-yr-old slash pine.

3.7 Total Green Weight per Acre

Genetic and competition control treatments significantly affected total green weight (Table 12). No statistically significant genetic treatment by competition control treatment interactions was observed. Total green weight was greater with improved than unimproved stock (Table 13, Figure 6) and statistically similar for improved bulk lot and improved single family plantings. Across competition control levels, total green weight was 93 tons/ac for unimproved stock and averaged 105 tons/ac for the improved stock treatments, a 12 ton/ac gain (13%) relative to unimproved stock. Complete competition control increased yield an average 16 tons/ac (17%) across genetic treatments.

Although the genetic treatment by competition control treatment interaction was not statistically significant, the total green weight per acre appeared greater for genetically improved plantings with complete vegetation control as compared to that expected from the performance of improved plantings without complete completion control and of unimproved plantings with complete competition control relative to that of unimproved plantings without complete competition control.

Table 12. Test of fixed effects for total green weight (tons/ac) of slash pine at age 21.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	48.0	7.65	0.0013
Competition Control	1	14.2	20.60	0.0004
Genetics* Competition Control	2	49.6	1.41	0.2545

Table 13. Summary of least squares means for total green weight (tons/ac) of slash pine at age 21.

	No Control	Complete Control	Average
Unimproved	88.7	97.3	93.0
Bulk Lot	95.7	115.3	105.5
Single Family	95.5	114.0	104.7
Average	93.3	108.9	101.1

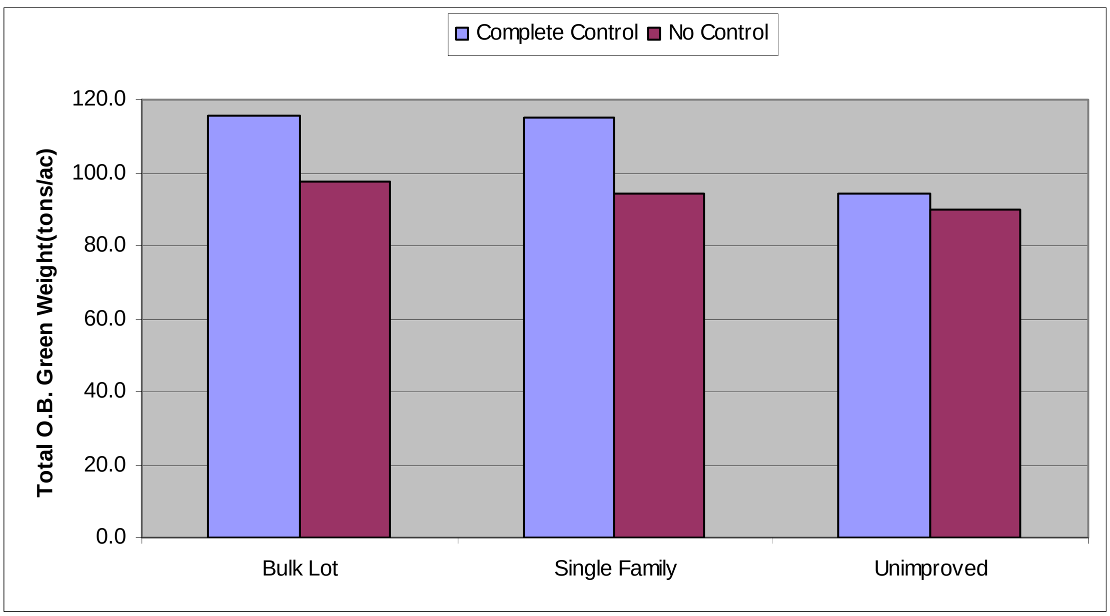

Figure 6. Total green weight per acre by treatment for 21-yr-old slash pine.

3.8 Merchantable Green Weight

Results for merchantable green weight showed the same trends as observed in the total green weight analysis with genetic and competition control treatments significantly affecting merchantable green weight and the absence of interactions (Table 14). Merchantable green weight was greater with improved than unimproved stock (Table 15, Figure 7) and statistically similar for improved bulk lot and improved single family plantings. Across competition control levels, merchantable green weight was 86 tons/ac for unimproved stock and averaged 98 tons/ac for the improved stock treatments, a 12 ton/ac gain (14%) relative to unimproved stock. Complete competition control increased yield an average 18 tons/ac (21%) across genetic treatments.

Although the genetic treatment by competition control treatment interaction was not statistically significant, the merchantable green weight per acre appeared greater for genetically improved plantings with complete vegetation control as compared to that expected from the performance of improved plantings without complete completion control and of unimproved plantings with complete competition control relative to that of unimproved plantings without complete competition control.

Table 14. Test of fixed effects for merchantable green weight o.b. to a 3-in. top o.b. (tons/ac) of slash pine.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	88.4	7.20	0.0013
Competition Control	1	14.2	25.27	0.0002
Genetics* Competition Control	2	86.2	1.35	0.2635

Table 15. Summary of least squares means for merchantable green weight o.b. to a 3-in. top o.b. (tons/ac) of slash pine at age 21.

	No Control	Complete Control	Average
Unimproved	80.8	91.4	86.1
Bulk Lot	87.4	108.9	98.2
Single Family	87.6	108.0	97.8
Average	85.3	102.8	94.1

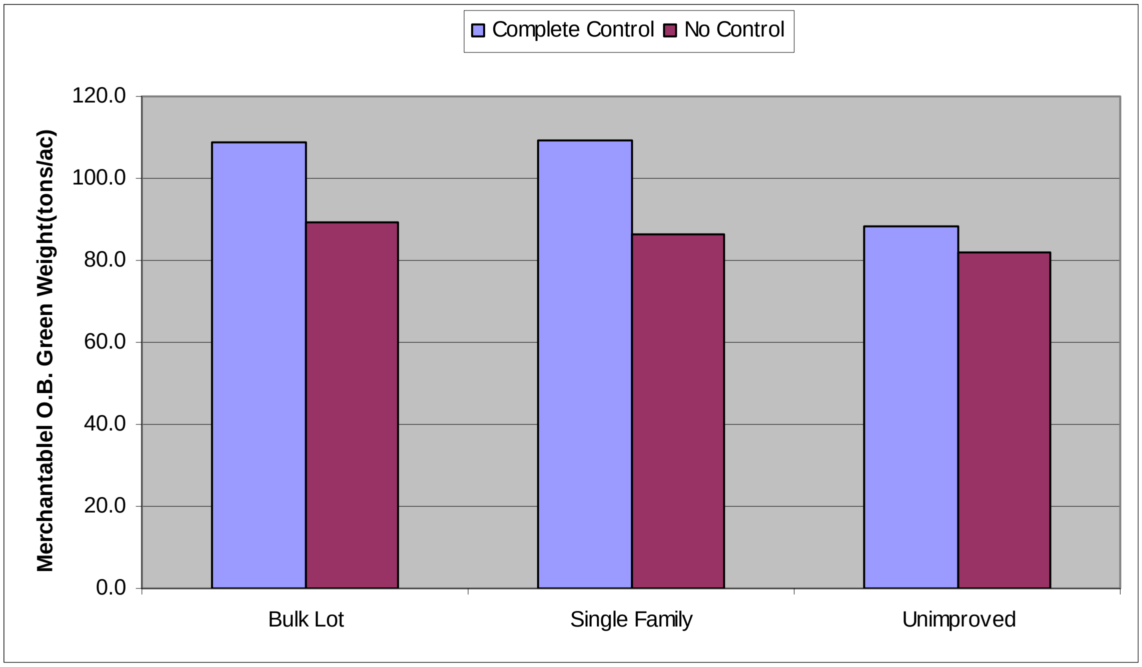

Figure 7. Merchantable green weight (3-in. top) per acre by treatment for 21-yr-old slash pine.

3.9 Pulpwood Green Weight

Results for pulpwood green weight show the same trends as observed in the total green weight analysis with genetic and competition control treatments significantly affecting pulpwood green weight and the absence of interactions (Table 16). Pulpwood green weight was greater with improved than unimproved stock (Table 17, Figure 8) and statistically similar for improved bulk lot and single family plantings. Across competition control levels, pulpwood green weight was 75 tons/ac for unimproved stock and averaged 83 tons/ac for the improved stock treatments, an 8 ton/ac gain (11%) relative to unimproved stock. Complete competition control increased yield an average 15 tons/ac (20%) across genetic treatments.

Although the genetic treatment by competition control treatment interaction was not statistically significant, the pulpwood green weight per acre appeared greater for genetically improved plantings with complete vegetation control as compared to that expected from the performance of improved plantings without complete completion control and of unimproved plantings with complete competition control relative to that of unimproved plantings without complete competition control.

Table 16. Test of fixed effects for pulpwood green weight o.b. to a 3-in. top o.b. (tons/ac) of slash pine at age 21.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	48.1	4.37	0.0181
Competition Control	1	14.1	31.75	<0.0001
Genetics* Competition Control	2	49.9	2.07	0.1369

Table 17. Summary of least squares means for pulpwood green weight o.b. to a 3-in. top o.b. (tons/ac) of slash pine at age 21.

	No Control	Complete Control	Average
Unimproved	71.1	78.4	74.7
Bulk Lot	73.6	92.7	83.2
Single Family	73.5	91.8	82.6
Average	72.7	87.6	80.2

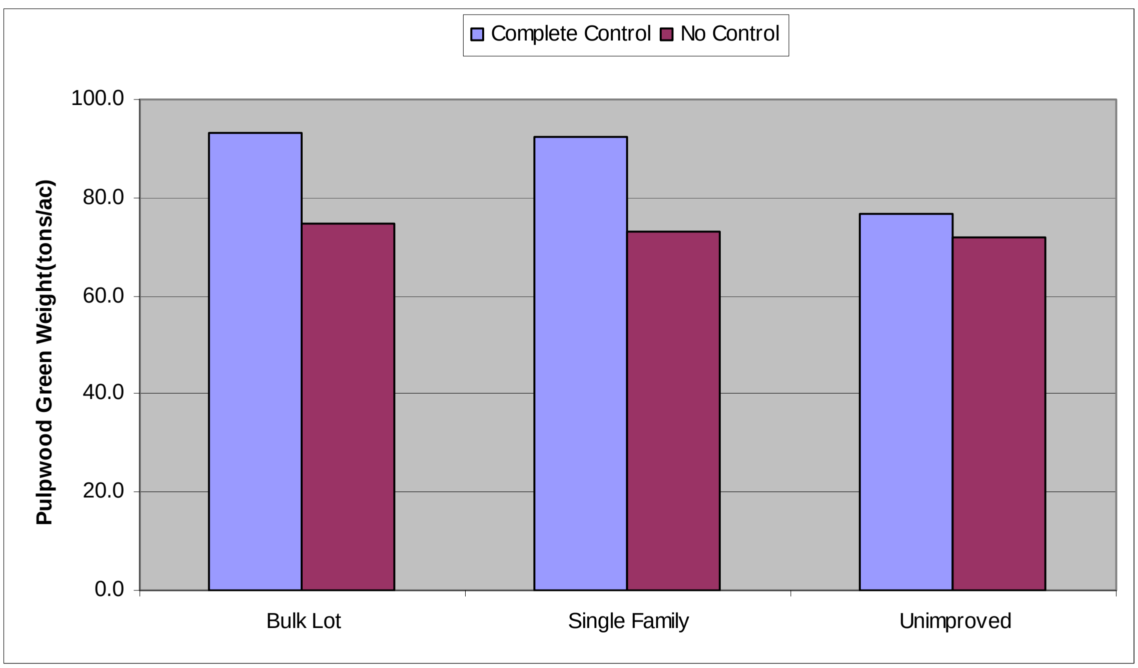

Figure 8. Pulpwood green weight (3-in. top) per acre by treatment for 21-yr-old slash pine.

3.10 Chip-N-Saw Green Weight

Chip-n-saw green weight was significantly increased by genetic entry but not by complete competition control (Table 18). The genetic by competition control interaction was not significant. Chip-n-saw green weight was significantly greater for the improved bulk lot plantings (13.5

tons/ac) than for the unimproved plantings (9.9 tons/ac) (Table 19) (Figure 9). Other differences between genetic entries were not significant. Note that the chip-n-saw calculation takes into account tree size and tree quality.

Table 18. Test of fixed effects for chip-n-saw green weight o.b. to a 6-in. top o.b. (tons/ac) of slash pine at age 21.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	79.4	3.29	0.0422
Competition Control	1	14.1	2.05	0.1740
Genetics* Competition Control	2	78.1	0.03	0.9703

Table 19. Summary of least squares means for chip-n-saw green weight o.b. to a 6-in. top o.b. (tons/ac) of slash pine at age 21.

	No Control	Complete Control	Average
Unimproved	8.9	10.9	9.9
Bulk Lot	12.5	14.4	13.5
Single Family	12.1	13.5	12.8
Average	11.1	12.9	12.0

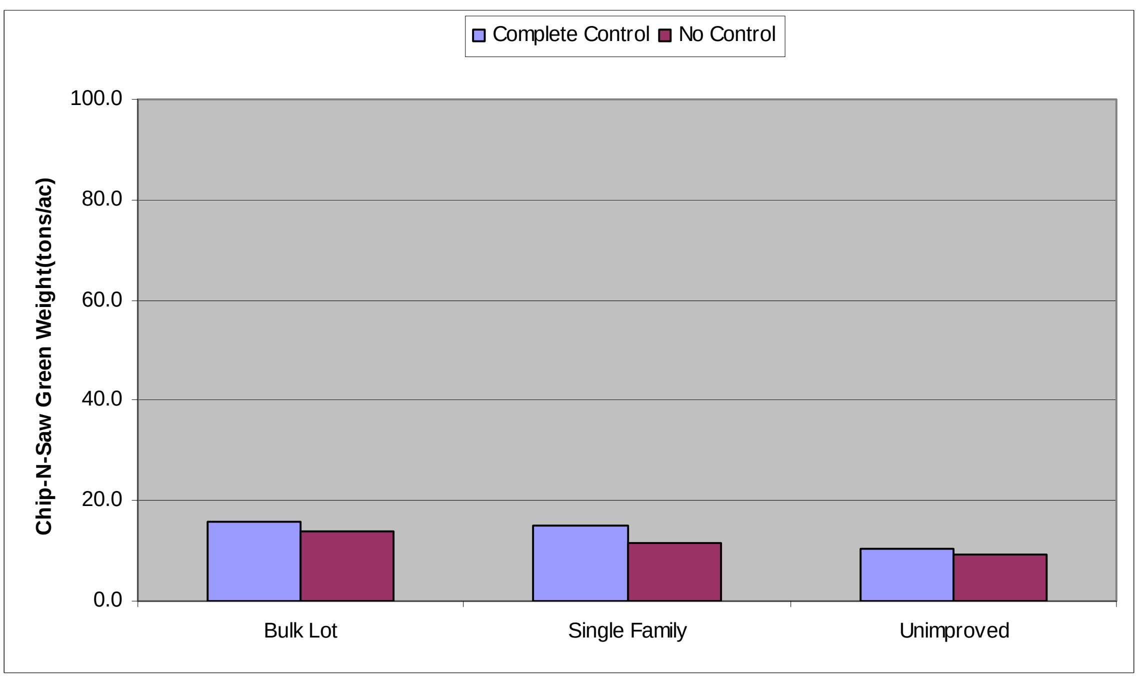

Figure 9. Chip-n-saw green weight (6-in. top) per acre by treatment for 21-yr-old slash pine.

3.11 Trees per Acre

There were significantly less trees per acre on plots receiving complete competition control (537 TPA) than on plots without complete competition control (579 TPA) (Tables 20 and 21, Figure 10). The improved bulk lot planting tended to have the greatest number of trees per acre and the unimproved planting the least although genetic treatment differences were only significant at alpha=0.13. The genetic treatment by competition control treatment interaction was not significant. This finding of lower trees per acre for the complete vegetation control treatment at age 21 was not observed through age 15 (Logan and Shiver, 2003).

Table 20. Test of fixed effects for trees per acre of slash pine at age 21.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	28.4	2.27	0.1219
Competition Control	1	13.5	9.52	0.0084
Genetics* Competition Control	2	25.9	1.25	0.3025

Table 21. Summary of least squares means for trees per acre of slash pine at age 21.

	No Control	Complete Control	Average
Unimproved	573	509	541
Bulk Lot	591	557	574
Single Family	573	544	559
Average	579	537	558

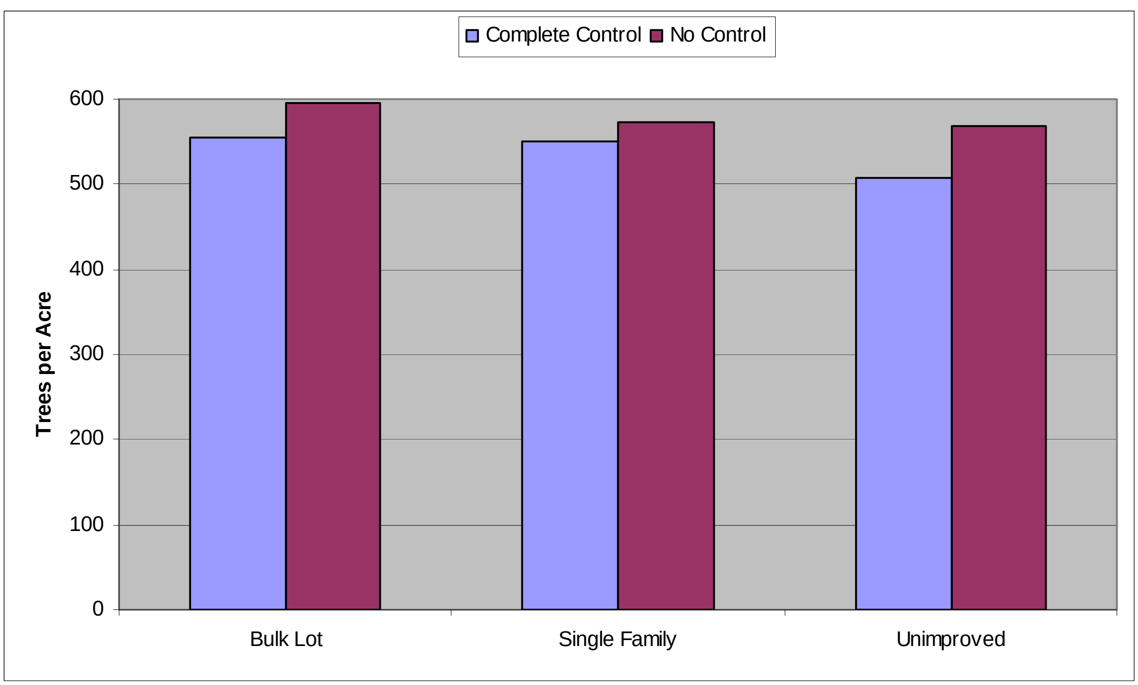

Figure 10. Trees per acre by treatment for 21-yr-old slash pine.

3.12 Percent Fusiform Infection

Genetic improvement significantly reduced infection rates while complete competition control significantly increased infection rates (Tables 22 and 23). There was not a significant difference in rust levels between improved bulk plantings and improved single family plantings. The mean rust infection rate for genetically improved plantings was 60% of the infection rate observed for unimproved plantings. Rust rates were 50% greater on plantings receiving complete vegetation control (16.5%) as compared to those without complete vegetation control (11%). The main effect trends were consistently observed and the genetic by competition control interaction was not significant (Table 23, Figure 11).

Table 22. Test of fixed effects for percent fusiform infection on slash pine at age 21.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	28.2	13.88	<0.0001
Competition Control	1	13.6	13.86	0.0024
Genetics* Competition Control	2	27	1.34	0.2789

Table 23. Summary of least squares means for percent fusiform infection of slash pine at age 21.

	No Control	Complete Control	Average
Unimproved	15.2	22.7	18.9
Bulk Lot	8.3	13.0	10.6
Single Family	9.7	13.7	11.7
Average	11.0	16.5	13.8

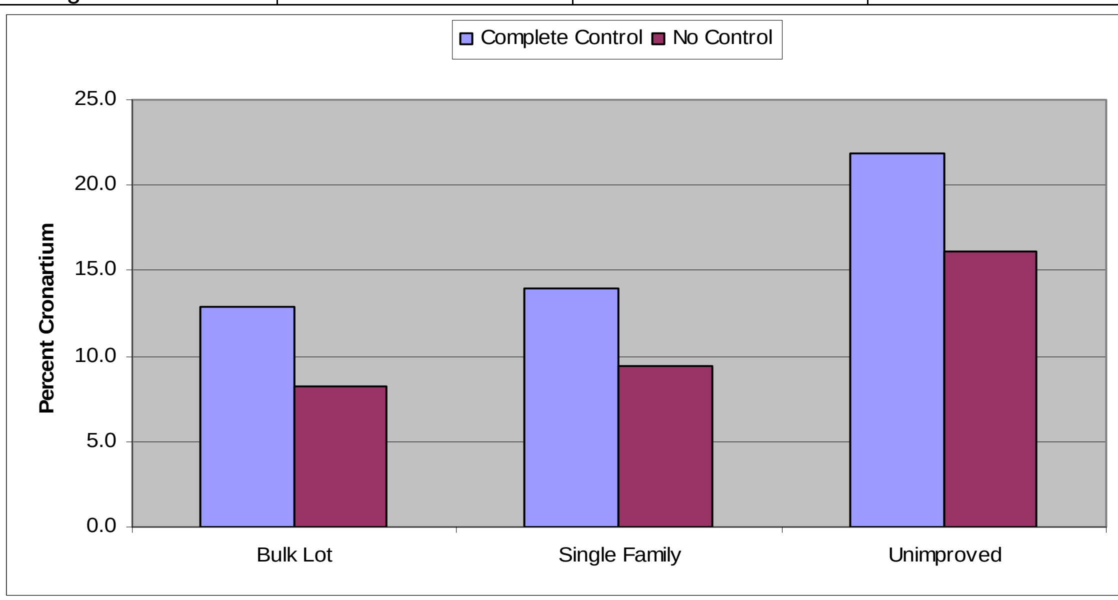

Figure 11. Percent fusiform rust infection by treatment for 21-yr-old slash pine.

3.13 Percent Defect-Free Trees

Competition control significantly reduced the proportion of trees without major defects (trees with sawtimber potential) (Tables 24 and 25). The percent of defect-free trees was 32.4% on plots without complete vegetation control as compared to 23.1% on plots with complete competition control (Table 25, Figure 12). The genetic treatment effect and the genetic by competition control treatment interaction were not significant.

Table 24. Test of fixed effects for percent defect-free trees of slash pine at age 21.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	26.2	0.89	0.4239
Competition Control	1	13.2	31.34	<0.0001
Genetics* Competition Control	2	60.9	1.63	0.2042

Table 25. Summary of least squares means for percent defect-free trees of slash pine at age 21.

	No Control	Complete Control	Average
Unimproved	28.9	23.2	26.1
Bulk Lot	33.6	22.0	27.8
Single Family	34.7	24.1	29.4
Average	32.4	23.1	27.8

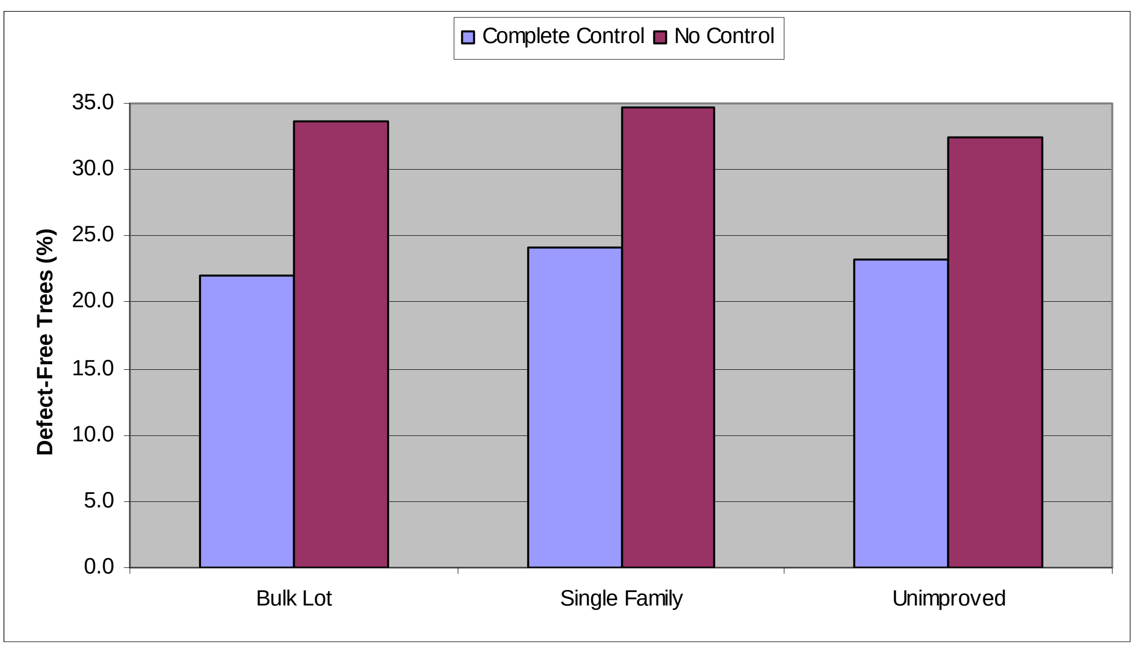

Figure 12. Percent defect-free trees (least square means) by treatment for 21-yr-old slash pine.

3.14 Percent Forked Trees

Competition control significantly increased the proportion of trees with forks (Tables 26 and 27). While this increase was significant, the percent of trees with forks on plots with complete competition control was only 3.9% (Table 27, Figure 13). The genetic treatment effect and the genetic by competition control treatment interaction were not significant.

Table 26. Test of fixed effects for percent forked trees of slash pine at age 21.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	27.1	0.04	0.9570
Competition Control	1	14	17.65	0.0009
Genetics* Competition Control	2	27.9	0.53	0.5938

Table 27. Summary of least squares means for percent forked trees of slash pine at age 21.

	No Control	Complete Control	Average
Unimproved	1.9	3.5	2.7
Bulk Lot	2.0	4.0	3.0
Single Family	1.6	4.3	2.9
Average	1.8	3.9	2.9

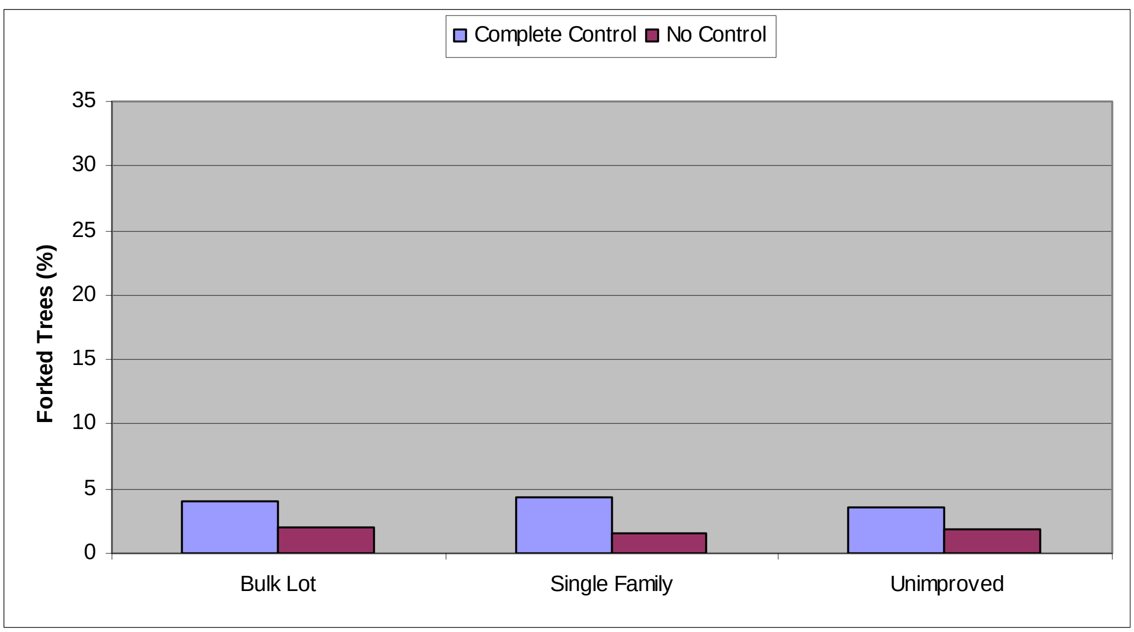

Figure 13. Percent forked trees (least square means) by treatment for 21-yr-old slash pine.

3.15 Percent of Trees with Crook or Sweep

Competition control significantly increased the proportion of trees with crook or sweep (Tables 28 and 29). While this increase was significant, the percent of trees with crook or sweep was exceptionally high on plots not receiving complete competition control (62.7%) and increased moderately on plots with complete competition control (70.2%) (Table 29, Figure 14). The genetic treatment effect and the genetic by competition control treatment interaction were not significant.

Table 28. Test of fixed effects for percent of trees with crook or sweep for slash pine at age 21.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	26.3	0.88	0.4257
Competition Control	1	12.9	19.99	0.0006
Genetics* Competition Control	2	69.2	0.39	0.6799

Table 29. Summary of least squares means for percent of trees with crook or sweep for slash pine at age 21.

	No Control	Complete Control	Average
Unimproved	64.7	70.4	67.5
Bulk Lot	62.4	71.2	66.8
Single Family	61.0	69.0	65.0
Average	62.7	70.2	66.5

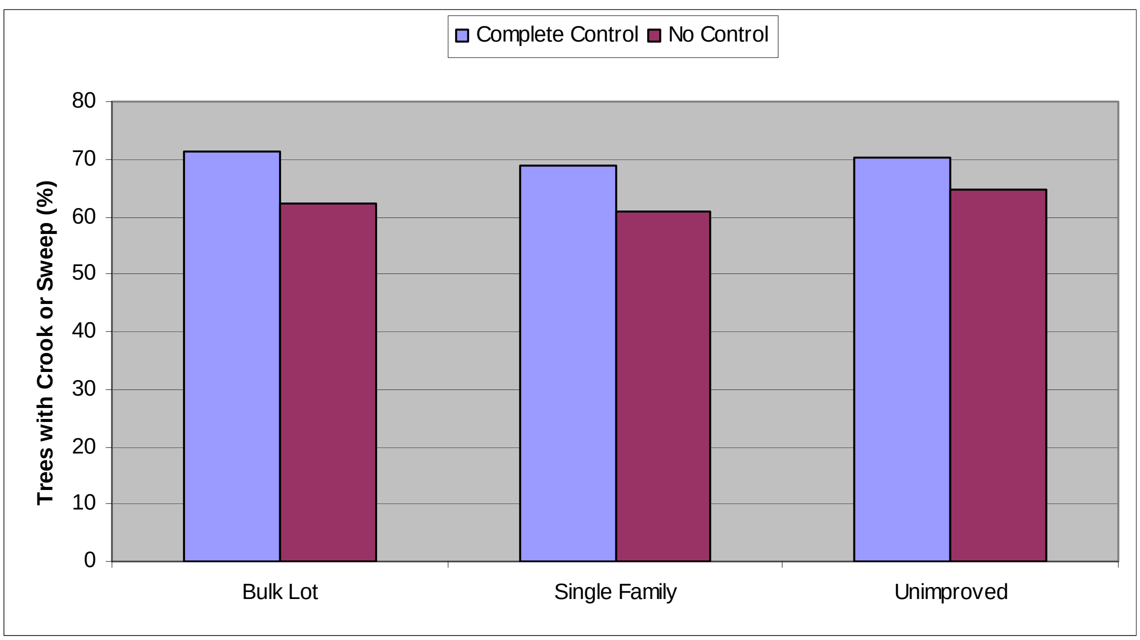

Figure 14. Percent of trees with crook or sweep (least squares mean) by treatment for 21-yr-old slash pine.

3.16 Stand Density Index

Improved genetics and competition control significantly affected stand density index (Table 30). Genetically improved plantings had greater stand density index than unimproved planting. Improved single family plantings and improved bulk lot plantings had similar stand density indices (Table 31, Figure 15). Stand density index was consistently greater on plots receiving complete vegetation control as compared to plots not receiving complete vegetation control. The interaction of genetic and competition control treatments on stand density index was not significant.

Although the genetic treatment by competition control treatment interaction was not statistically significant, the stand density index appeared greater for genetically improved plantings with complete vegetation control as compared to that expected from the performance of improved plantings without complete completion control and of unimproved plantings with complete competition control relative to that of unimproved plantings without complete competition control.

Table 30. Test of fixed effects for stand density index of slash pine at age 21.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	50.5	4.77	0.0127
Competition Control	1	14	5.92	0.0289
Genetics* Competition Control	2	50.9	1.42	0.2515

Table 31. Summary of least squares means for stand density index of slash pine at age 21.

	No Control	Complete Control	Average
Unimproved	262	269	266
Bulk Lot	271	299	285
Single Family	269	296	282
Average	267	288	278

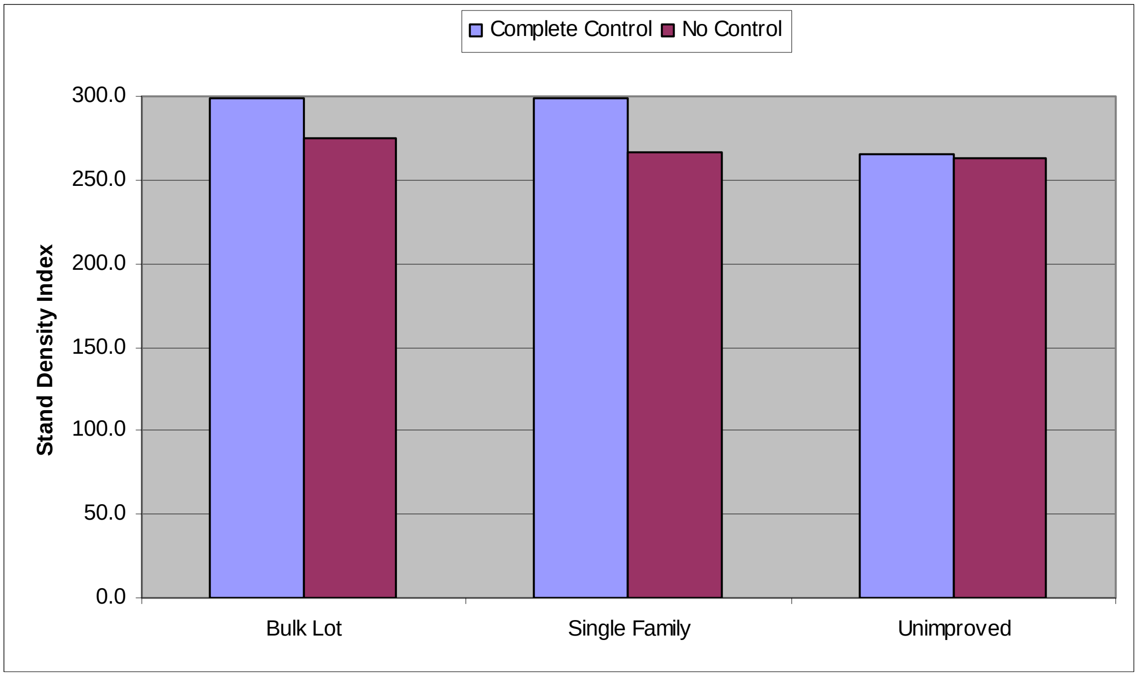

Figure 15. Stand density index by treatment for 21-yr-old slash pine.

3.17 Relative Spacing

The main effect of genetics on relative spacing was significant while that of competition control and the genetics by competition control interaction were not significant (Table 32). Improved planting stock plots had significantly lower relative densities, 0.161 for bulk lot plantings and 0.163 for single family plantings, as compared to unimproved stock plots with 0.174 (Table 33, Figure 16). Bulk lot and single family improved plantings did not differ significantly in relative spacing.

Table 32. Test of fixed effects for relative spacing of slash pine at age 21.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	45.3	7.25	0.0019
Competition Control	1	13.9	1.08	0.3171
Genetics* Competition Control	2	46.1	0.35	0.7033

Table 33. Summary of least squares means for relative spacing of slash pine at age 21.

	No Control	Complete Control	Average
Unimproved	0.1752	0.1737	0.1744
Bulk Lot	0.1644	0.1579	0.1611
Single Family	0.1666	0.1591	0.1628
Average	0.1687	0.1635	0.1670

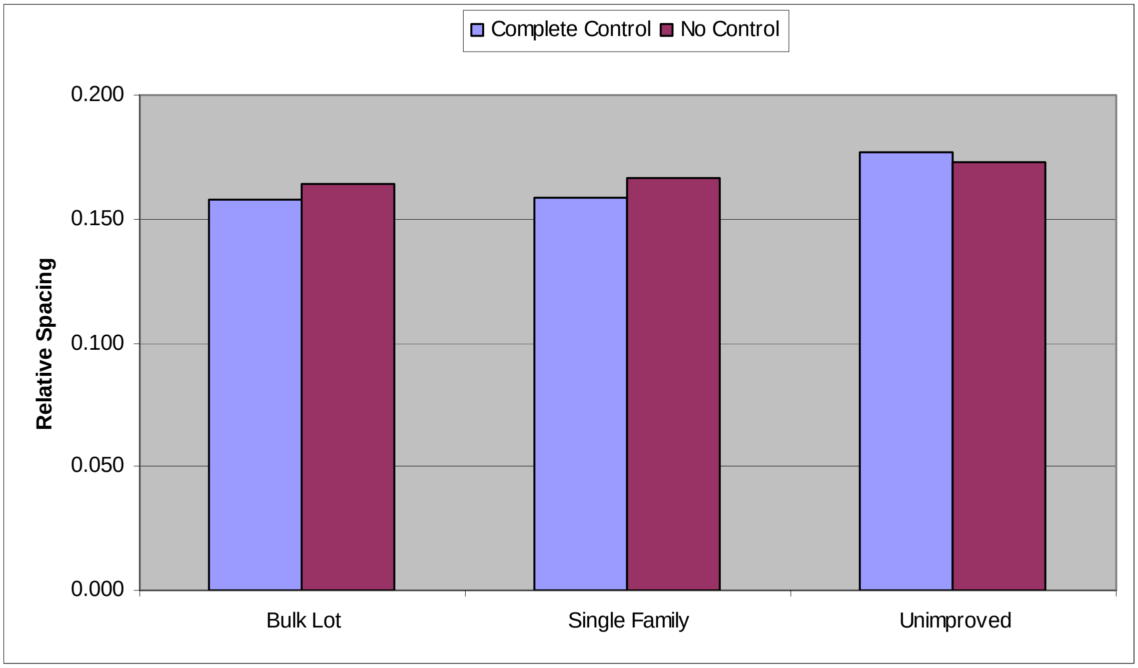

Figure 16. Relative spacing by treatment for 21-yr-old slash pine.

3.18 Average Crown Length

The main effect of vegetation control treatments was significant while the main effect of genetic treatments and the genetic by vegetation control treatment interaction were not significant (Table 34). Crown length was greater on plots receiving complete competition control (16.9 ft) as compared to plots not receiving complete competition control (16.1 ft) (Table 35, Figure 17).

Table 34. Test of fixed effects for average crown length of slash pine at age 21.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	29	0.37	0.6933
Competition Control	1	77.4	8.91	0.0038
Genetics* Competition Control	2	76.9	0.23	0.7922

Table 35. Summary of least squares means for average crown length of slash pine.

	No Control	Complete Control	Average
Unimproved	16.1	17.1	16.6
Bulk Lot	16.2	16.9	16.5
Single Family	16.0	16.6	16.3
Average	16.1	16.9	16.5

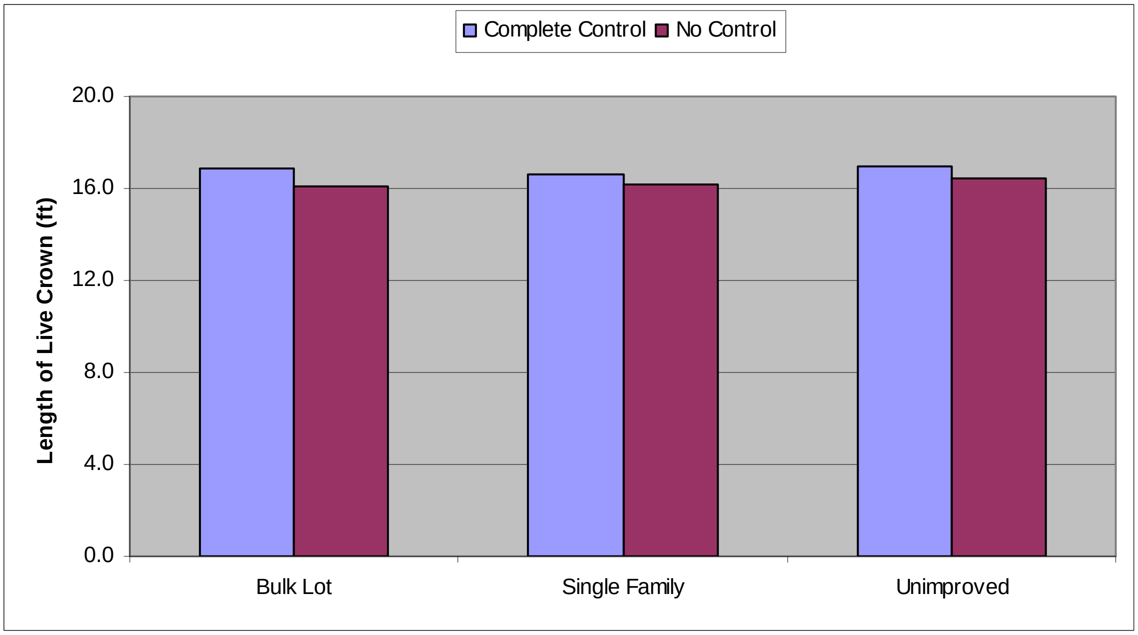

Figure 17. Average live crown length by treatment for 21-yr-old slash pine.

3.19 Average Crown Ratio

Average crown ratio was significantly affected by genetic treatments but not by competition control or the interaction of genetic and competition control treatments (Table 36). Crown ratio was greater for unimproved plantings (0.313) than for improved plantings (mean of 0.292) (Table 37, Figure 18). Improved single family plantings and improved bulk lot plantings did not differ significantly in crown ratio.

Table 36. Test of fixed effects for average crown ratio of slash pine at age 21.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	51	12.3	<0.0001
Competition Control	1	14	1.8	0.2013
Genetics* Competition Control	2	52.9	0.80	0.4536

Table 37. Summary of least squares means for average crown ratio of slash pine at age 21.

	No Control	Complete Control	Average
Unimproved	0.3121	0.3131	0.3126
Bulk Lot	0.2972	0.2916	0.2944
Single Family	0.2961	0.2850	0.2906
Average	0.3018	0.2966	0.2992

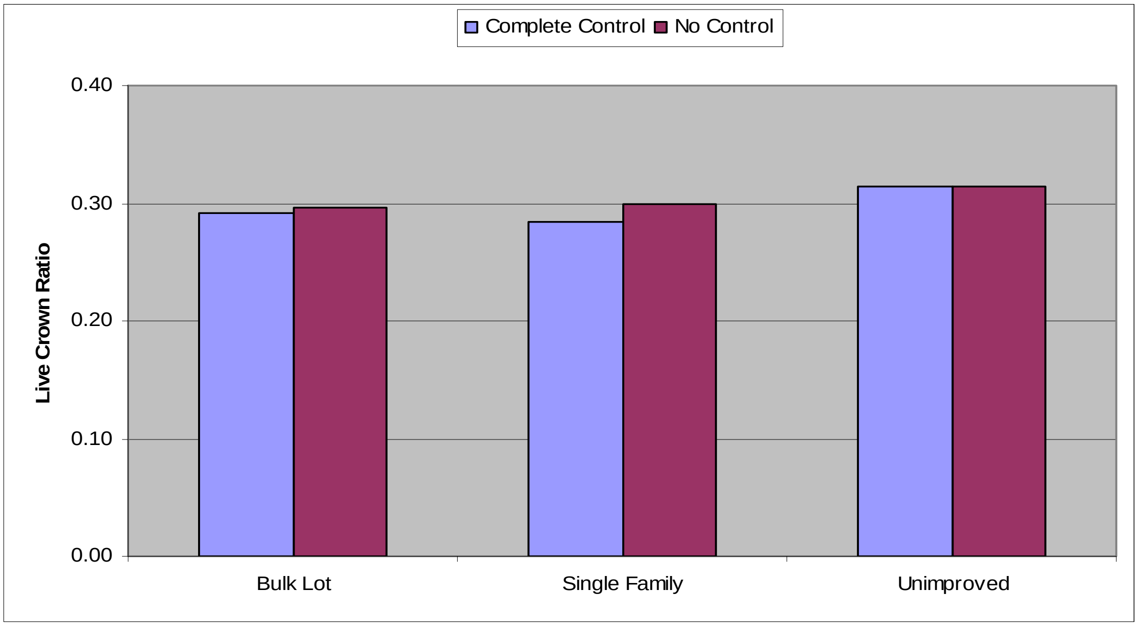

Figure 18. Average crown ratio by treatment for 21-yr-old slash pine.

4. CUMULATIVE RESULTS THROUGH AGE 21

4.1 Average Dbh

Patterns of average dbh with age are presented by genetics main effects (Figure 19), competition control main effects (Figure 20), and for contrasting treatment combinations (Figure 21).

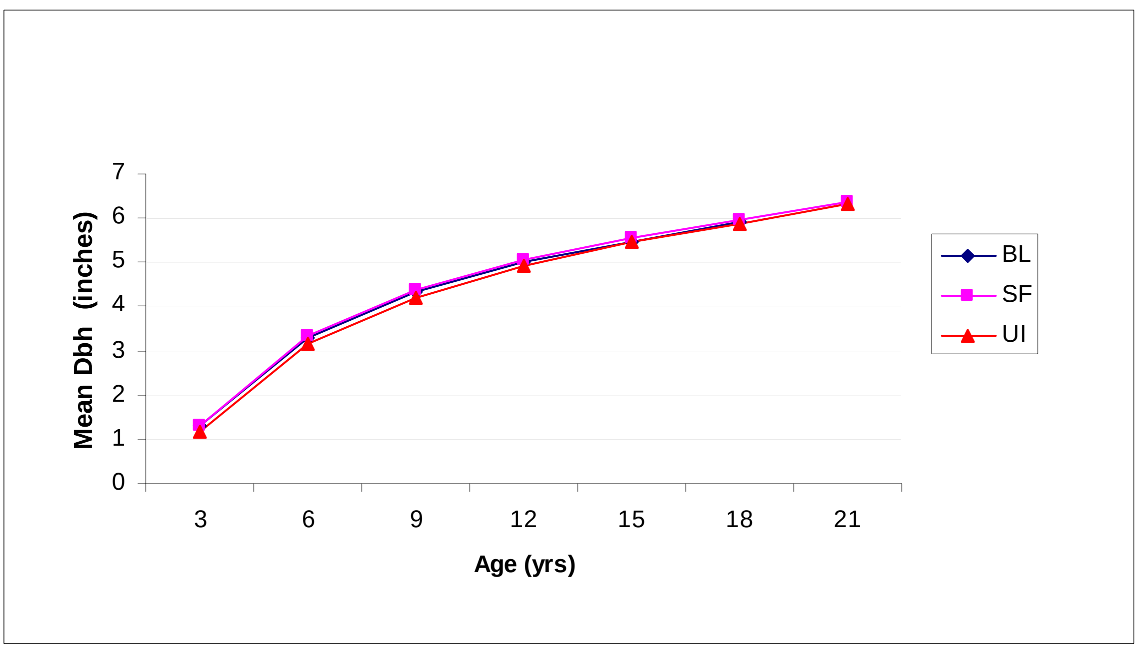

Figure 19. Mean dbh of slash pine by age for improved bulk lot (BL), improved single family (SF) and unimproved (UI) plantings across competition control treatments through age 21

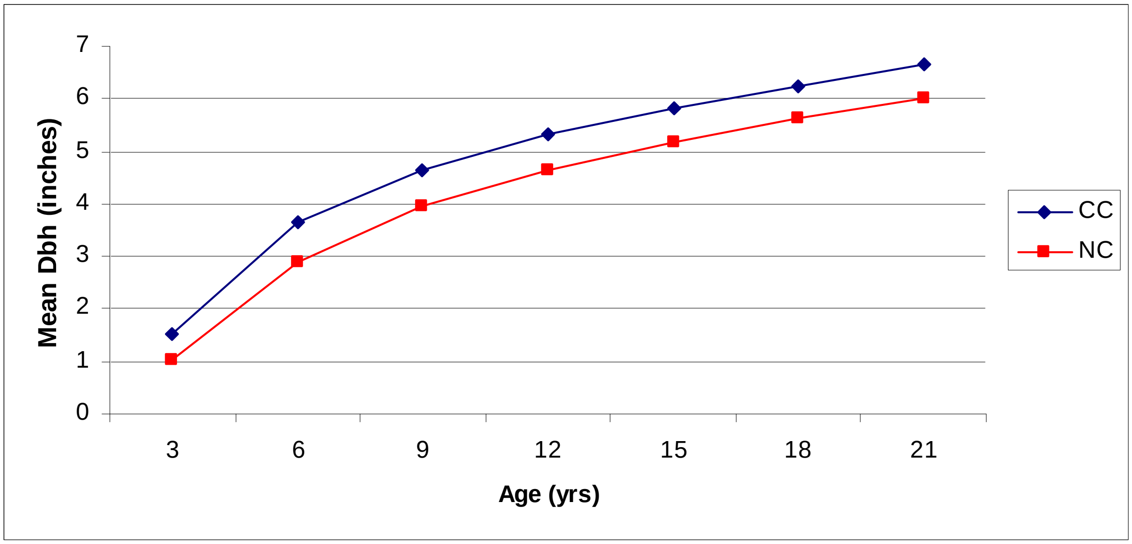

Figure 20. Mean dbh of slash pine by age for complete competition control (CC) and without complete competition control (NC) across genetic treatments through age 21.

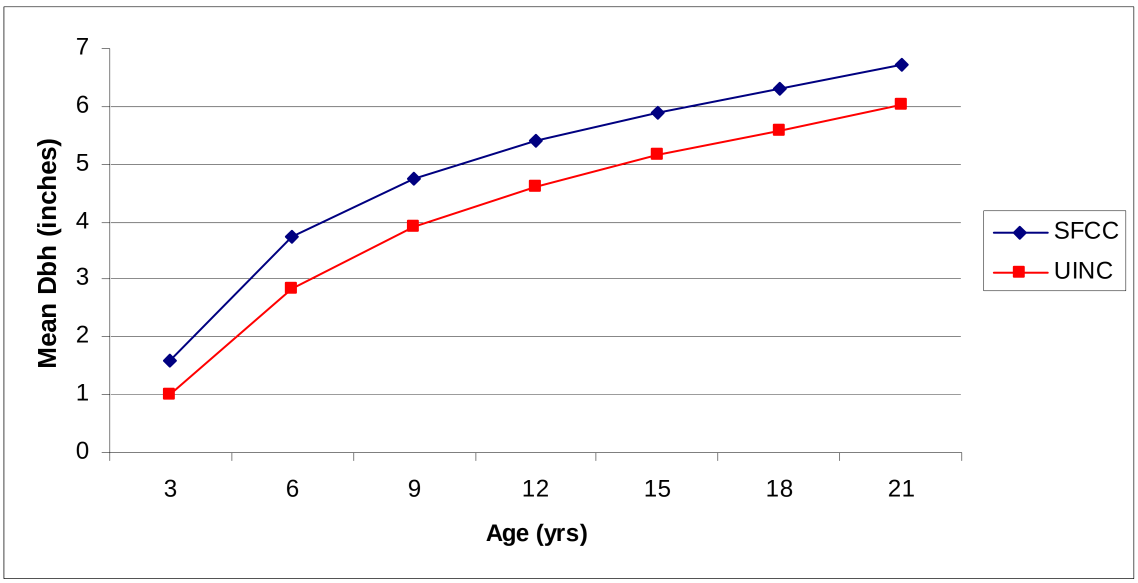

Figure 21. Mean dbh of slash pine by age for contrasting treatments of improved single family genetics with complete competition control (SFCC) and unimproved genetics without complete competition control (UINC) through age 21.

4.2 Average Dominant Height

Patterns of average dominant height with age are presented by genetics main effects (Figure 22), competition control main effects (Figure 23), and for contrasting treatment combinations (Figure 24).

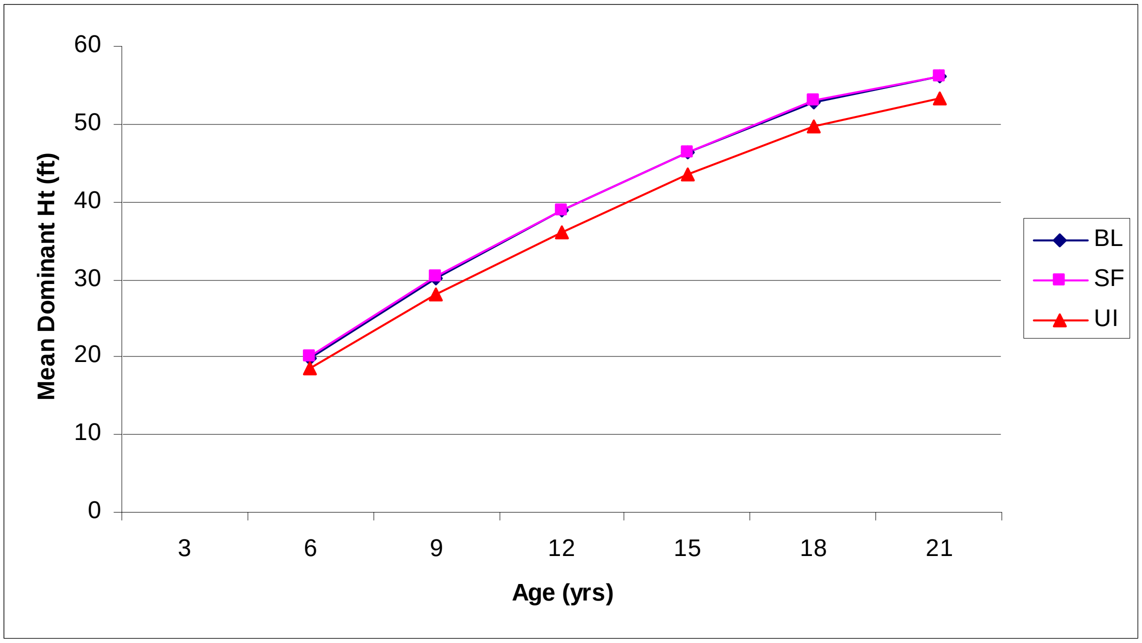

Figure 22. Mean dominant height of slash pine by age for improved bulk lot (BL), improved single family (SF), and unimproved plantings (UI) across competition control treatments through age 21.

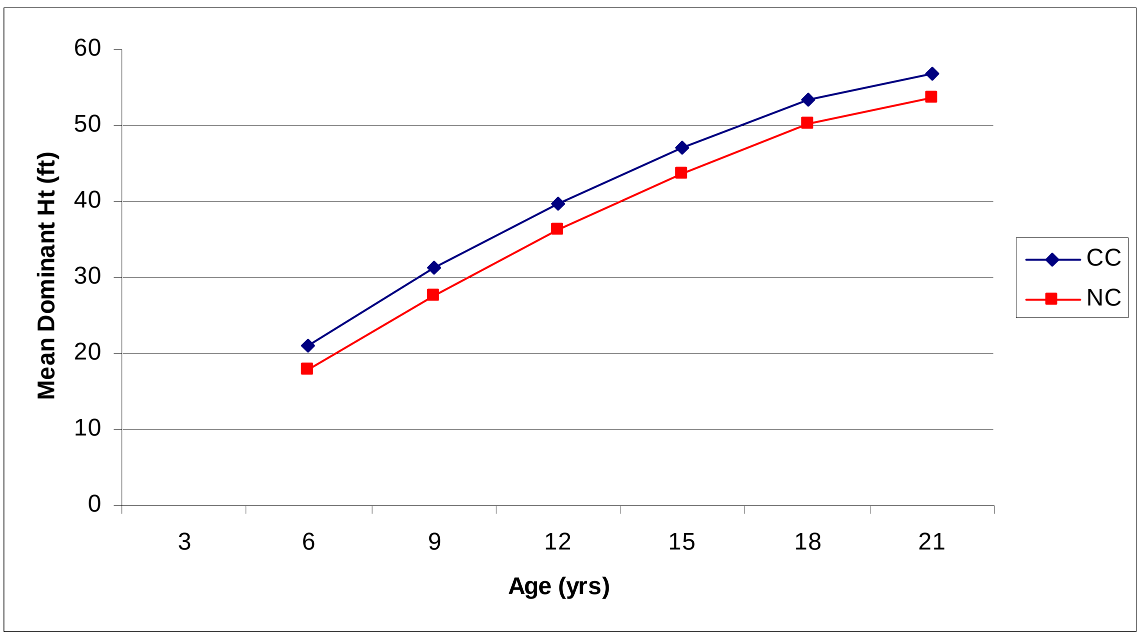

Figure 23. Mean dominant height of slash pine by age for complete competition control (CC) and without complete competition control (NC) across genetic treatments through age 21.

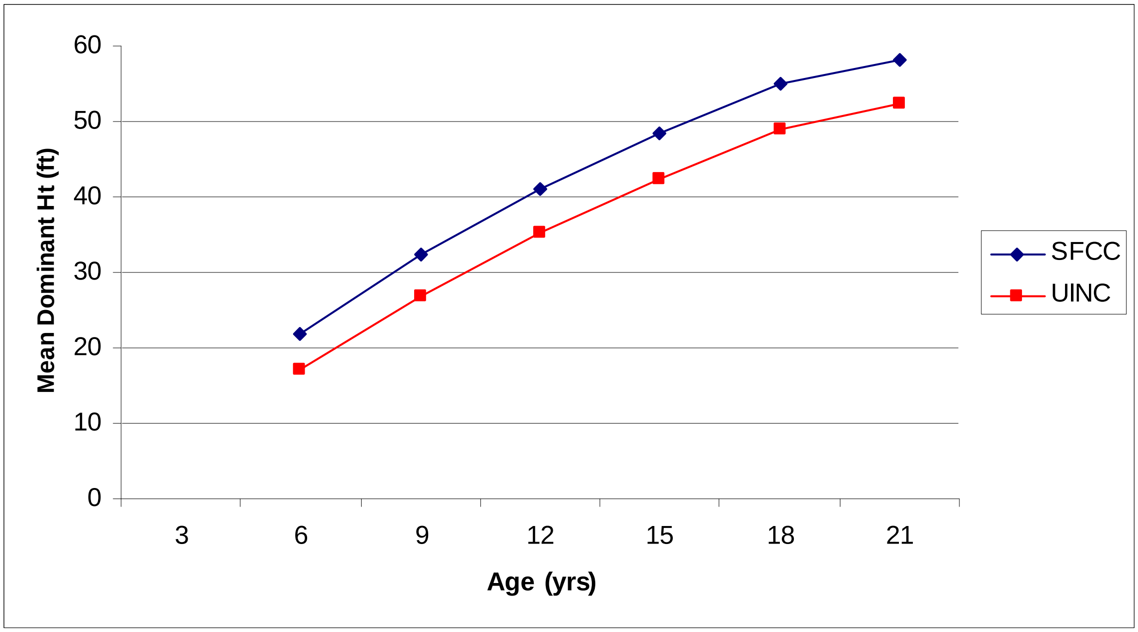

Figure 24. Mean dominant height of slash pine by age for contrasting treatments of improved single family genetics with complete competition control (SFCC) and unimproved genetics without complete competion control (UNINC) through age 21.

4.3 Basal Area per Acre

Patterns of basal area per acre with age are presented by genetics main effects (Figure 25), competition control main effects (Figure 26), and for contrasting treatment combinations (Figure 27).

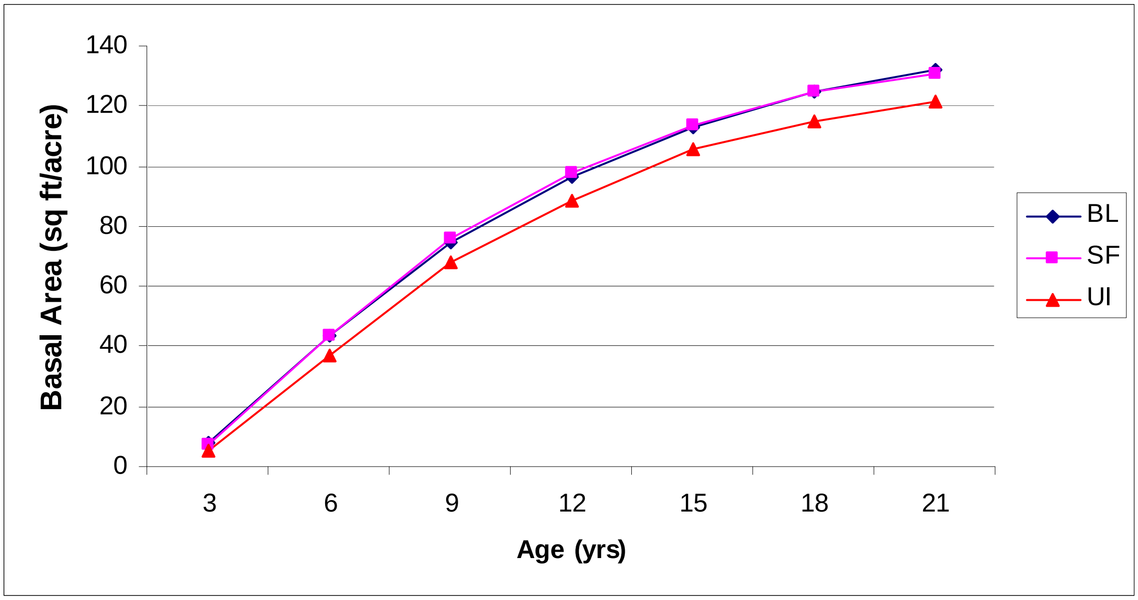

Figure 25. Mean basal area per acre of slash pine by age for improved bulk lot (BL), improved single family (SF), and unimproved plantings (UI) across competition control treatments through age 21.

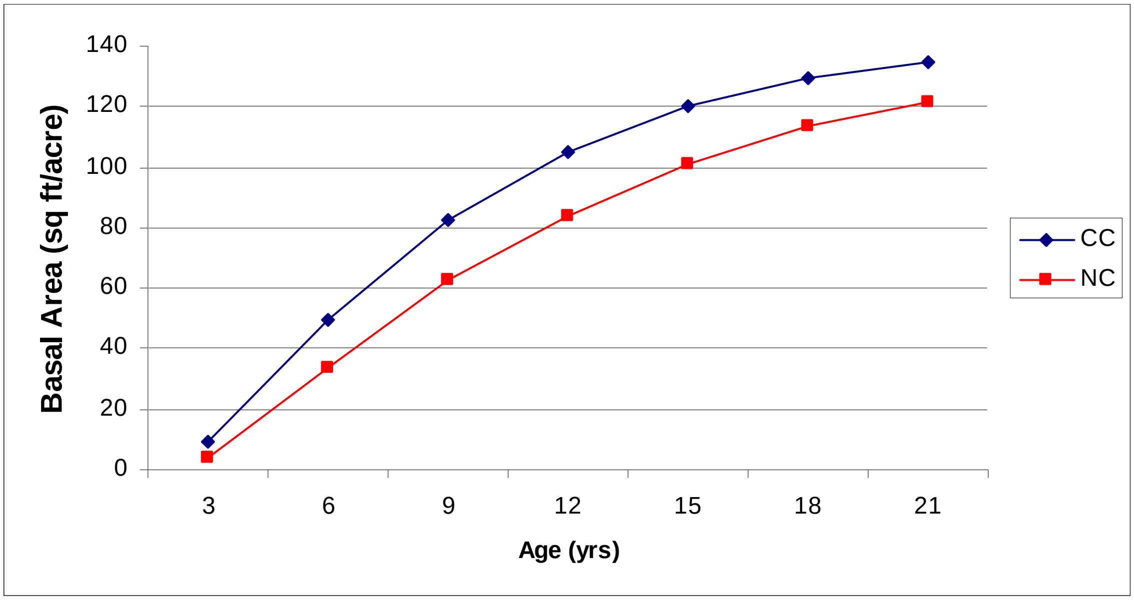

Figure 26. Mean basal area per acre of slash pine by age for complete competition control (CC) and without complete competition control (NC) across genetic treatments through through age 21.

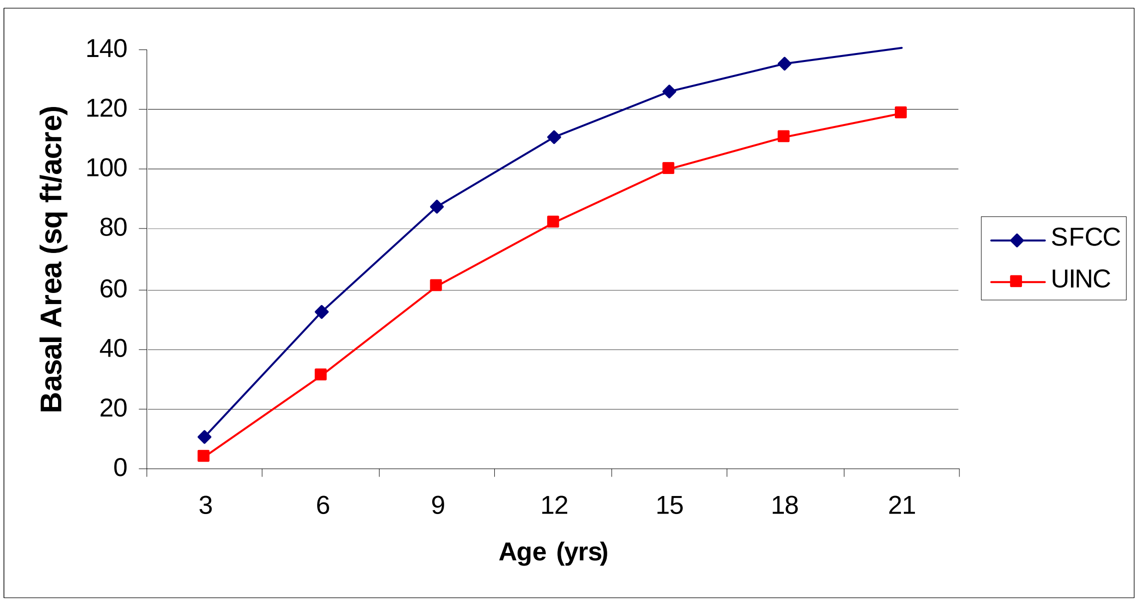

Figure 27. Mean basal area per acre of slash pine by age for contrasting treatments of improved single family genetics with complete competition control (SFCC) and unimproved genetics without complete competion control (UNINC) through age 21.

4.4 Total Stem Weight per Acre

Patterns of mean total green weight per acre with age are presented by genetics main effects (Figure 28), competition control main effects (Figure 29), and for contrasting treatment combinations (Figure 30).

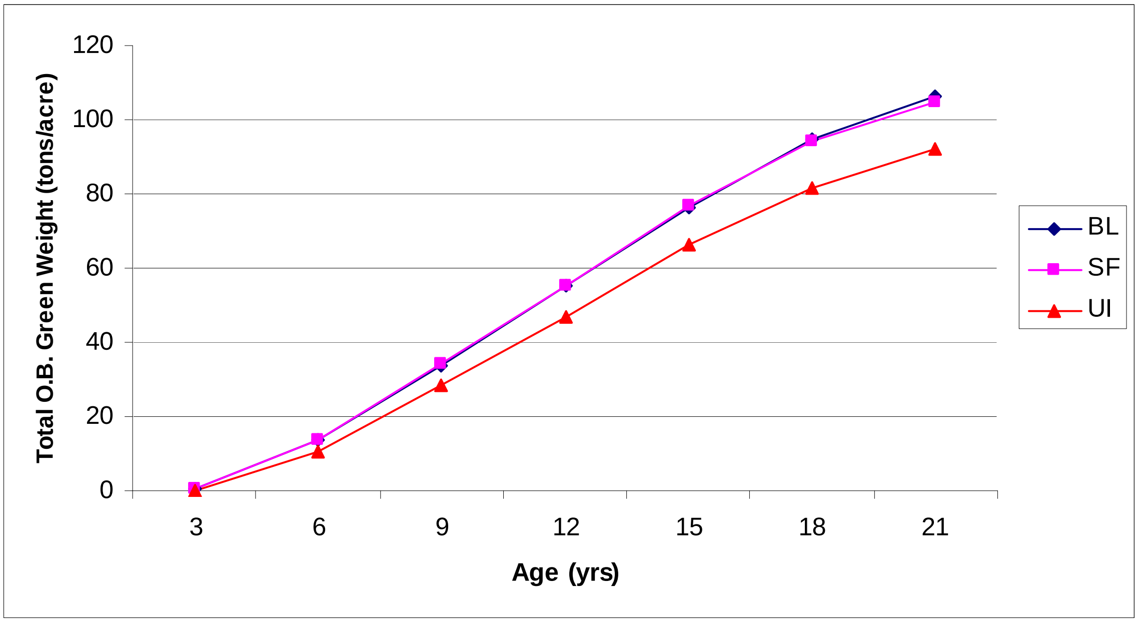

Figure 28. Mean total green weight per acre of slash pine by age for improved bulk lot (BL), improved single family (SF), and unimproved plantings (UI) across competition control treatments through age 21.

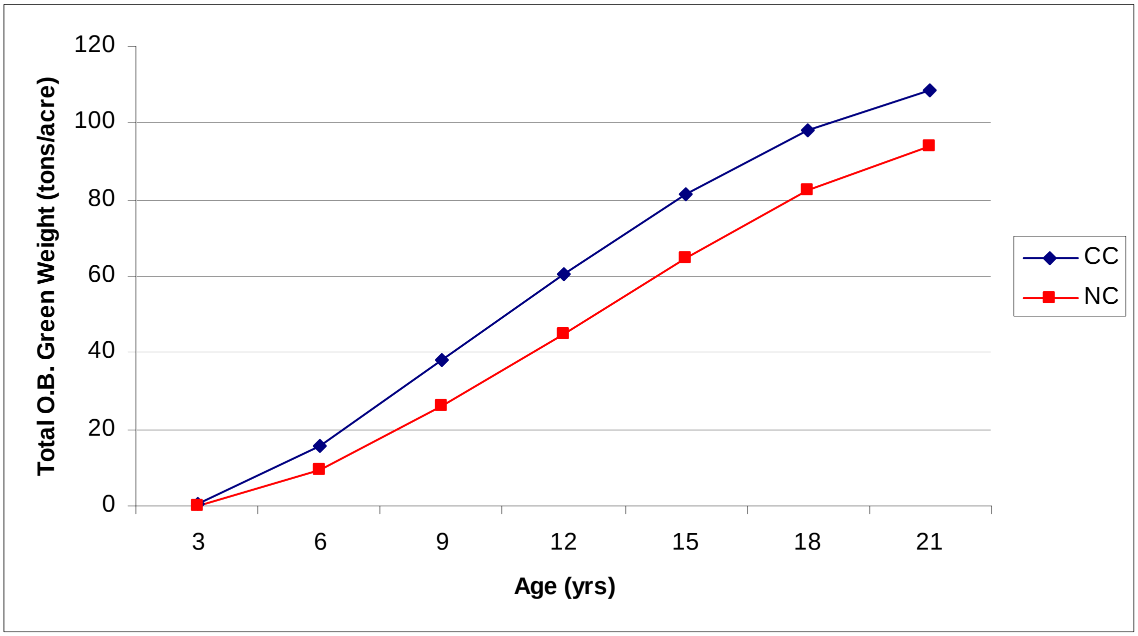

Figure 29. Mean total green weight per acre of slash pine by age for complete competition control (CC) and without complete competition control (NC) across genetic treatments through age 21.

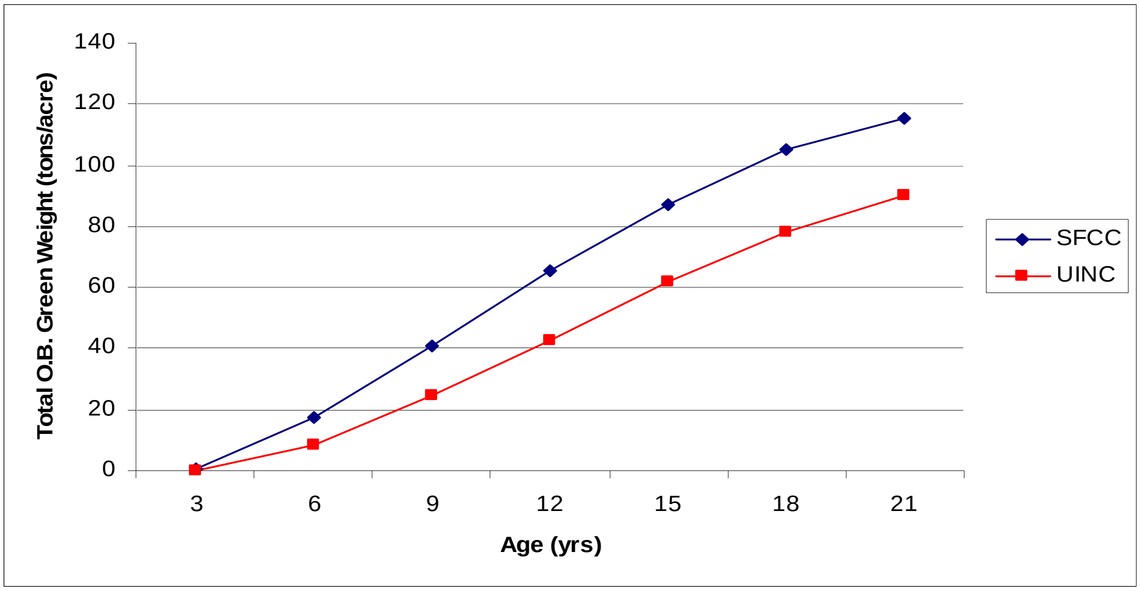

Figure 30. Mean total green weight per acre of slash pine by age for contrasting treatments of improved single family genetics with complete competition control (SFCC) and unimproved genetics without complete competion control (UNINC) through age 21.

4.5 Trees per Acre

Tree per acre trends through age 21 by genetics main effects (Figure 31), competition control main effects (Figure 32), and for contrasting treatment combinations (Figure 33) are presented below.

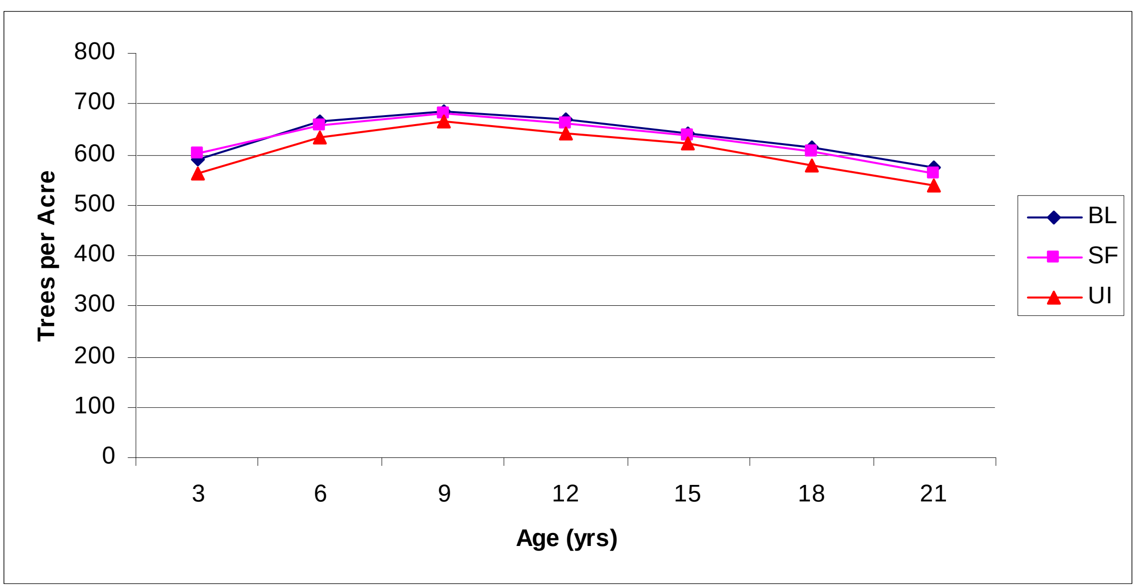

Figure 31. Mean trees per acre of slash pine by age for improved bulk lot (BL), improved single family (SF), and unimproved (UI) plantings across competition control treatments through age 21.

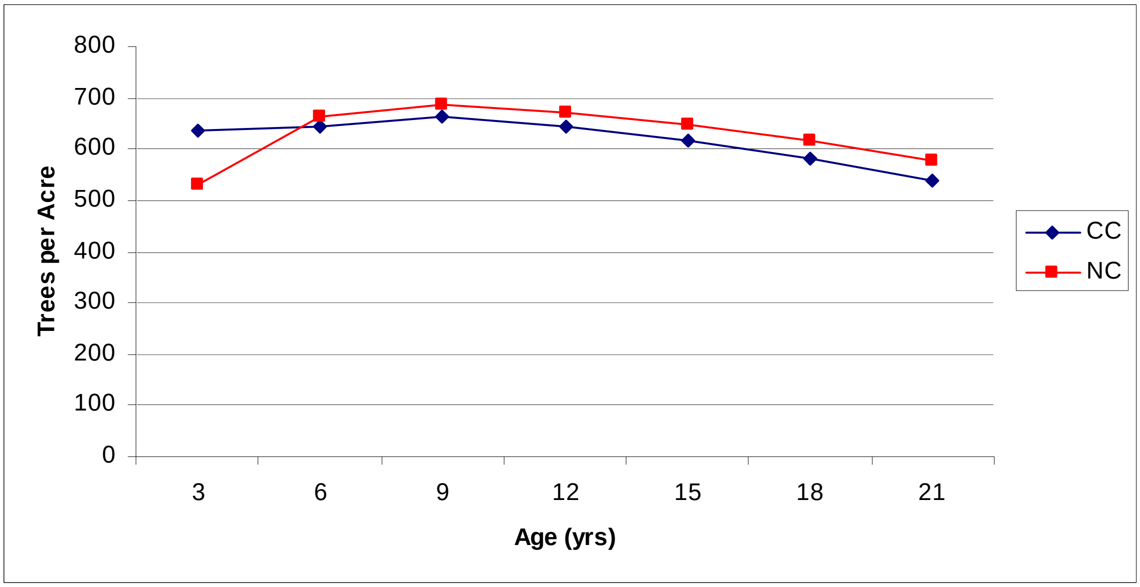

Figure 32. Mean trees per acre of slash pine by age for complete competition control (CC) and without complete competition control (NC) across genetic treatments through age 21.

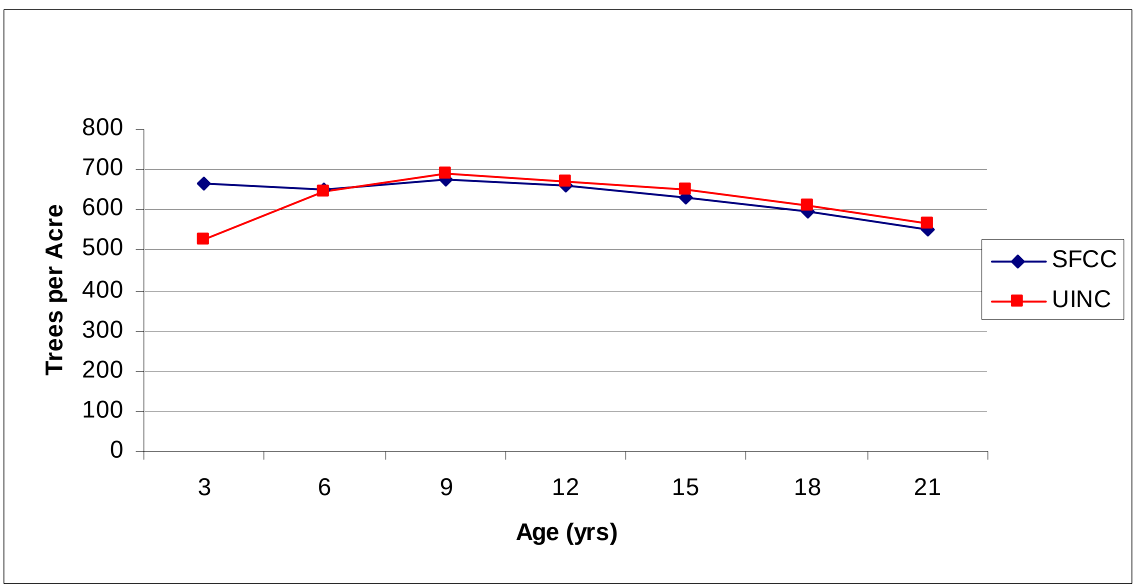

Figure 33. Mean trees per acre of slash pine by age for contrasting treatments of improved single family genetics with complete competition control (SFCC) and unimproved genetics without complete competion control (UNINC) through age 21.

4.6 Stand Density Index

Stand density index trends through age 21 by genetics main effects (Figure 34), competition control main effects (Figure 35), and for contrasting treatment combinations (Figure 36) are shown below.

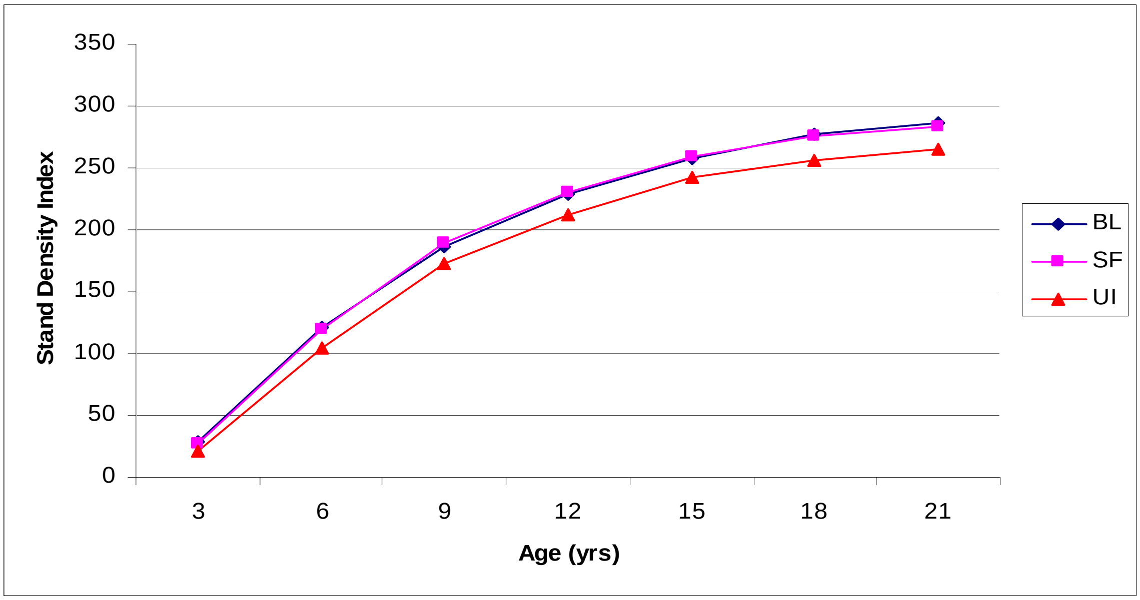

Figure 34. Stand density index of slash pine by age for improved bulk lot (BL), improved single family (SF), and unimproved plantings (UI) across competition control treatments through age 21.

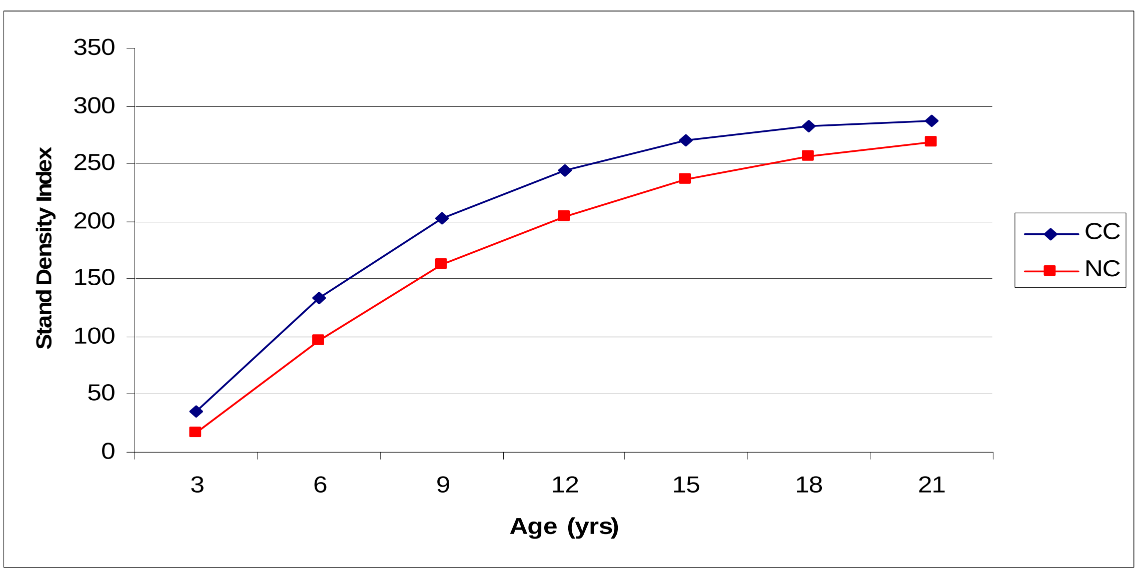

Figure 35. Stand density index of slash pine by age for complete competition control (CC) and without complete competition control (NC) across genetic treatments through age 21.

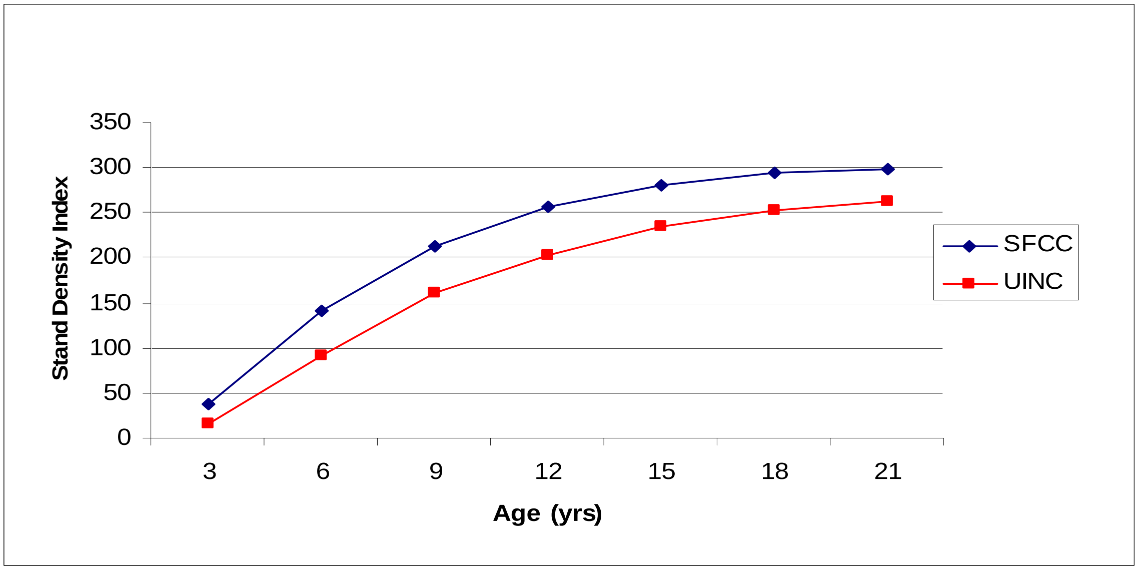

Figure 36. Mean stand density index of slash pine by age for contrasting treatments of improved single family genetics with complete competition control (SFCC) and unimproved genetics without complete competion control (UNINC) through age 21.

4.7 Relative Spacing

Relative spacing trends through age 21 by genetics main effects (Figure 37), competition control main effects (Figure 38), and for contrasting treatment combinations (Figure 39) are shown below.

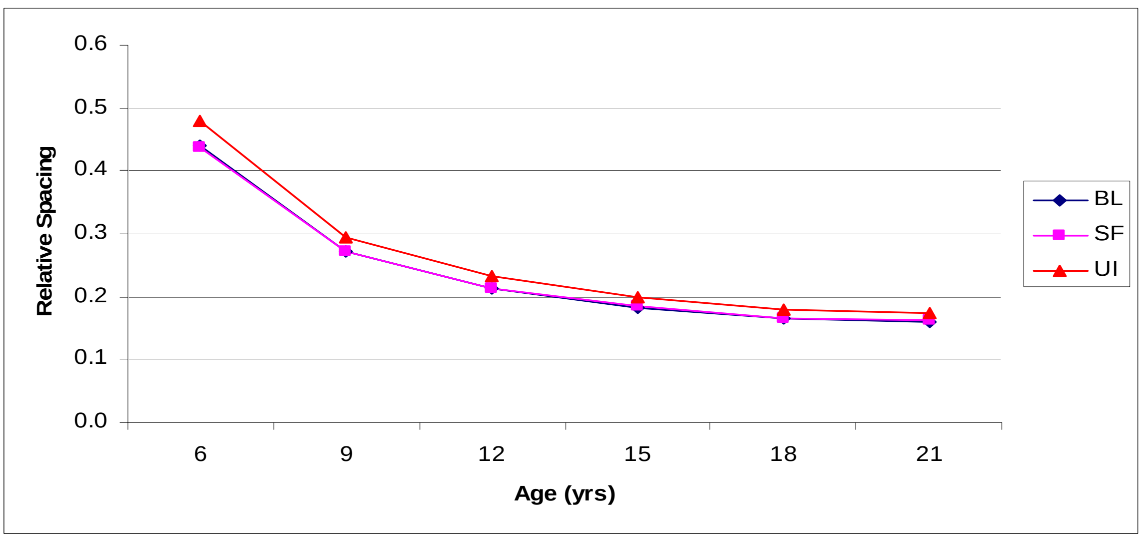

Figure 37. Relative spacing of slash pine by age for improved bulk lot (BL), improved single family (SF), and unimproved (UI) plantings across competition control treatments through age 21.

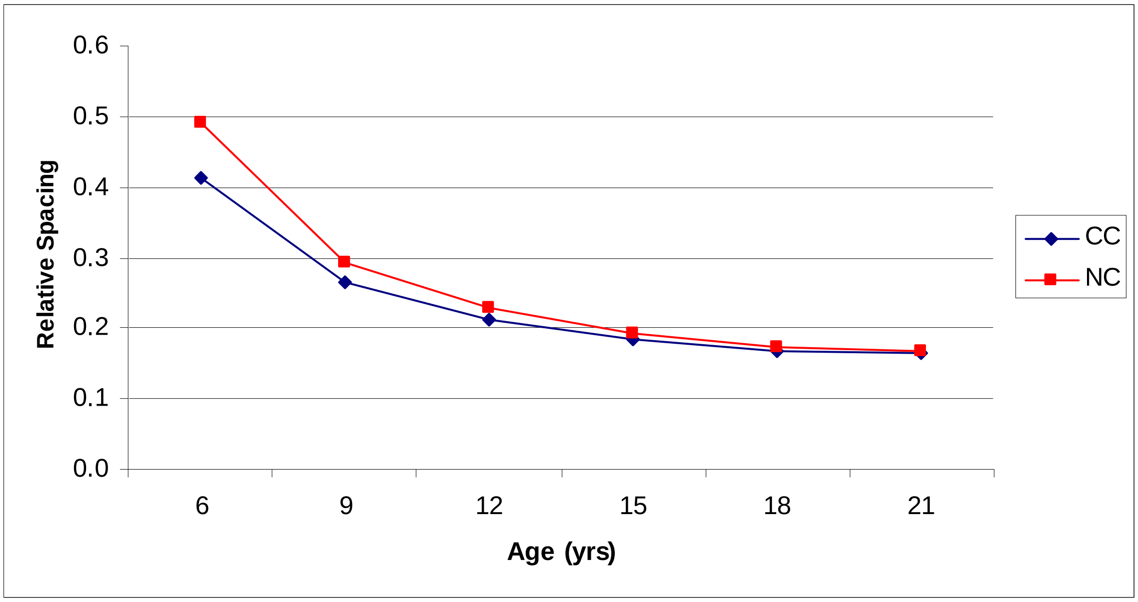

Figure 38. Relative spacing of slash pine by age for complete competition control (CC) and without complete competition control (NC) across genetic treatments through age 21.

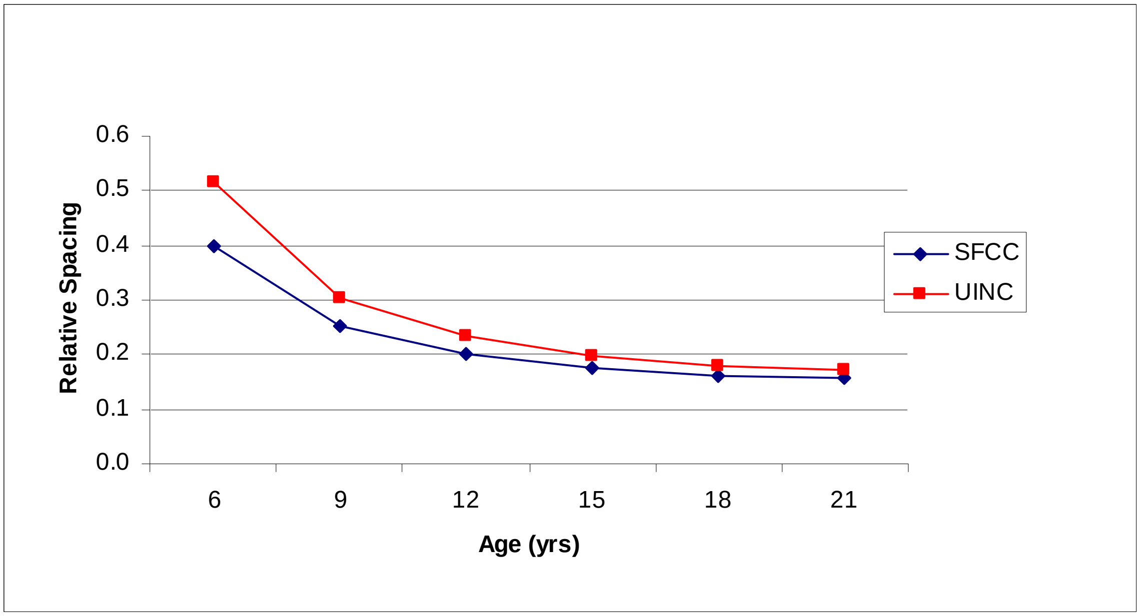

Figure 39. Mean relative spacing of slash pine by age for contrasting treatments of improved single family genetics with complete competition control (SFCC) and unimproved genetics without complete competion control (UNINC) through age 21.

5. STATISTICAL SIGNIFICANCE OF GENETIC AND COMPETITION CONTROL MAIN EFFECTS AND INTERACTION ON PERIODIC GROWTH

5.1 Statistical Tests for Genetic and Competition Control Main Effects and Interactions in Periodic Growth from Ages 15 to 18 and from Ages 18 to 21

Periodic growth in per acre basal area, volume and green weight between ages 15 and 18 years was significantly greater for the improved plantings as compared to that for the unimproved plantings (Table 38). For this period, the positive effect of improved genetics contrasts with less basal area per acre growth for stands receiving complete vegetation control than stands without complete competition control. Periodic growth between ages 18 and 21 was not significantly affected by treatment except for the continued trend of less basal area growth in stands with complete competition control compared to those without complete competition control (P=0.10)

Table 38. Summary of results from statistical analysis of periodic increment of slash pine between the ages of 15 and 18 years.

	Effect			
Periodic Growth Attribute	Genetics (G)	Competition Control (CC)	G x CC Interaction	Comment
	Prob. > F[a]			
Average DBH	NS	(0.11)	NS	Complete vegetation control had less growth than not complete control
Average Dominant Height	NS	NS	NS	
Average Basal Area per Acre	(0.06)	*	NS	Improved genetics had greater growth than unimproved genetics Complete vegetation control had less growth than not complete control.
Total O.B. Volume per Acre	*	NS	NS	Improved genetics had greater growth than unimproved.
Merchantable O.B. Volume per Acre	*	NS	NS	Improved genetics had greater growth than unimproved.
Total O.B. Green Weight per Acre	*	NS	NS	Improved genetics had greater periodic growth than unimproved.
Merchantable O.B. Green Weight per Acre	*	NS	NS	Improved genetics had greater periodic growth than unimproved

[a] * indicates significance at alpha = 0.05; number in parenthesis indicates significance at alpha between 0.05 and 0.20; NS indicates not significant at alpha=0.20.

Table 39. Summary of results from statistical analysis of periodic increment of slash pine between the ages of 18 to 21 years.

	Effect			
Periodic Growth Attribute	Genetics (G)	Competition Control (CC)	G x CC Interaction	Comment
	Prob. > F[a]			
Average DBH	NS	NS	NS	
Average Dominant Height	NS	NS	NS	
Average Basal Area per Acre	NS	(0.10)	NS	Complete vegetation control had less growth than not complete control.
Total O.B. Volume per Acre	NS	NS	NS	
Merchantable O.B. Volume per Acre	NS	NS	NS	
Total O.B. Green Weight per Acre	NS	NS	NS	
Merchantable O.B. Green Weight per Acre	NS	NS	NS	

[a] * indicates significance at alpha = 0.05; number in parenthesis indicates significance at alpha between 0.05 and 0.20; NS indicates not significant at alpha=0.20.

5.2 Trends in Statistical Significance of Genetic and Competition Control Main Effects on Periodic Growth through Age 21

Temporal patterns in statistical significance of responses differed between the genetic and competition control main effects (Table 40). Periodic gains from improved planting stock occurred over a more extended period during the rotation as compared to periodic gains from complete competition control that were more marked during earlier periods. These patterns reflect both the nature of the treatments as well as their relative effects on the rate of stand development. The improved genetic material has desirable growth attributes that persist throughout the rotation and have had a relatively moderate impact on stand development and stand stocking. In contrast, the complete competition control treatment, while increasing site resources available to the pine component throughout the rotation, had the greatest relative impact on resource availability earlier in the rotation. Additionally, the large early responses resulting from competition control has significantly impacted stocking to a degree that basal area growth in stands with this treatment was actually less than that observed in stands without complete competition control between the ages of 15 to 21 years.

Table 40. Summary of slash pine response patterns to genetic improvement and complete competition control in periodic growth through age 21[a].

	Treatment	
Periodic Growth Attribute	Genetic Improvement (GI)	Complete Competition Control (CC)
	Period and Treatment Performance	
Average Dbh	0 to 12 yrs; Improved = Unimproved 12 to 15 yrs; Improved < Unimproved 15 to 21 yrs; Improved = Unimproved	0 to 6 yrs; Complete > Not Complete 6 to 21 yrs; Complete = Not Complete
Average Dominant Height	0 to 12 yrs; Improved > Unimproved 12 to 15 yrs; GI x CC Interaction[b] 15 to 21 yrs; Improved = Unimproved	0 to 6 yrs; Complete > Not Complete 6 to 12 yrs; Complete = Not Complete 12 to 15 yrs; GI x CC Interaction[b] 15 to 21 yrs; Complete = Not Complete
Basal Area per Acre	0 to 15 yrs; Improved = Unimproved 15 to 18 yrs; Improved > Unimproved (0.06) 18 to 21 yrs; Improved = Unimproved	0 to 9 yrs; Complete > Not Complete 9 to 15 yrs; Complete = Not Complete 15 to 21 yrs; Complete < Not Complete (0.10)
Volume or Weight per Acre	0 to 12 yrs; Improved > Unimproved 12 to 15 yrs; Improved = Unimproved 15 to 18 yrs; Improved > Unimproved 18 to 21 yrs; Improved = Unimproved	0 to 15 yrs; Complete > Not Complete 15 to 21 yrs; Complete = Not Complete

[a] alpha=0.05 for detecting treatment differences in periodic growth unless otherwise indicated.

[b] Periodic height growth was greatest with the improved bulk planting in the absence of complete competition control and least with the unimproved planting in the presence of complete competition control.

6. RESPONSES TO GENETIC IMPROVEMENT ALONE, COMPETITION CONTROL ALONE AND THEIR COMBINATION

6.1 Cumulative Mean Responses to Genetically Improved Plantings Alone, Complete Competition Control Alone, and their Combination with Age through 21 Years

Cumulative mean response patterns through 21 years to genetically improved plantings alone, complete competition control alone, and the combination of genetically improved plantings and complete competition control in mean dbh, mean dominant height, basal area per acre, and total stem green tons per acre are presented in Figures 40, 41, 42, and 43, respectively. Mean responses to the genetically improved plantings and complete competition control combination were markedly greater than the summation of the responses from the individual treatments (genetic improvement or complete vegetation control), especially at later ages. This pronounced trend contrasts with the general lack of statistically significant genetic by competition control interactions reported both in the current report as well as in earlier reports (Logan and Shiver 2003). The results from these different analyses suggest that responses to genetic improvement and competition control will be at least additive and likely more than additive especially at later ages.

Mean absolute response in dominant height to genetically improved plantings alone reached a plateau by about age 15. As indicated from the statistical tests discussed earlier, there was not a marked response in dbh due to genetically improved plantings. Absolute responses to competition control alone peaked at 6, 9, 9, and 15 for mean dbh, mean dominant height, basal area per acre, and tons per acre, respectively. The response to the genetically improved planting and complete competition control combination in dominant height, basal area per acre and tons per acre was of greater magnitude and approximated maximum values at later ages than expected based on the responses observed for improved plantings alone and competition control alone.

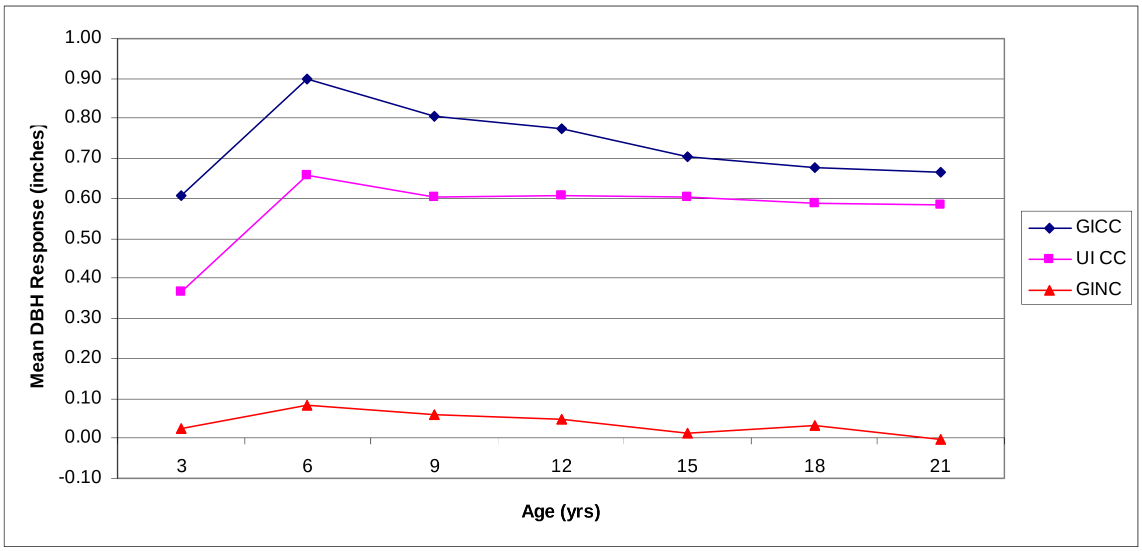

Figure 40. Slash pine cumulative response in mean dbh by age to genetic improvement alone (GINC), complete competition control alone (UICC), and the combination of genetic improvement and complete competiton control (GICC) through age 21. The base treatment for calculating response was the genetically unimproved planting without complete competition control.

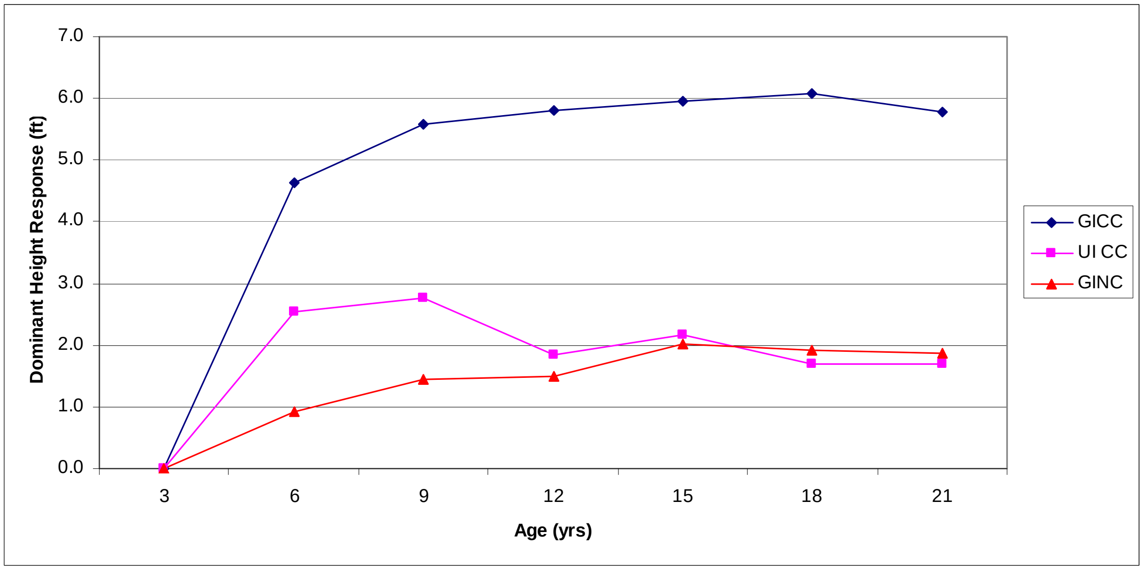

Figure 41. Slash pine cumulative response in mean height by age to genetic improvement alone (GINC), complete competition control alone (UICC), and the combination of genetic improvement and complete competiton control (GICC) through age 21. The base treatment for calculating response was the genetically unimproved planting without complete competition control.

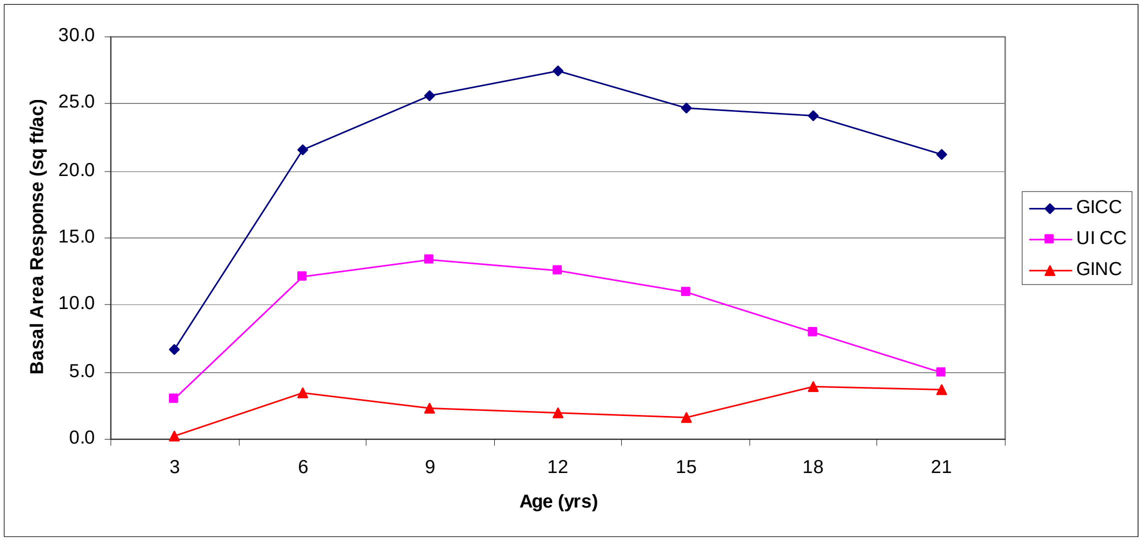

Figure 42. Slash pine cumulative response in basal area per acre by age to genetic improvement alone (GINC), complete competition control alone (UICC), and the combination of genetic improvement and complete competiton control (GICC) through age 21. The base treatment for calculating response was the genetically unimproved planting without complete competition control.

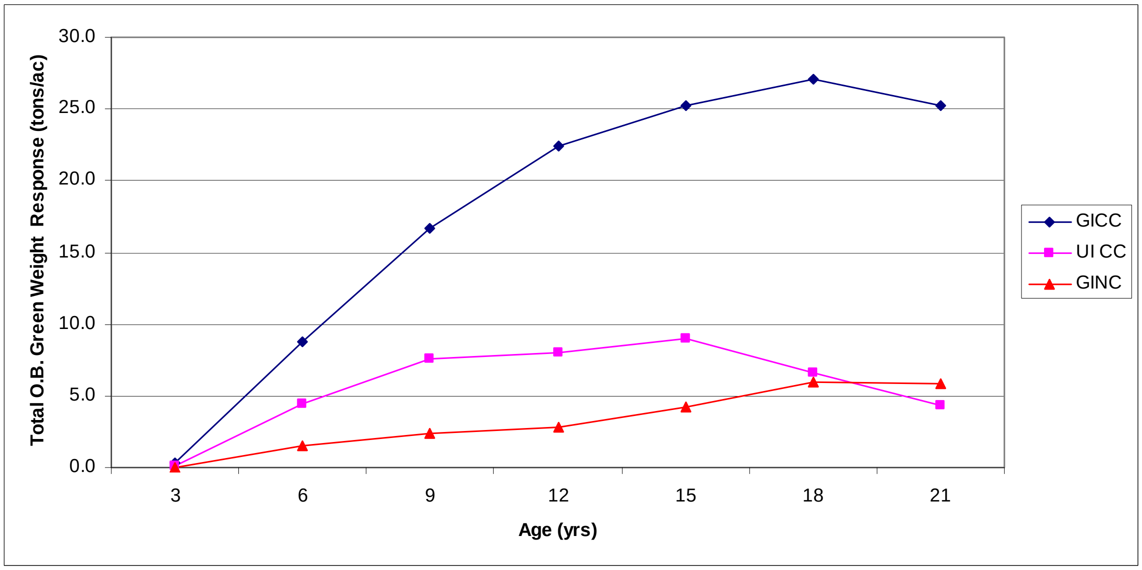

Figure 43. Slash pine cumulative response in total o. b. green weight per acre by age to genetic improvement alone (GINC), complete competition control alone (UICC), and the combination of genetic improvement and complete competiton control (GICC) through age 21. The base treatment for calculating response was the genetically unimproved planting without complete competition control.

6.2 Periodic Annual Responses to Genetically Improved Plantings Alone, Complete Competition Control Alone and their Combination with Age through 21 Years

Periodic annual responses to genetically improved plantings alone, complete competition control alone, and the combination of improved plantings and complete competition control in mean dbh, mean dominant height, basal area per acre, and total stem green tons per acre increment are presented in Figures 44, 45, 46, and 47, respectively. Periodic annual responses in mean dbh, mean dominant height and basal area per acre to the individual treatments and their combination peaked during the ages of 1 to 3 years, 4 to 6 years and 4 to 6 years, respectively. Periodic annual responses in tons per acre growth to complete competition control and the combination of complete competition control and genetic improvement peaked during the period 4 to 6 years of age while the response to genetic improvement alone remained at a relatively stable though low level between the ages of 4 and 18 years.

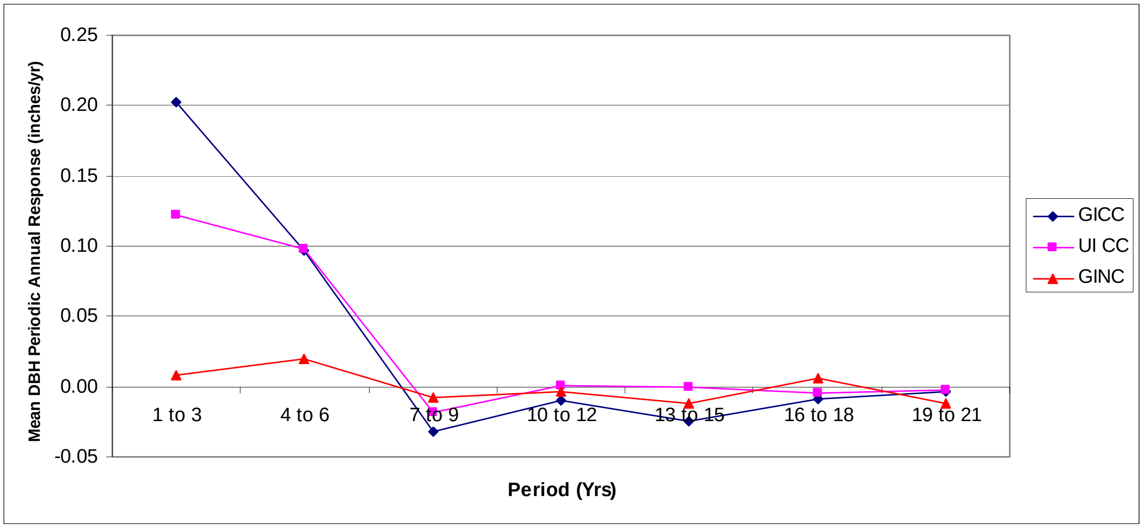

Figure 44. Slash pine periodic annual response in mean dbh increment by age to genetic improvement alone (GINC), complete competition control alone (UICC), and the combination of genetic improvement and complete competiton control (GICC) through age 21. The base treatment for calculating response was the genetically unimproved planting without complete competition control.

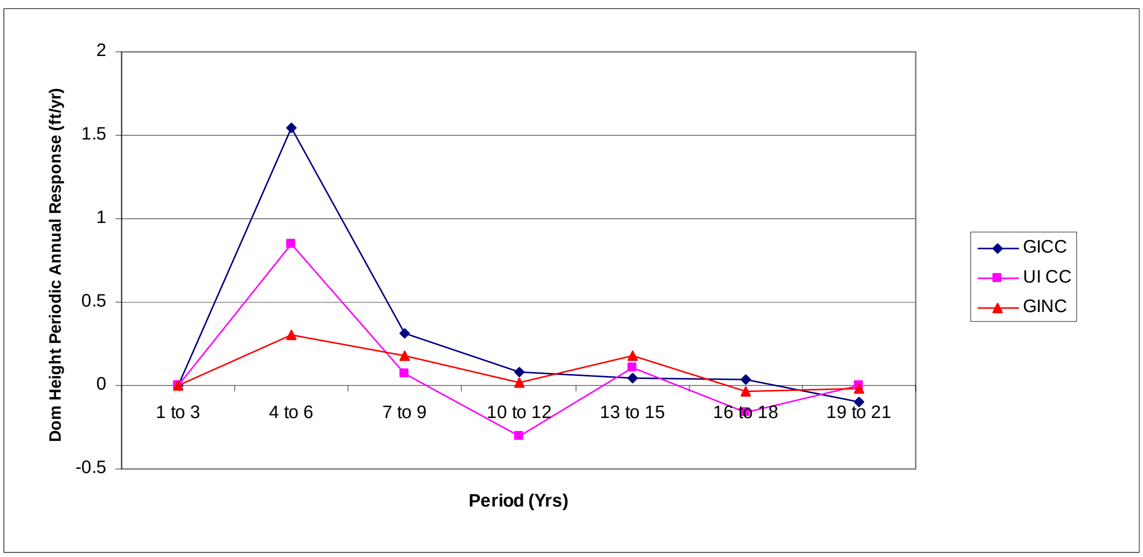

Figure 45. Slash pine periodic annual response in mean dominant height increment by age to genetic improvement alone (GINC), complete competition control alone (UICC), and the combination of genetic improvement and complete competiton control (GICC) through age 21. The base treatment for calculating response was the genetically unimproved planting without complete competition control.

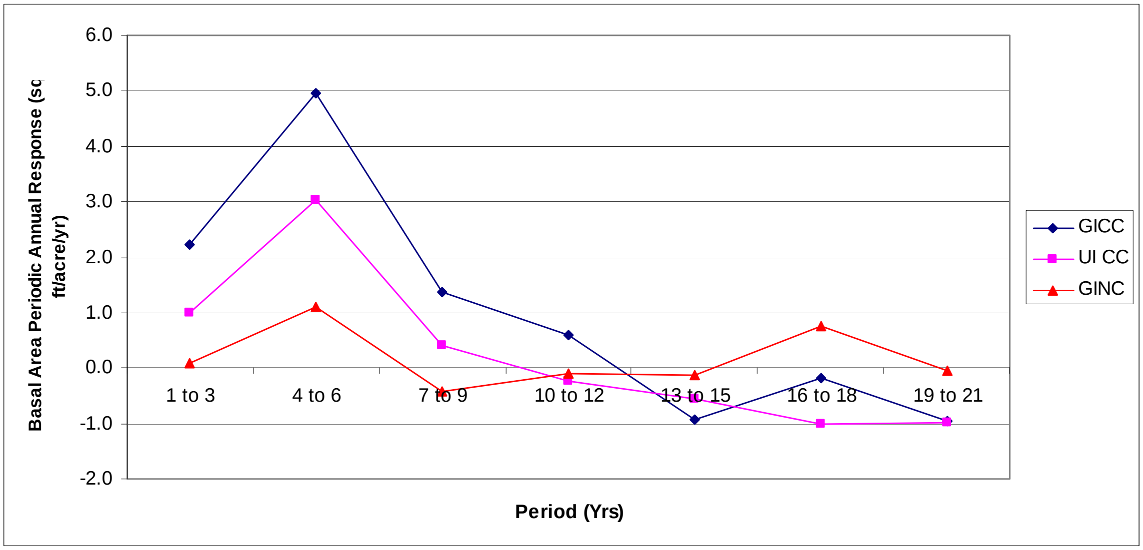

Figure 46. Slash pine periodic annual response in basal area per acre increment by age to genetic improvement alone (GINC), complete competition control alone (UICC), and the combination of genetic improvement and complete competiton control (GICC) through age 21. The base treatment for calculating response was the genetically unimproved planting without complete competition control.

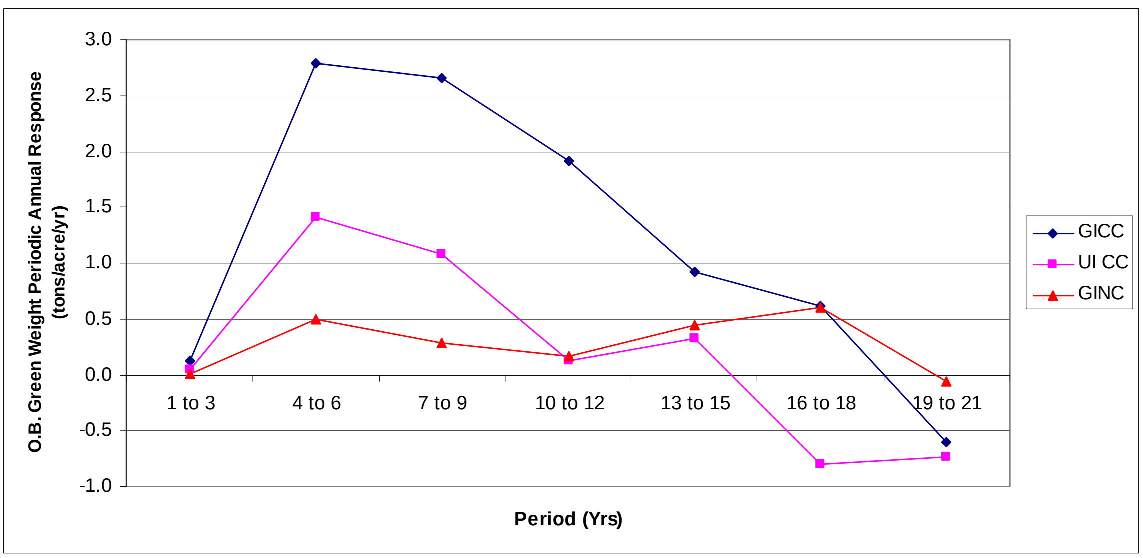

Figure 47. Slash pine periodic annual response in total o. b. green weight per acre ..increment by age to genetic improvement alone (GINC), complete competition control alone (UICC), and the combination of genetic improvement and complete competiton control (GICC) through age 21. The base treatment for calculating response was the genetically unimproved planting without complete competition control.

7. DISCUSSION

Results through age 21 show that genetic improvement and complete competition control applied alone or in combination provide significant, long-term gains in slash pine plantation productivity. The age 21 results build on those reported through age 15 by Logan and Shiver (2003).

Productivity gains from block plantings of first generation improved slash pine either deployed as single family plantings or mixtures of families, averaged 12 tons green weight per acre across the competition control treatments. This represents a gain of 13% over that observed for the unimproved plantings. The gain in total volume was 376 ft^3/acre or 12.2% more than that observed without genetic improvement. This level of gain is very similar to the 14% volume gain reported for seed planted extensively during the 1975 to 1995 period from 1.0 generation, rogued orchards in the Cooperative Forest Genetics Research Program (White and Byram, 2004).

The improved, first generation, slash pine plantings markedly increased rust resistance. At 21 years of age, 11.2% of improved trees had a stem infection as compared to 18.9% of unimproved trees with stem infections. This represents a 41% reduction in the incidence of trees with stem infections and is substantially greater than the 18% reduction estimate (assuming a 50% infection rate for unimproved plantings) across multiple seed orchards as reported by White and Byram (2004). The particularly marked improvement in rust resistance in this study probably reflects the emphasis on rust resistance in the family selection process.

The genetic gains reported reflect the level of genetic improvement for the families available and planted during the mid-1980s. Genetic gains from seed available after 2002 from advanced generation orchards are much greater than those from first generation orchards. Gains from advanced generation orchards over unimproved seed are on the order of 30% in volume and 60% in less rust infestations (assuming 50% rust incidence for unimproved trees) (White and Byram, 2004).

The similar performance of the improved first generation slash pine deployed in single family blocks or blocks of intimate family mixtures indicates that managers have considerable flexibility in deployment approaches for similar genetic material. This result contrasts with that reported by Roth et al. (2007) for full-sib slash pine at age 5 where there was a trend in greater (3%) per acre basal area, stem volume and aboveground biomass in mixed family plantings as compared to single family plantings. The authors proposed that differential pest or environmental stress between the mixed and single family plots may explain the observed difference. As with the results from the present study, loblolly pine performance in single family blocks and intimate family mixtures were similar for half-sib families at age 21 (Kane and Harrison, 2008) and full-sib families at age 5 (Roth et al., 2007).

Complete and sustained competition control during the life of the study resulted in pronounced and persistent improvements in slash pine productivity. At age 21, gains from complete competition control across genetic treatments averaged 16 tons per acre or 17% relative to that without the complete competition control. These gains compare to those to complete competition control of about 16 and 32 tons/acre at age 20 on non-Spodosols and Spodosols, respectively, for slash pine in the PMRC Slash Pine Flatwoods Site Preparation Study (Zhao et al., 2009). Loblolly pine, in a companion study to that reported here, showed a 29 ton per acre increase (24%) due to complete competition control at age 21 in the Coastal Plain (Kane and Harrison, 2008). Other studies have documented consistent slash pine productivity gains from either competition control during site preparation and in young plantations (Zhao et al., 2008) or from mid-rotation release (Oppenheimer et al., 1989). While the research approach of repeated herbicide applications to achieve complete and sustained competition control in the present study is not realistic on an operational scale, operationally efficient regimes including mechanical and chemical site preparation and targeted herbaceous weed control and woody control treatments during the rotation can result in excellent, rotation length competition control and substantial productivity responses.

Complete competition control significantly increased rust incidence and reduced stem quality. At age 21, rust incidence was 16% in stands with complete competition control as compared to 11% in stands without complete competition control. Stands with complete competition control showed a significant if modest increase in the percentage of forked trees and the percentage of trees with crook or sweep. The percentage of defect-free trees was less for stands with complete competition control (23.1%) than for stands without complete competition control (32.4%). The increase in rust levels associated with complete competition control in this study is similar to results from the PMRC Slash Pine Site Preparation Study where at age 20 years, stem rust incidence was 21% and 12% for slash pine with and without complete competition control, respectively, on plots that had been chopped, burned and bedded (Zhao et al., 2007).

The lack of consistent, statistically significant, genetic treatment by competition control treatment interactions and the trend at older ages for productivity gains to be greater for the genetically improved planting and complete competition control combination than that expected from the responses to genetic improvement and complete competition control alone, indicate that managers can combine similarly improved genetic stock with aggressive competition control and expect to received the full benefits of both the genetic improvement and the competition control, and perhaps some additional gain. The trend at later ages of greater than additive responses to genetic improvement and complete competition control is consistent with the observation that the growth advantage of superior genotypes relative to inferior genotypes increases as site productivity increases (McKeand et al., 2006). The lack of statistically significant genetic by competition control interactions is consistent with past studies that suggest that significant genetic by environment (silviculture) interactions have not been of major importance given the genotypes deployed and the silvicultural systems implemented (McKeand et al., 2006). After reviewing literature on genetic by environment interactions, Roth et al. (2007) concluded that it appears that the interaction may become significant only under extremes in seed source movement and/or site productivity and that relatively few genotypes from the population may contribute to this response. However, the likelihood of significant genotype by environmental interactions increases as managers deploy full-sib families or clones, especially under increased silvicultural intensity (McKeand et al., 2006). Significant genotype by silvicultural treatment intensity interactions were found for both slash pine and loblolly pine using elite full-sib families and contrasting silvicultural intensities with the best overall performing families responding the greatest to intensive treatment (Roth et al., 2007).

Temporal patterns in response to genetic improvement alone, complete competition control alone, and the genetic improvement – complete competition control combination varied markedly. Responses to genetic improvement alone generally increased with age, responses to competition control alone generally peaked and thereafter declined substantially, and responses to the improved genetics – complete competition control combination peaked at a relatively high level at later ages and thereafter declined modestly. Temporal patterns of responses to complete competition control observed in this study were consistent with those observed in the PMRC Slash Pine Flatwoods Site Preparation Study (Zhao et al. 2009).

The cumulative effect of early growth gains for both genetically improved planting and complete competition control is that, at a given age, treated stands are at a more advanced stage of stand development with more intra-specific competition than stands with unimproved genetic stock and/or without complete competition control. By age 21, basal area was 140 ft^2/acre for stands with improved genetics and complete competition control and 118 ft^2/acre for stands with unimproved genetics and without complete competition control. Stand density index on improved stock and complete vegetation control plots was 298 (75% of maximum SDI) as compared to 262 (66% of maximum SDI) on plots without genetic improvement or complete competition control. Cumulative basal area per acre has probably approached its maximum at age 21. In the PMRC Slash Pine Flatwoods Study, planted at 545 trees/acre, basal area on plots that were only chopped, burned, and bedded appeared to peak at between 115 and 130 ft^2/acre while those on plots with similar site preparation plus complete and sustained competition control reached between 140 to 150 ft^2/acre at the final measurement of age 26 (Zhao et al., 2007). Through age 12 years in the PMRC Coastal Plain Culture Density Study, slash pine cumulative basal area appeared to reach a plateau at about 140 ft^2/acre for the 900 and 1500 tree/acre planting densities combined with intensive culture (complete and sustained competition control and frequent fertilization) and for the 1500 tree/acre planting density combined with operational culture (good operational competition control and fertilization) (Kane, PMRC summary data).

The growth patterns reported are for nonthinned stands that may or may not have received any fertilization. Both thinning and post-establishment fertilization are relatively common practices in slash pine plantation silviculture. By age 21, intra-specific competition was present and nutrient limitations were likely limiting stand productivity at some locations. Slash pine plantations growing in the Flatwoods of Florida and Georgia often respond positively in growth to fertilization (Fisher and Garbett, 1980; Jokela et al., 2000; Zhao et al., 2009). Age 21 mean dominant heights in the present study were 54 feet and 58 feet for the improved genetics without complete competition control treatment and the improved genetics with complete competition control treatment, respectively. This is comparable to age 20 mean dominant heights of 53 feet and 58 feet for the chop, burn and bed treatment and the chop, burn, bed, and complete competition control treatment, respectively, on the PMRC Slash Pine Flatwoods Site Preparation Study. In the site preparation study, a fertilization regime (fertilization at ages 1, 12, and 17 years) increased age 20 dominant height by 7 feet and 5 feet for chopped, burned, and bedded plots and for plots that were chopped, burned, bedded and received complete competition control, respectively.

The response patterns observed in this study can inform development of models for predicting responses from genetic improvement and vegetation management at similar levels to those examined and to their combination. Dominant height gains from genetic improvement alone followed a Type B response pattern; absolute gains in dominant height reached their maximum by about age 15 and were thereafter maintained. Responses to complete competition control alone followed a Type C response pattern; absolute gains in dominant height reached their maximum by about age 9 and thereafter showed a slight decline. Basal area response patterns for the individual treatments are similar to those for dominant height. For the combination of genetic improvement and complete vegetation control, both dominant height and basal area response followed a Type B pattern. Maximum dominant height response was achieved by about age 18 years and maximum per acre basal area response was attained at about age 12 years.

8. CONCLUSIONS

Conclusions are based on results through 21 years of age for slash pine plantations in the Flatwoods of Florida and Georgia that had not been thinned and with uncertain fertilization history.

Observed productivity gains (13% in green weight) from slash pine first generation improved stock planted in block plots were very similar to expected genetic gains for this population. This result provides assurance to forest managers that genetic gain estimates developed using similar approaches to those for the subject population of this report are applicable to performance of similar genetic material in block plantings. Observed gains in rust resistance (41% reduction in stem infestations) were greater that those expected.

Single family blocks and mixed family blocks demonstrated similar performance in productivity, rust resistance, and quality. This suggests that managers have considerable flexibility in deployment strategies for genetic populations with similar attributes to those examined in this study.

Effective and sustained competition control provides consistent, substantial and persistent slash pine plantation productivity gains on flatwoods sites. Complete competition control increased slash pine plantation productivity by an average of 16 green tons/acre (17%) across genetic treatments. Complete competition control resulted in modest increases in rust incidence and decreases in tree quality.

Managers can combine similarly improved genetic stock with aggressive competition control and expect to receive the full benefits of both the genetic improvement and the competition control, and perhaps some additional gain. While the statistical analysis performed did not detect significant interactions between genetic improvement and competition control treatments for tree and stand attributes, trends in responses to genetically improved plantings alone, competition control alone, and their combination suggest that responses to the combination treatment are greater than that expected from the responses observed when genetic improved plantings and complete competition control are implemented without the other. This trend was most evident at the older ages evaluated.

Temporal patterns in response to genetic improvement alone, complete competition control alone, and the genetic improvement – complete competition control combination varied markedly.

Responses to genetic improvement alone generally increased with age, responses to competition control alone generally peaked and thereafter declined substantially, and responses to the improved genetics – complete competition control combination peaked at a relatively high level at later ages and thereafter declined modestly.

The response patterns observed in this study can inform development of models for predicting responses from genetic improvement and vegetation management at similar levels to those examined and to their combination.

The individual treatments and their combinations did not affect age 21 diameter distribution attributes of dbh range, skewness, and kurtosis suggesting that specific adjustments are not required for diameter distribution estimation.

9. LITERATURE CITED

Fisher, R. F. and W. S. Garbett. 1980. Response of semimature slash and loblolly pine plantations to fertilization with nitrogen and phosphorus. SSSAJ 44:850-854.

Fox, T. R., E. J. Jokela, and H. L. Allen. 2007. The development of pine plantation silviculture in the southern United States. J. For. 105(7):337-347.

Jokela, E. J., D. S. Wilson, and J. E. Allen. 2000. Early growth responses of slash and loblolly pine following fertilization and herbaceous weed control treatments at establishment. South. J. Appl. For. 24(1):23-30.

Kane, M. B. and W. M. Harrison. 2008. Loblolly pine improved planting stock-vegetation control study: Age 21 results. UGA Warnell School of Forestry and Natural Resources. PMRC Technical Report 2008-2. 84 pp.

Lauer, D. K. and G. R. Glover. 1998. Early pine response to control of herbaceous and shrub vegetation in the flatwoods. South. J. Appl. For. 22(4):201-208.

Logan, S. R. and B. D. Shiver. 2003. Slash pine improved planting stock-vegetation control study: Age 15 results. UGA Warnell School of Forestry and Natural Resources. PMRC Technical Report 2003-2. 27 pp.

McKeand, S. E., E. J. Jokela, D. A. Huber, T. D. Byram, H. L. Allen, B. Li, and T. Mullin. 2006. Performance of improved genotypes of loblolly pine across different soils, climates and silvicultural inputs. For. Ecol. Manag. 227:178-184.

Oppenheimer, M. J., B. D. Shiver, and J. W. Rheney. 1989. Ten-year growth response of midrotation slash pine plantations to control of competing vegetation. Can. J. For. Res. 19:239-334.

Pienaar, L.V., Burgan T., and Rheney, J.W., 1987. Stem volume, taper, and weight equations for site-prepared loblolly pine plantations. Univ of Ga., School of Forest Resources PMRC Res. Pap. 1987-1. Univ. of Ga., Athens, GA. 11 pp.

Reineke, L.H., 1933. Perfecting a stand density index for even-aged forests. Jour. Agric. Res. 46: 627-683.

Roth, B. E., E. J. Jokela, T. A. Martin, D. A. Martin, D. A. Huber, and T. L. White. 2007. Genotype x environment interactions in selected loblolly and slash pine plantations in the southeastern United States. For. Ecol. Manag. 238:175-188.

Shepard, J. P., J. Creighton, and H. Duzan. 2004. Forestry herbicides in the United States: An overview. Wildlife Society Bulletin 32(4):1020-1027.

White, T. L. and T. D. Byram. 2004. Slash pine tree improvement. In: Dickens, E. D., J. P. Barnett, W. G. Hubbard, and E. G. Jokela (eds.). Slash pine: still growing and growing! Proceedings of the slash pine symposium. Gen. Tech. Rep. SRS-76. Asheville, NC, U.S. Department of Agriculture, Forest Service. Southern Forest Research Station. 148 p.

Yeiser, H. L. and A. W. Ezell. 2004. Competition control in slash pine (Pinus elliottii Englelm.) plantations. In: Dickens, E. D., J. P. Barnett, W. G. Hubbard, and E. G. Jokela (eds.). Slash pine: still growing and growing! Proceedings of the slash pine symposium. Gen.

Tech. Rep. SRS-76. Asheville, NC, U.S. Department of Agriculture, Forest Service. Southern Forest Research Station. 148 p.

Zhao, D., M Kane, B. Borders, and M. Harrison. 2007. Slash pine site preparation study: Age 26 results. UGA Warnell School of Forestry and Natural Resources. PMRC Technical Report 2007-3. 63 pp.

Zhao, D., M Kane, B. Borders, and M. Harrison. 2008. Pine growth response to different site preparation methods with or without post-plant herbaceous weed control in North Florida's Lower Coastal Plain. For. Ecol. Manag. 255:2512-2523

Zhao, D., M Kane, B. Borders, and M. Harrison. 2009. Long-term effects of site preparation treatments, complete competition control, and repeated fertilization on growth of slash pine plantations in the Flatwoods of the southeastern United States. For. Sci. 55(5):403-410.