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

Plantation Management Research Cooperative

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EXECUTIVE SUMMARY

A designed experimental study was established at multiple locations in the Coastal Plain region of Georgia and northern Florida, and the Piedmont region of South Carolina, Georgia and Alabama with the objective of evaluating the impacts of first generation genetic improvement, and of combining genetic improvement and complete vegetation control on yields of loblolly pine. 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 (bulk lot). The two levels of competition control were either none other than that provided by the operational site preparation or complete and sustained control. Results at age 21 for active installations in the Coastal Plain (10 installations) and Piedmont (10 installations) are the subject of this report. Detailed results are presented for age 21 tree and stand attributes as well as periodic growth from ages 18 to 21 years. Trends in plantation performance by treatment during the 21-year period using installations active at each measurement period are presented.

A mixed model approach was used to analyze the age 21 measurements for this study and the 3-yr periodic growth from ages 18 to 21 years. Installation and all installation interactions were treated as random factors and competition control and genetics were treated as fixed factors. Treatment effects were considered significant at alpha=0.05. Previous reported analysis supplemented the current analysis to examine temporal patterns of response to genetic improvement and complete vegetation control.

At age 21, both genetic improvement and competition control significantly increased loblolly pine plantation productivity in both the Coastal Plain and the Piedmont. Effects of genetic improvement and competition control on tree and stand attributes at age 21 years were additive; responses to genetic improvement were similar for operational site preparation plantings and complete competition plantings and responses to complete vegetation control were similar across the genetic treatments tested. Deployment of improved, first generation stock in single family blocks or bulk lot family mixtures yielded similar plantation performance.

In the Coastal Plain, age 21 total green weight was 114, 137, 123, and 155 tons/acre for the unimproved and operational site preparation, unimproved and complete competition control, improved stock and operational site preparation, and improved stock and complete competition control treatments, respectively. The gain from improved genetic stock across competition control treatments was 13 tons per acre (11%). The response to complete competition control was 29 tons per acre (24%). Genetically improved trees had significantly greater average and dominant height as compared with unimproved trees. Differences in mean diameter between unimproved and improved stock were not significant. Complete competition control significantly increased average tree height and diameter. Complete competition control accelerated stand development as indicated by significantly lower trees per acre (587 vs 616), higher stand density index (365 vs 331) and lower relative spacing (0.141 vs 0.149) on complete competition control plots as compared with operational site preparation only plots. Genetic improvement significantly improved tree health and quality. Plantings with improved stock had a lower incidence of trees with fusiform rust stem galls (9.4% vs 20.6%) and crook or sweep (51.5% vs 68.5%) and a higher proportion of defect-free trees (42.4% vs 23.1%) as compared to plantings with unimproved stock. Complete competition control did not significantly affect tree quality attributes in the Coastal Plain.

Temporal response patterns in the Coastal Plain varied for genetic and competition control effects. The improved stock used in this study increased height growth and volume and weight yields but did not increase tree dbh or per acre basal area. Gains from improved genetics increased through age 12 and were maintained thereafter through age 21. In contrast, complete competition control increased tree height and dbh growth as well as per acre basal area, volume, and weight. Responses to complete competition control generally approached their maximum for dbh and height at age 6, for per acre basal area at age 9, and for per acre volume and weight at

age 12. Thereafter, cumulative responses tended to decline somewhat with the exception of per acre volume and weight which showed no significant decline in cumulative response with increasing age.

In the Piedmont, age 21 total green weight was 112, 143, 138, and 158 tons/acre for the unimproved and operational site preparation, unimproved and complete competition control, improved stock and operational site preparation only, and improved stock and complete competition control treatments, respectively. The gain from improved genetic stock across competition control treatments was 21 tons per acre (14%). The response to complete competition control across genetic treatments was 24 tons per acre (19%). Genetically improved trees had significantly greater average and dominant height and dbh as compared with unimproved trees. Complete competition control significantly increased both tree height and diameter. Complete competition control accelerated stand development as indicated by significantly higher stand density index (379 vs 341) and lower relative spacing (0.142 vs 0.152) on complete competition control plots as compared with operational site preparation only plots. Plots with improved genetic stock had lower relative spacing (0.142 vs 0.156) than unimproved stock but did not differ from unimproved stock in trees per acre or stand density index. Genetic improvement significantly improved tree health and quality. Plantings with improved stock had a lower incidence of trees with fusiform rust stem galls (14.8% vs 22.4%) and forks (53% vs 70%) and a higher proportion of defect-free trees (36% vs 23%) as compared to plantings with unimproved stock. Complete competition control tended to lower tree quality with a smaller percentage of defect-free trees (29% vs 35%) and a larger proportion of trees with crook or sweep (6% vs 3%) on complete competition control plots as compared with operational site preparation only plots.

Temporal response patterns in the Piedmont varied for genetic and competition control effects. The improved stock used in this study increased tree height and dbh growth and per acre basal area, volume and weight. Gains from improved genetics increased through age 6 for dbh and basal area per acre, through age 12 for height, and through age 15 for volume and weight per acre. These gains from improved stock were maintained through age 21. Complete competition control also increased tree height and dbh growth as well as per acre basal area, volume, and weight. As observed in the Coastal Plain, Piedmont responses to complete competition control generally reached their maximum for dbh and height at age 6, for per acre basal area at age 9, and for per acre volume and weight at age 12. Thereafter, cumulative responses tended to decline somewhat with the exception of per acre volume and weight which showed no significant decline in cumulative response with increasing age.

These updated results confirm earlier findings that 1) gains from 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; 3) effective competition control provides consistent, substantial and persistent productivity gains; 4) the general lack of interaction suggest that, for this and similar levels of genetic improvement, gains from genetic improvement and significant competition control are additive.

The response patterns observed in this study can inform model development for predicting responses from genetic improvement and vegetation management. Dominant height gains from genetics followed a Type B response pattern; absolute gains in dominant height reached their maximum by about age 12 and were thereafter maintained. Responses to complete competition control followed a Type C response pattern; absolute gains in dominant height reached their maximum by about age 6 and thereafter declined somewhat with increasing age.

The growth patterns reported are for nonthinned stands that did not receive any fertilization following plantation establishment. By age 21, intra-specific competition was severe. Basal area per acre was 181 and 190 ft^2/acre on improved and complete competition control plots in the Coastal Plain and Piedmont, respectively; stand density index was 371 and 380 (82% and 84% of maximum SDI) in the Coastal Plain and Piedmont, respectively. Average live crown ratio on most plots ranged from 0.34 to 0.36.

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1. INTRODUCTON

The Plantation Management Research Cooperative (PMRC) was established at the University of Georgia in 1976 with the objectives of (1) developing growth and yield models for site prepared pine plantations and (2) designing and implementing experiments that will lead to increased site productivity and development of growth and yield models incorporating site and management practices for pine plantations in the Southeast.

PMRC studies have shown that control of competing vegetation can increase productivity in pine plantations by as much as 100 percent (Pienaar and Rheney, 1995). Another widely used regeneration practice is planting genetically-improved seedlings. Results from loblolly pine first generation progeny tests indicate that volume gains from 7% to 19% (Talbert *et. al.,* 1985) are possible. Progeny tests, however, were typically planted as single row plots and often received better cultural treatments, such as mowing and fertilization, than operational plantations. It is possible that these cultural treatments could confound and perhaps lead to estimates of genetic gain that are not achieved in block plot plantings of single families or mixtures of improved families. Data from row plots are not useful for developing growth and yield systems that provide breakdowns of stand structure in addition to total yield. Consequently, it is difficult for forest planners to rely solely on block plot data to estimate potential gains from using genetically-improved seedlings.

The PMRC designed and installed a study in 1986-87 with the following objectives:

(1) to evaluate the impact of first generation genetic improvement on yields for planning purposes,

(2) to evaluate the impact on yields of combining genetic improvement and complete and sustained vegetation control, and

(3) to evaluate single family genetically-improved plantations versus bulk lot genetically-improved plantations.

This paper summarizes the results of the age 21 measurement analysis of loblolly pine for this study from 10 Coastal Plain installations and 10 Piedmont installations. Also included are the results of the analysis of the 3-year growth between ages 18 and 21 and growth trends during the 21 year period. This document complements earlier PMRC reports on this study (Harrison and Shiver, 2005; Logan and Shiver, 2003).

2. METHODS

A designed study was established at 16 locations in the Coastal Plain (Lower Coastal Plain and Upper Coastal Plain) of Georgia and northern Florida, and at 15 locations in the Piedmont of South Carolina, Georgia and Alabama. By age 21, 10 installations in each region were active and subject to measurement and analysis.

Genetically-improved seed were obtained by polling the PMRC membership to determine the top ten families by region for each company. The six top-ranked families for each region were tentatively scheduled for inclusion in the study. The families were then checked by personnel at the North Carolina State University Cooperative Tree Improvement Program. They compared the family rankings with those provided by the PMRC cooperators and paid particular attention to disease resistance. 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. North Carolina State University Cooperative Tree Improvement Program identification for families chosen for inclusion in the PMRC Improved Planting Stock-Vegetation Control Study by region.

Coastal Plain	Piedmont
7-34	12-12
10-5	5-5
17-5	12-9
10-25	12-7
7-56	1-14
7-2	15-42

Unimproved seed was obtained from International Forest Seed Company. This unimproved seed was obtained in the same regions encompassed by the study and from areas other than seed orchards or seed production areas. There were two separate lots of unimproved seed corresponding to the regions in the study.

Bulk lot improved stock was obtained by mixing equal amounts of seed from the six selected families for a particular region. 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 (UNC),
(2) Unimproved stock, complete vegetation control (UCC),
(3) Bulk lot improved stock, no vegetation control (BNC),
(4) Bulk lot improved stock, complete vegetation control (BCC),
(5) Replicate plot of one of the first four treatments,
(6) Single family improved stock, no vegetation control (SNC),
(7) Single family improved stock, complete control (SCC), and
(8) Replicate plot of one of the single family treatments.

Each plot was randomly assigned to one of the six 2 x 3 factorial treatment combinations or a replicated treatment. Each treatment plot was 0.4 ac in size with a centrally-located 0.2 ac measurement plot. The two levels of vegetation 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. 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 in January, 1987 at a density of 700-750 trees per acre. Every third pine tree on the measurement plot was measured for total height (ft) after the third growing season and was measured for dbh to the nearest 0.1 in., total height, and checked for stem cankers caused by fusiform rust (*Cronartium quercum* f. sp. *fusiforme*) after the 6^{th}, 9^{th}, 12^{th}, 15^{th}, 18^{th} and 21^{st} growing seasons. After the 9^{th}, 12^{th}, 15^{th}, 18^{th} and 21^{st} growing seasons, all trees on the measurement plots were measured for dbh and checked for stem cankers. After the 15^{th}, 18^{th} and 21^{st} growing seasons, all trees were assigned a quality code to indicate future suitability (or unsuitability) for solid wood products. Quality codes included defect tree, fork, crook or sweep, canker and broken top. Height-to-live-crown measurements were taken on height measurement trees after the 15^{th}, 18^{th} and 21^{st} growing seasons.

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 and merchantable (2-in. top ob) tree volumes and weights were estimated using total and merchantable volume and weight equations developed by Pienaar, *et. al.* (1987). Chip-n-saw weights were calculated based solely on tree dimensions for trees with dbh equal or greater than 8 inches to a 6-inch top. Pulpwood weights were calculated for trees with dbh equal or greater than 4 inches to a 2-inch diameter top. Chip-n-saw yields were subtracted from tree weights to determine pulpwood weight.

Stand density index (SDI) and relative spacing (RS) were calculated for each plot to assess 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:

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

Installations were treated as random factors of the experiment since region-wide recommendations were the objectives 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 competition control and genetics were treated as fixed factors. The two levels of competition control were either none, other than that provided by the operational site preparation, or complete control. Genetic improvement was either unimproved, bulk lot or single family.

The analyses for the Coastal Plain and Piedmont regions were completed separately on the following dependent variables: average dbh, range in dbh, skewness and kurtosis statistics of the dbh distribution, average dominant height, surviving trees per acre, basal area per acre, total and merchantable stem volume, total and merchantable stem green weight, pulpwood weight, chip-n-saw weight, percent fusiform rust infection, percentage of defect-free trees, crook/sweep percent, percentage of forked trees, and live crown length and live crown ratio. Main effects of genetic improvement were calculated by averaging across both vegetation control treatments and main vegetation control effects were determined by averaging across all genetics treatments. Unless otherwise indicated, the α=0.05 significance level was the standard for identifying statistically significant effects. 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.

Increments in mean dbh, dominant height, and per acre basal area and total and merchantable volume and weight for the age 18 to 21 year period were calculated and analyzed using the mixed model approach to identify differences in period growth patterns.

Tree (mean dbh, dominant height) and stand (per acre basal are, total green weight, number of 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 the six individual genetic and competition control treatment combinations. For a given measurement age, data from active installations were used for this graphical analysis. For the Coastal Plain, 16 installations were active at time of the 3- through 15-year measurements, 13 were active at the 18-year measurement and 10 were active at the 21-year measurement. For the Piedmont, 15 installations were active through the age 18 year measurement and 10 were active at the 21-year measurement.

Finally, temporal trends in genetic gains and competition control responses were evaluated by synthesizing periodic increment information from previous PMRC reports (Harrison and Shiver, 2005; Logan and Shiver, 2003) and the current analysis.

3. AGE 21 RESULTS

3.1 Average DBH

3.1.1 Coastal Plain

Competition control significantly increased average dbh in the Coastal Plain an average of 0.71 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 (reproduced from SAS® output) for average dbh (in.) of loblolly pine at age 21 in the Coastal Plain.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	55.7	0.32	0.7259
Competition Control	1	8.8	41.27	0.0001
Genetics* Competition Control	2	55.2	0.84	0.4379

Table 3. Summary of least squares means for average dbh (in.) of loblolly pine at age 21 in the Coastal Plain.

	No Control	Complete Control	Average
Unimproved	6.65	7.25	6.95
Bulk Lot	6.57	7.28	6.92
Single Family	6.58	7.40	6.99
Average	6.60	7.31	6.95

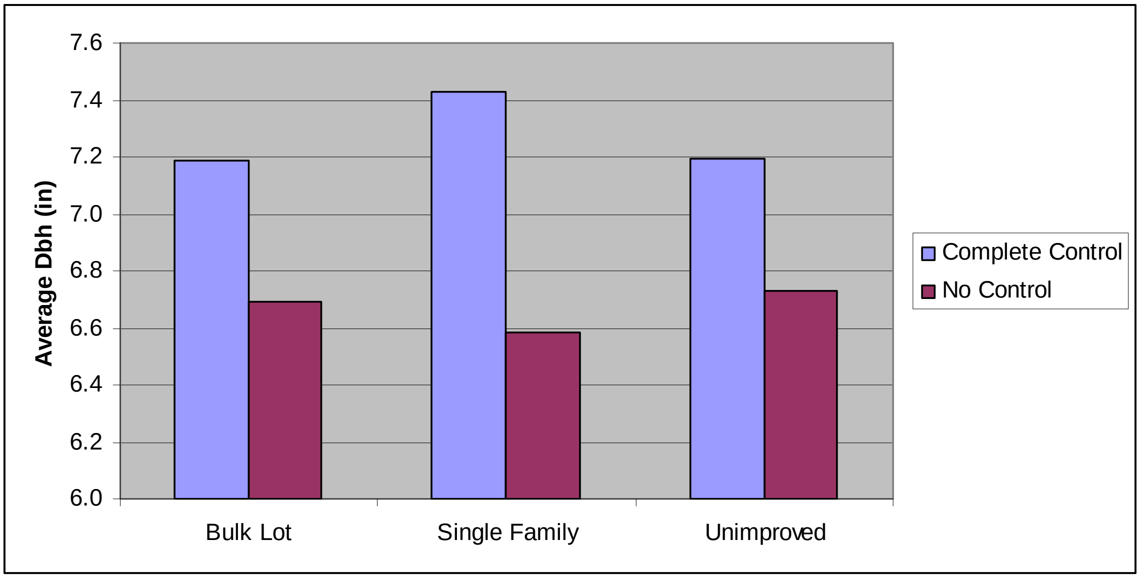

Figure 1. Mean dbh by treatment for 21-yr-old loblolly pine in the Coastal Plain.

3.1.2 Piedmont

Both vegetation control and genetics had significant effects on average dbh (Table 4). The interaction between genetic stock and competition control was not significant. Competition control significantly increased average dbh an average of 0.44 inches across all genetic treatments. A t-test on the differences of least square means detected no significant difference between bulk lot and single family plantings, but bulk lot and single family plantings increased average dbh 0.24 inches and 0.36 inches, respectively, over unimproved stock. The least square means for average dbh by treatment are summarized in Table 5 and arithmetic means are presented in Figure 2.

Table 4. Test of fixed effects (reproduced from SAS® output) for average dbh (in.) of loblolly pine at age 21 in the Piedmont.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	58.0	5.96	0.0044
Competition Control	1	8.6	23.34	0.0011
Genetics* Competition Control	2	56.5	1.32	0.2745

Table 5. Summary of least squares means for average dbh (in.) of loblolly pine at age 21 in the Piedmont.

	No Control	Complete Control	Average
Unimproved	7.28	7.81	7.55
Bulk Lot	7.79	8.03	7.91
Single Family	7.39	7.94	7.67
Average	7.49	7.93	7.71

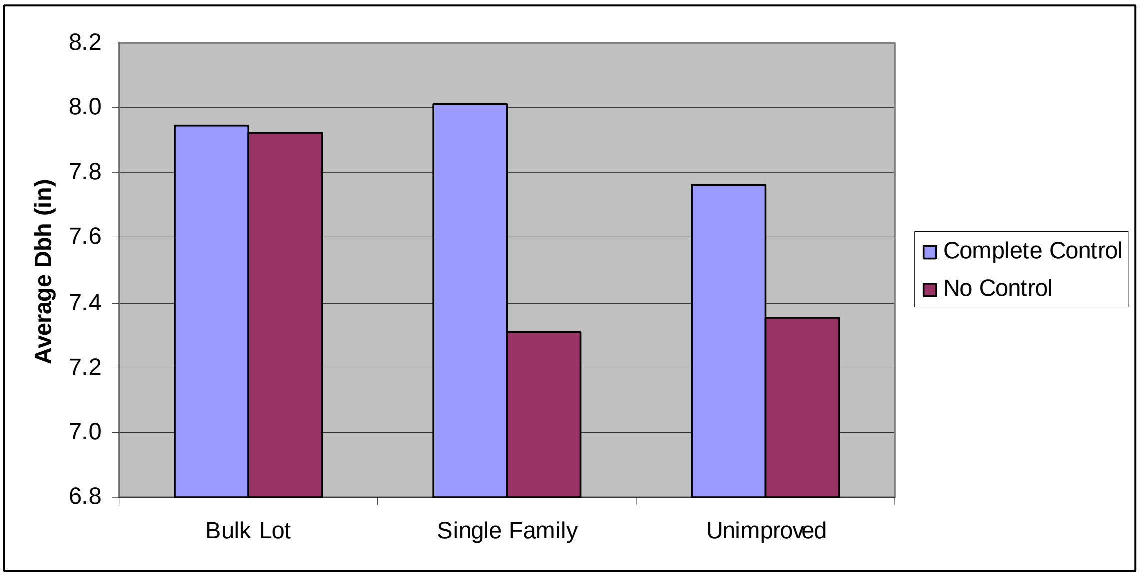

Figure 2. Mean dbh by treatment for 21-yr-old loblolly pine in the Piedmont.

3.2 Range, Skewness, and Kurtosis of the DBH Distribution

3.2.1 Coastal Plain

Dbh range did not differ significantly by treatment. Skewness of dbh differed significantly between unimproved plantings (0.037) and the improved bulk lot plantings (-0.152). Skewness for single family blocks (-0.057) was intermediate and did not differ from the other genetic treatments. There was a significant genetic by competition control treatment interaction for kurtosis with very different patterns observed for the genetic treatments depending on the competition control treatments. On plots with operational site preparation only, age 21 dbh kurtosis was -0.348 for unimproved plantings, -0.108 for improved, single family plantings and -0.471 for improved, bulk lot plantings. In contrast, on plots with complete competition control, dbh kurtosis was -0.291 for unimproved plantings, -0.347 for single family plantings and -0.043 for bulk lot plantings.

3.2.2 Piedmont Analysis

In the Piedmont region, the average range in dbh was greater for unimproved plantings (7.6 inches) than for improved plantings (7.0 inches). The genetic treatment by competition control treatment was significant for dbh skewness. On plots with operational site preparation only, age 21 dbh skewness was 0.099 for unimproved plantings, -1.1973 for single family plantings and -0.1086 for bulk lot plantings. In contrast, on plots with complete competition control, dbh skewness was 0.004 for unimproved plantings, 0.097 for single family plantings and 0.078 for bulk lot plantings. Kurtosis of dbh was not significantly affected by treatment.

3.3 Average Dominant Height

3.3.1 Coastal Plain

Both competition control and genetics main effects were significant and there was an absence of significant interaction (Table 6). Competition control increased average dominant height in the Coastal Plain an average of 5.0 ft at age 21 across all genetic treatments (Table 7 and Figure 3). While there was no significant difference between single family and bulk lot plantings, these treatments increased dominant height by 3.6 ft and 2.8 ft over unimproved stock, respectively.

Table 6. Test of fixed effects (reproduced from SAS® output) for average dominant height (ft) of loblolly pine at age 21 in the Coastal Plain.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	27.1	5.91	0.0074
Competition Control	1	7.9	27.77	0.0008
Genetics* Competition Control	2	27.3	1.64	0.2132

Table 7. Summary of least squares means for average dominant height (ft) of loblolly pine at age 21 in the Coastal Plain.

	No Control	Complete Control	Average
Unimproved	55.5	58.3	56.9
Bulk Lot	56.9	62.5	59.7
Single Family	57.2	63.8	60.5
Average	56.5	61.5	59.0

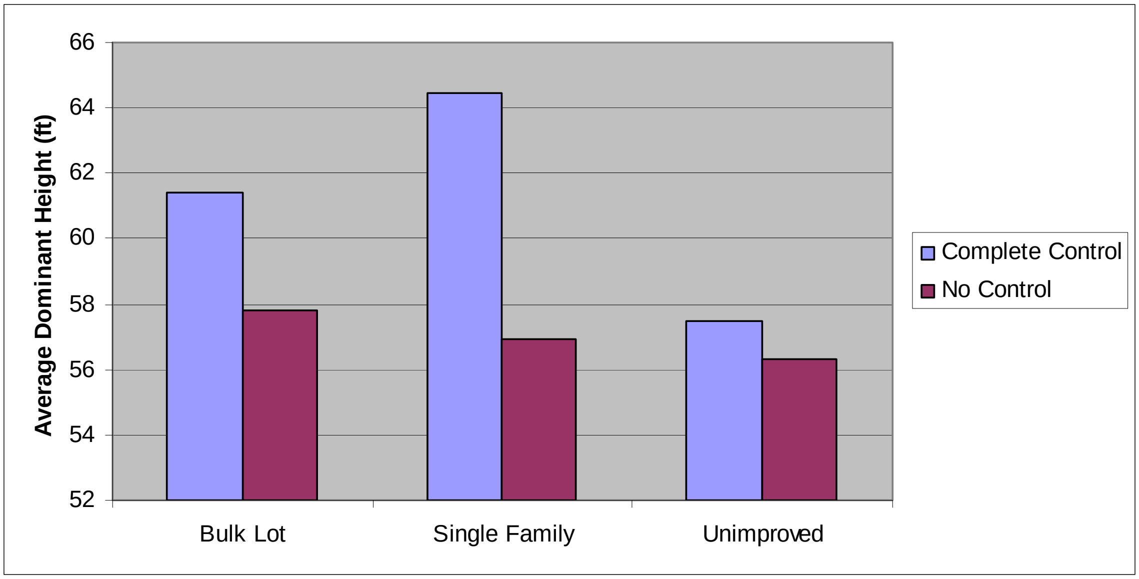

Figure 3. Mean dominant height by treatment for 21-yr-old loblolly pine in the Coastal Plain.

3.3.2 Piedmont

Both vegetation control and improved genetic stock had significant effects on average dominant height (Table 8). The interaction between genetic stock and competition control was not significant. Competition control significantly increased average dominant height an average of 3.1 ft across all genetic treatments (Table 9 and Figure 4). A t-test on the differences of least square means detected no significant differences between bulk lot and single family plantings; bulk lot increased average dominant height by 6.8 ft and single family by 5.3 ft over unimproved stock.

Table 8. Test of fixed effects (reproduced from SAS® output) for average dominant height (ft) of loblolly pine at age 21 in the Piedmont.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	19.1	31.17	<0.0001
Competition Control	1	4.1	24.38	<0.0001
Genetics* Competition Control	2	53.8	1.67	0.1969

Table 9. Summary of least squares means for average dominant height (ft) of loblolly pine at age 21 in the Piedmont.

	No Control	Complete Control	Average
Unimproved	55.7	60.4	58.0
Bulk Lot	64.0	65.7	64.8
Single Family	61.3	63.3	63.3
Average	60.3	63.4	61.8

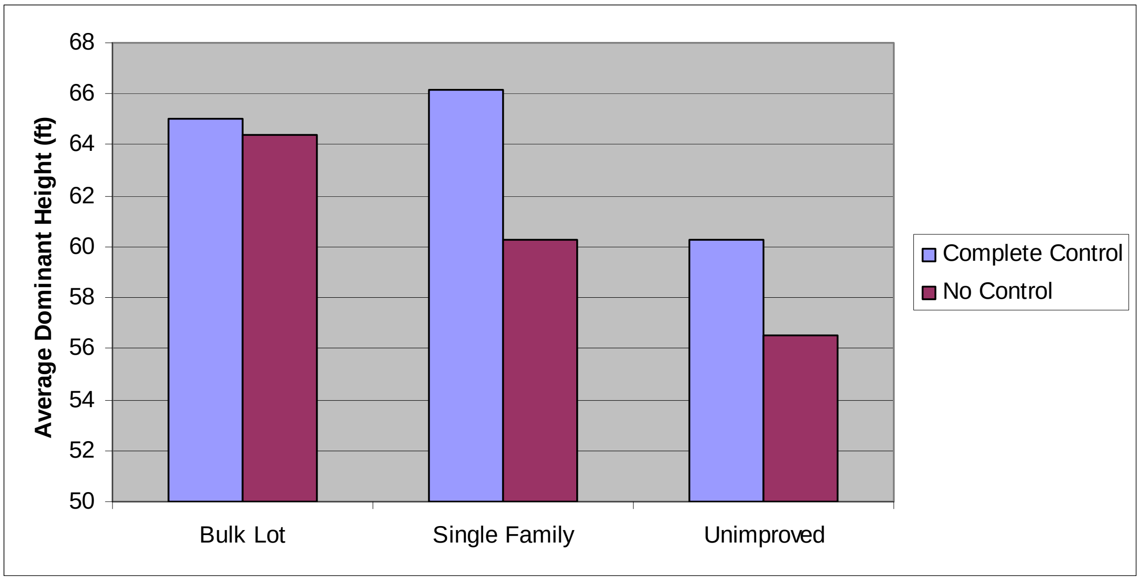

Figure 4. Mean dominant height by treatment for 21-yr-old loblolly pine in the Piedmont.

3.4 Basal Area per Acre

3.4.1 Coastal Plain

Vegetation control significantly affected basal area per acre while apparent genetic effects where not statistically significant (Table 10). The interaction between competition control and genetic stock was not significant. Competition control significantly increased basal area an average 22.4 ft^2/ac across all levels of genetic stock (Table 11) while basal area per acre ranged from 163.2 ft^2/ac for unimproved plantings to 169.8 ft^2/ac for improved, single family plantings. Least square means of basal area per acre for the different treatment combinations are presented in Table 11 and arithmetic means are provided in Figure 5.

Table 10. Test of fixed effects (reproduced from SAS® output) for basal area (ft^2/ac) of loblolly pine at age 21 in the Coastal Plain.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	27.6	1.86	0.1748
Competition Control	1	8.32	41.56	0.0002
Genetics* Competition Control	2	28.1	1.37	0.2711

Table 11. Summary of least squares means for basal area (ft^2/ac) of loblolly pine at age 21 in the Coastal Plain.

	No Control	Complete Control	Average
Unimproved	154.6	171.7	163.2
Bulk Lot	155.6	177.5	166.6
Single Family	155.6	184.0	169.8
Average	155.3	177.7	166.5

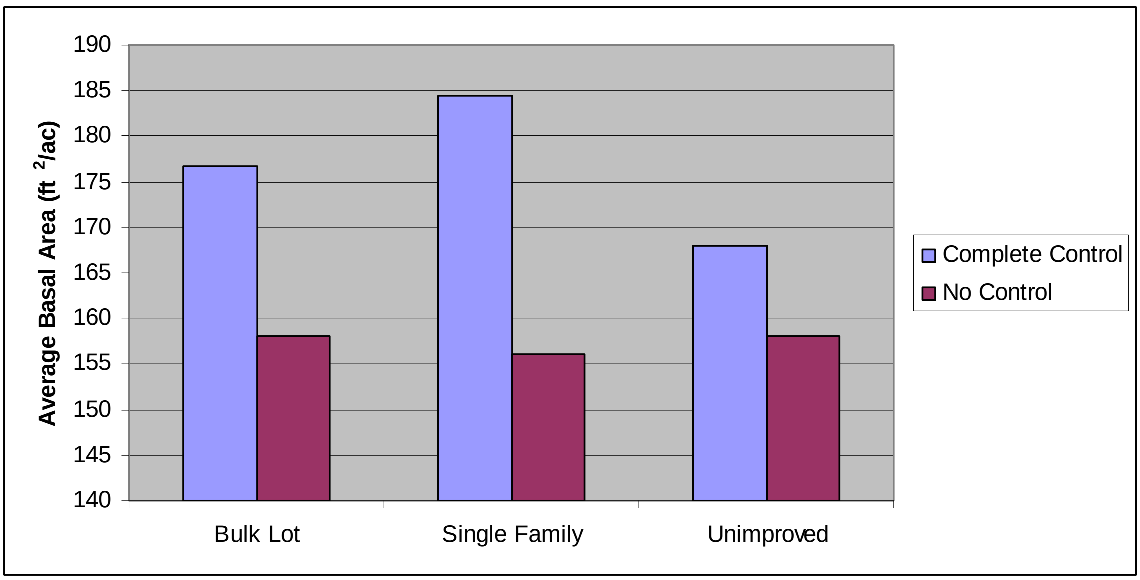

Figure 5. Basal area per acre by treatment for 21-yr-old loblolly pine in the Coastal Plain.

3.4.2 Piedmont

The vegetation control treatment had the only significant effect on basal area per acre in the Piedmont (Table 12). Although the genetic by vegetation control interaction was not significant at age 21, there was a pattern of greater basal area for improved stock than unimproved stock in the absence of complete vegetation control in contrast to similar basal area per acre across genetic treatments on plots receiving complete vegetation control (Table 13, Figure 6). Through age 15, there was a significant interaction between vegetation control and genetic stock with regards to per acre basal area in the Piedmont region (Logan and Shiver, 2003).

Table 12. Test of fixed effects (reproduced from SAS® output) for basal area (ft^2/ac) of loblolly pine at age 21 in the Piedmont.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	18.0	1.97	0.1682
Competition Control	1	9.1	17.14	0.0025
Genetics* Competition Control	2	17.5	1.61	0.2286

Table 13. Summary of least squares means for basal area (ft^2/ac) of loblolly pine at age 21 in the Piedmont.

	No Control	Complete Control	Average
Unimproved	155.3	187.5	171.4
Bulk Lot	175.5	191.9	183.7
Single Family	168.6	188.5	178.6
Average	166.5	189.3	177.9

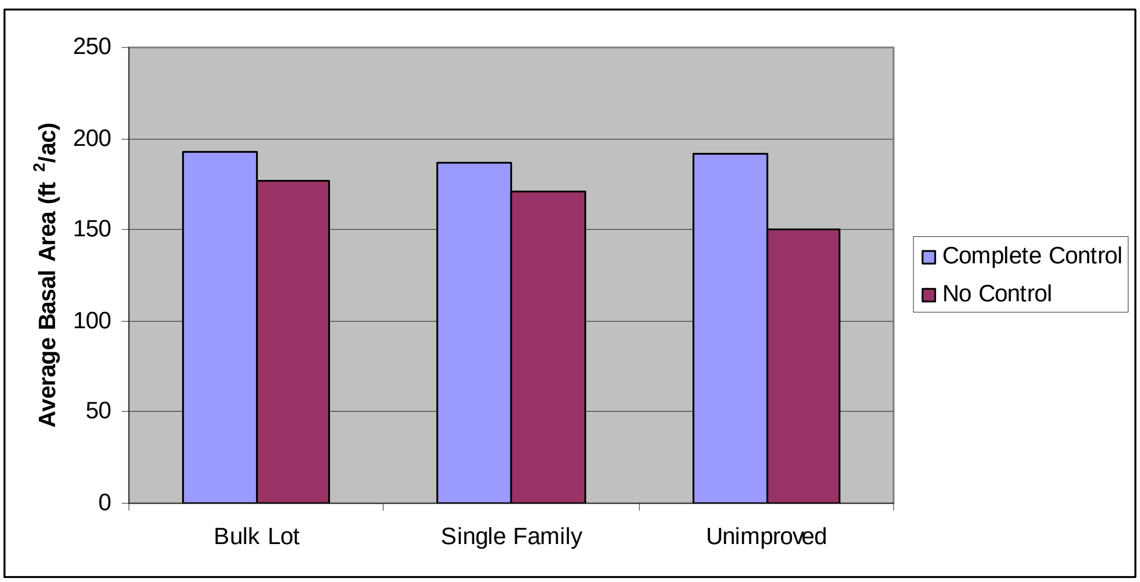

Figure 6. Basal area per acre by treatment for 21-yr-old loblolly pine in the Piedmont.

3.5 Total Volume per Acre

3.5.1 Coastal Plain

Genetic and competition control treatments significantly affected total volume per acre (Table 14). There was no significant interaction between genetics and competition control. Total volume 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, total volume was 4508 ft^3/ac for unimproved stock and averaged 4964 ft^3/ac for improved treatments, a gain of 456 ft^3/ac (10.1%) relative to unimproved stock. Complete competition control increased yield an average of 1012 ft^3/ac (23.5%) across all genetic treatments.

Table 14. Test of fixed effects (reproduced from SAS® output) for total volume (ft^3/ac) of loblolly pine at age 21 in the Coastal Plain.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	29.0	6.53	0.0045
Competition Control	1	8.6	37.38	0.0002
Genetics* Competition Control	2	29.5	0.99	0.3819

Table 15. Summary of least squares means for total volume (ft^3/ac) of loblolly pine at age 21 in the Coastal Plain.

	No Control	Complete Control	Average
Unimproved	4109	4908	4508
Bulk Lot	4364	5366	4865
Single Family	4446	5680	5063
Average	4306	5318	4812

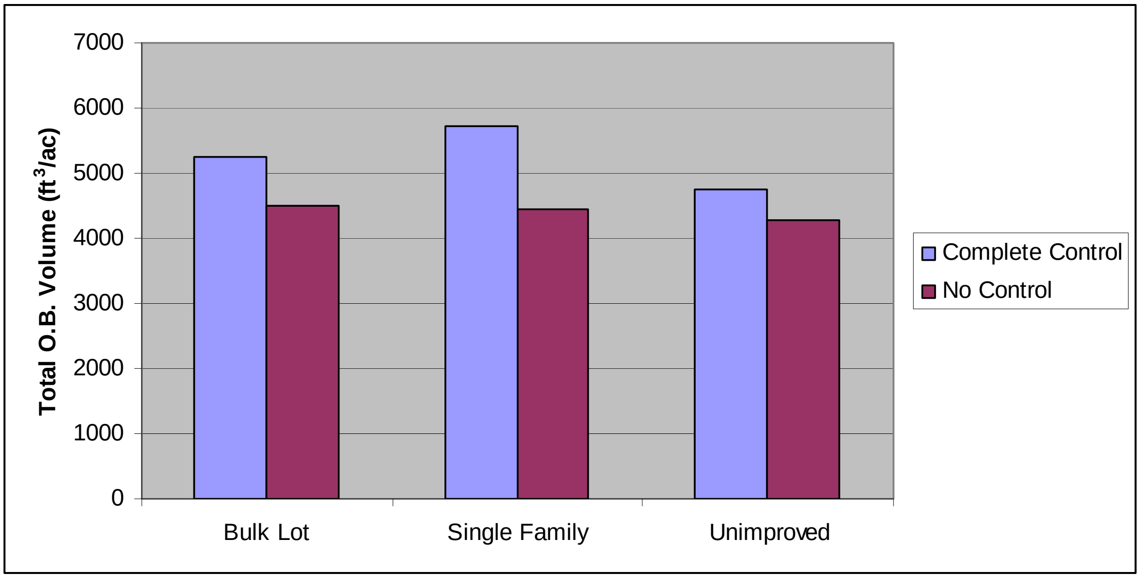

Figure 7. Total volume per acre by treatment for 21-yr-old loblolly pine in the Coastal Plain.

3.5.2 Piedmont

As observed in the Coastal Plain, Piedmont results show significant effects of genetic and competition control treatments on total volume and a lack of interactions (Table 16). Improved genetic stock yielded significantly greater total volume than unimproved stock (Table 17, Figure 8). Improved bulk lot plantings and improved single family plantings did not differ significantly in total volume. The average total volume for improved stock of 5414 ft^3/ac represents a gain of 695 ft^3/ac (14.7%) compared to total volume of unimproved stock. Complete competition control increased yield an average 846 ft^3/ac (17.8%) across all genetic treatments.

Table 16. Test of fixed effects (reproduced from SAS® output) for total volume (ft^3/ac) of loblolly pine at age 21 in the Piedmont.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	18.4	7.45	0.0043
Competition Control	1	9.1	19.35	0.0017
Genetics* Competition Control	2	18.0	1.40	0.2734

Table 17. Summary of least squares means for total volume (ft^3/ac) of loblolly pine at age 21 in the Piedmont.

	No Control	Complete Control	Average
Unimproved	4165	5274	4719
Bulk Lot	5288	5840	5564
Single Family	4825	5702	5264
Average	4759	5605	5182

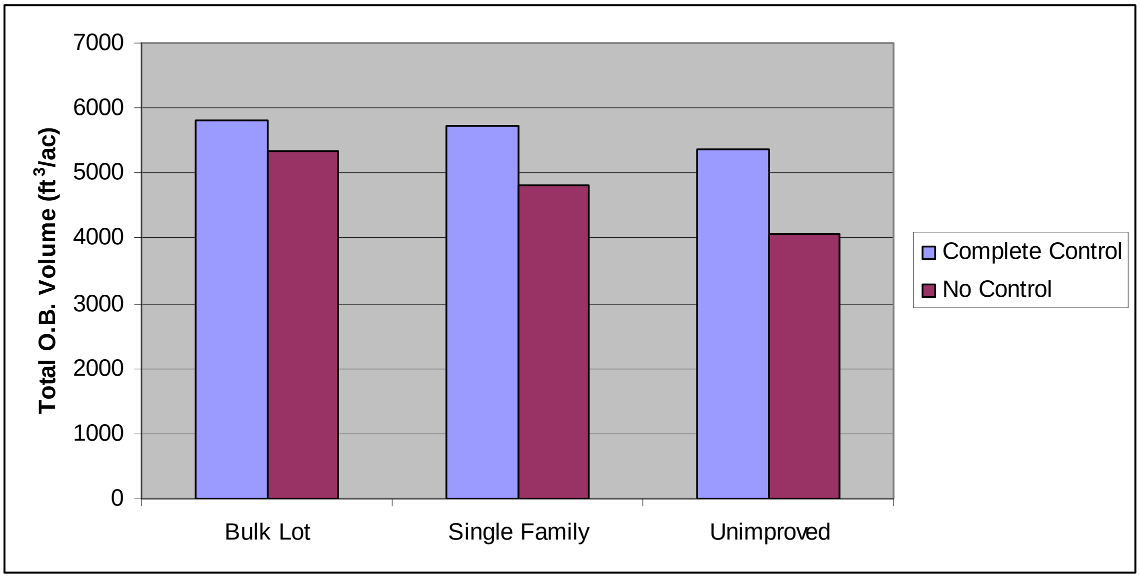

Figure 8. Total volume per acre by treatment for 21-yr-old loblolly pine in the Piedmont.

3.6 Merchantable Volume

3.6.1 Coastal Plain

Results for merchantable volume (2-in. top) are essentially the same as for total volume with significant genetic and competition control effects and the lack of significant interactions (Table 18). Merchantable volume was greater with improved than unimproved stock (Table 19, Figure 9) and statistically similar for improved bulk lot and improved single family plantings. Across competition control levels, merchantable volume was 4442 ft^3/ac for unimproved stock and averaged 4898 ft^3/ac for the improved stock treatments, a gain of 456 ft^3/ac (10.3%) relative to unimproved stock. Complete competition control increased yield an average of 1038 ft^3/ac (24.6%) across all genetic treatments.

Table 18. Test of fixed effects (reproduced from SAS® output) for merchantable volume (o.b. to a 2-in. top o.b. (ft^3/ac) of loblolly pine at age 21 in the Coastal Plain.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	28.7	6.41	0.0050
Competition Control	1	8.6	37.77	0.0002
Genetics* Competition Control	2	29.3	0.97	0.3912

Table 19. Summary of least squares means for merchantable volume o.b. to a 2-in. top o.b. (ft^3/ac) of loblolly pine at age 21 in the Coastal Plain.

	No Control	Complete Control	Average
Unimproved	4030	4855	4442
Bulk Lot	4284	5315	4799
Single Family	4367	5625	4996
Average	4227	5265	4746

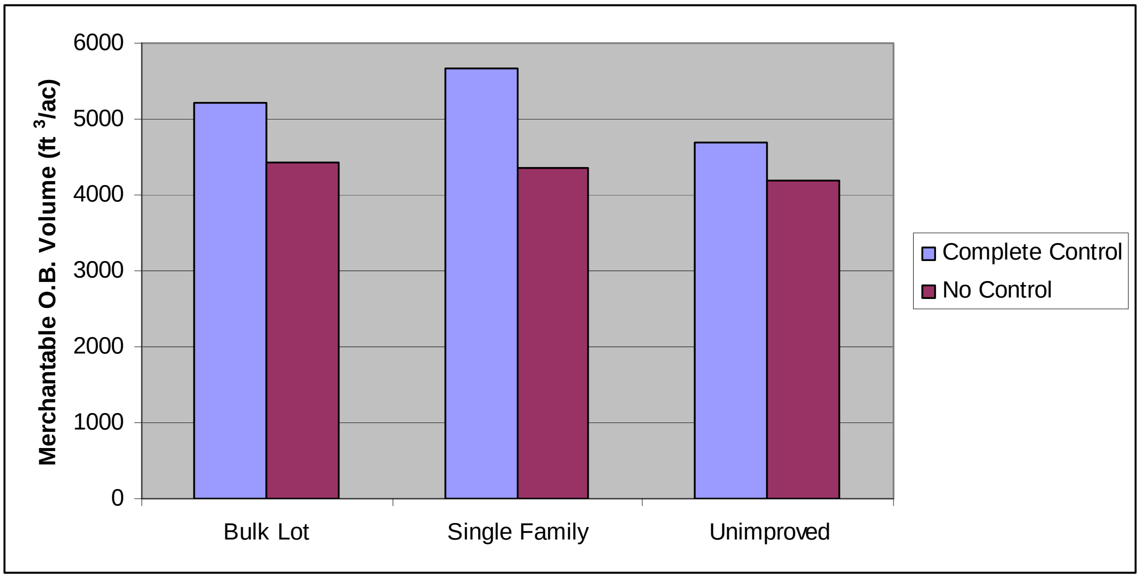

Figure 9. Merchantable volume (2-in. top) per acre by treatment for 21-yr-old loblolly pine in the Coastal Plain.

3.6.2 Piedmont

Similar to results in the Coastal Plain, results for merchantable volume (2-in. top) in the Piedmont are essentially the same as for total volume with significant genetic and competition control effects and the lack of significant interactions (Table 20). Improved genetic stock yielded significantly greater merchantable volume than unimproved stock (Table 21, Figure 10). Improved bulk lot plantings and improved single family plantings did not differ significantly in merchantable volume. The average merchantable volume for improved stock of 5373 ft^3/ac represents a 697 ft^3/ac gain (14.8%) compared to merchantable volume of unimproved stock. Complete competition control increased yield an average 857 ft^3/ac (18.2%) across all genetic treatments.

Table 20. Test of fixed effects (reproduced from SAS® output) for merchantable volume o.b. to a 2-in. top o.b. (ft^3/ac) of loblolly pine at age 21 in the Piedmont.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	18.5	7.56	0.0040
Competition Control	1	9.1	20.06	0.0015
Genetics* Competition Control	2	18.0	1.41	0.2692

Table 21. Summary of least squares means for merchantable volume o.b. to a 2-in. top o.b. (ft^3/ac) of loblolly pine at age 21 in the Piedmont.

	No Control	Complete Control	Average
Unimproved	4116	5236	4676
Bulk Lot	5245	5804	5525
Single Family	4774	5667	5220
Average	4712	5569	5140

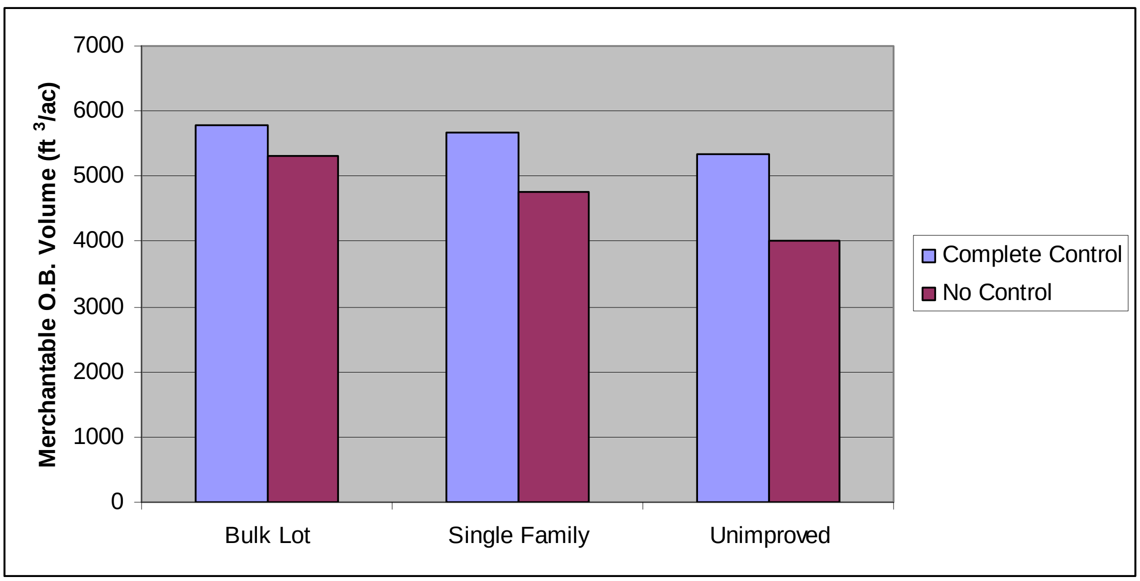

Figure 10. Merchantable volume (2-in. top) per acre by treatment for 21-yr-old loblolly pine in the Piedmont.

3.7 Total Green Weight per Acre

3.7.1 Coastal Plain

Genetic and competition control treatments significantly affected total green weight (Table 22). Effects of genetics and competition control treatments were additive as no significant interactions were observed. Total green weight was greater with improved than unimproved stock (Table 23, Figure 11) and statistically similar for improved bulk lot and improved single family plantings. Across competition control levels, total green weight was 126 tons/ac for unimproved stock and averaged 139 tons/ac for the improved stock treatments, a 13 ton/ac gain (10.3%) relative to unimproved stock.   Complete competition control increased yield an average 29 tons/ac (24.1%) across genetic treatments.

Table 22. Test of fixed effects (reproduced from SAS® output) for total green weight (tons/ac) of loblolly pine at age 21 in the Coastal Plain.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	29.1	6.78	0.0038
Competition Control	1	8.6	36.75	0.0002
Genetics* Competition Control	2	29.6	0.96	0.3931

Table 23. Summary of least squares means for total green weight (tons/ac) of loblolly pine at age 21 in the Coastal Plain.

	No Control	Complete Control	Average
Unimproved	114.3	137.3	125.8
Bulk Lot	121.9	150.6	136.3
Single Family	124.4	159.7	142.0
Average	120.2	149.2	134.7

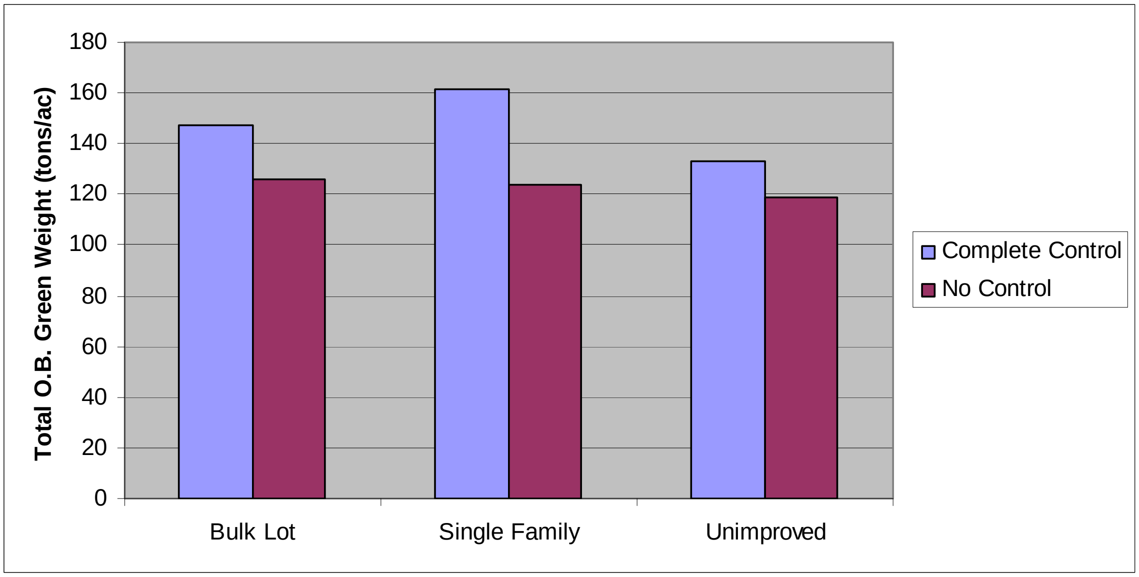

Figure 11. Total green weight per acre by treatment for 21-yr-old loblolly pine in the Coastal Plain.

3.7.2 Piedmont

Genetic and competition control treatments significantly affected total green weight (Table 24). Effects of genetics and competition control treatments were additive as significant interactions were not observed. Total green weight was greater with improved than unimproved stock (Table 25, Figure 12) and statistically similar for improved bulk lot and improved single family plantings. Across competition control levels, total green weight was 128 tons/ac for unimproved stock and averaged 148 tons/ac for the improved stock treatments, a 20 ton/ac gain (15.6%) relative to unimproved stock. Complete competition control increased yield an average 24 tons/ac (18.5%) across genetic treatments.

Table 24. Test of fixed effects (reproduced from SAS® output) for total green weight (tons/ac) of loblolly pine at age 21 in the Piedmont.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	15.8	8.23	0.0028
Competition Control	1	9.1	19.22	0.0017
Genetics* Competition Control	2	18.0	1.48	0.2540

Table 25. Summary of least squares means for total green weight (tons/ac) of loblolly pine at age 21 in the Piedmont.

	No Control	Complete Control	Average
Unimproved	111.9	143.1	127.5
Bulk Lot	145.0	160.1	152.6
Single Family	130.9	156.3	143.6
Average	129.3	153.2	141.2

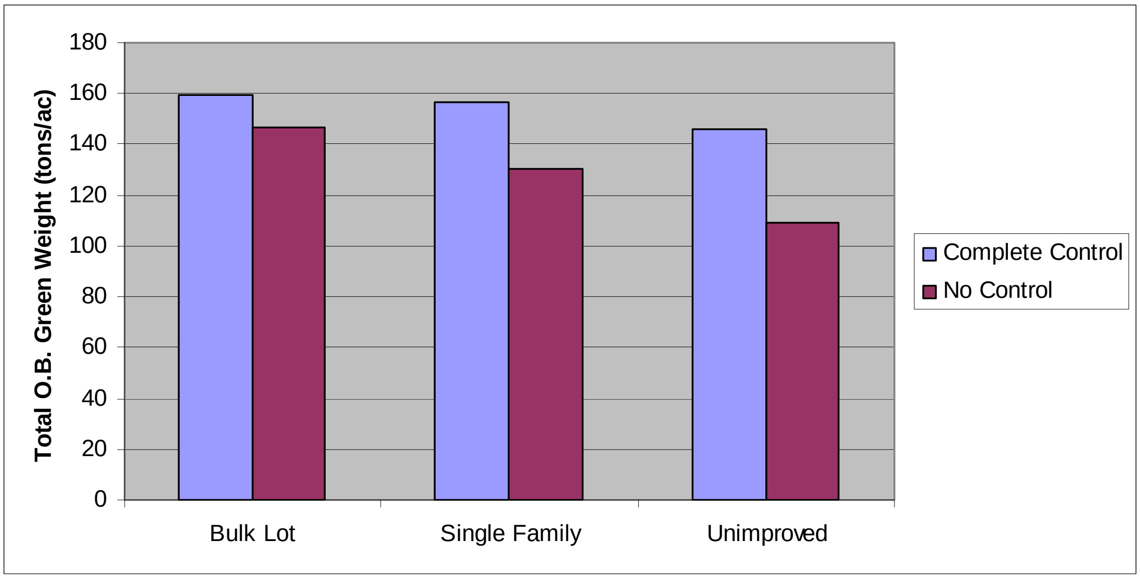

Figure 12. Total green weight per acre by treatment for 21-yr-old loblolly pine in the Piedmont.

3.8 Merchantable Green Weight

3.8.1 Coastal Plain

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 26). Merchantable green weight was greater with improved than unimproved stock (Table 27, Figure 13) and statistically similar for improved bulk lot and improved single family plantings. Across competition control levels, merchantable green weight was 124 tons/ac for unimproved stock and averaged 137 tons/ac for the improved stock treatments, a 13 ton/ac gain (10.5%) relative to unimproved stock. Complete competition control increased yield an average 30 tons/ac (25.2%) across genetic treatments.

Table 26. Test of fixed effects (reproduced from SAS® output) for merchantable green weight o.b. to a 2-in. top o.b. (tons/ac) of loblolly pine at age 21 in the Coastal Plain.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	28.9	6.64	0.0042
Competition Control	1	8.6	37.13	0.0002
Genetics* Competition Control	2	29.4	0.94	0.4023

Table 27. Summary of least squares means for merchantable green weight o.b. to a 2-in. top o.b. (tons/ac) of loblolly pine at age 21 in the Coastal Plain.

	No Control	Complete Control	Average
Unimproved	111.9	135.6	123.7
Bulk Lot	119.5	149.0	134.2
Single Family	121.9	157.9	139.9
Average	117.8	147.5	132.6

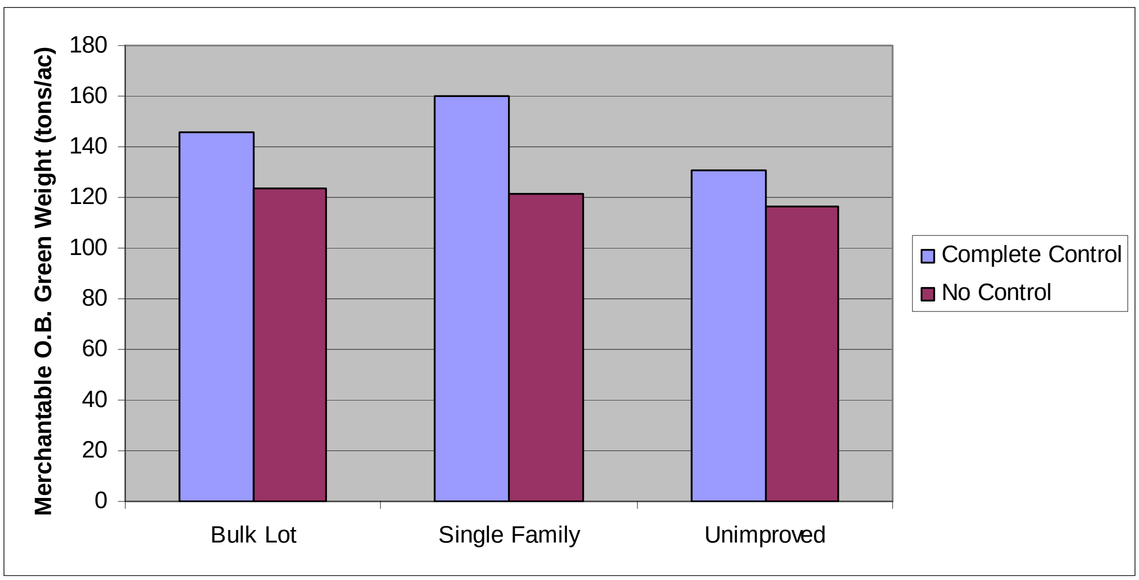

Figure 13. Merchantable green weight (2-in. top) per acre by treatment for 21-yr-old loblolly pine in the Coastal Plain.

3.8.2 Piedmont

As seen for the Coastal Plain installations, results for merchantable green weight in the Piedmont 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 28). Merchantable green weight was greater with improved than unimproved stock (Table 29, Figure 14) and statistically similar for improved bulk lot and improved single family plantings. Across competition control levels, merchantable green weight was 126 tons/ac for unimproved stock and averaged 148 tons/ac for the improved stock treatments, a 22 ton/ac gain (17.4%) relative to unimproved stock. Complete competition control increased yield an average 24 tons/ac (18.9%) across genetic treatments.

Table 28. Test of fixed effects (reproduced from SAS® output) for merchantable green weight o.b. to a 2-in. top o.b. (tons/ac) of loblolly pine at age 21 in the Piedmont.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	18.5	8.34	0.0026
Competition Control	1	9.1	19.86	0.0015
Genetics* Competition Control	2	18.0	1.49	0.2510

Table 29. Summary of least squares means for merchantable green weight o.b. to a 2-in. top o.b. (tons/ac) of loblolly pine at age 21 in the Piedmont.

	No Control	Complete Control	Average
Unimproved	110.4	141.9	126.2
Bulk Lot	143.7	158.9	151.3
Single Family	129.4	155.1	142.2
Average	127.8	152.0	139.9

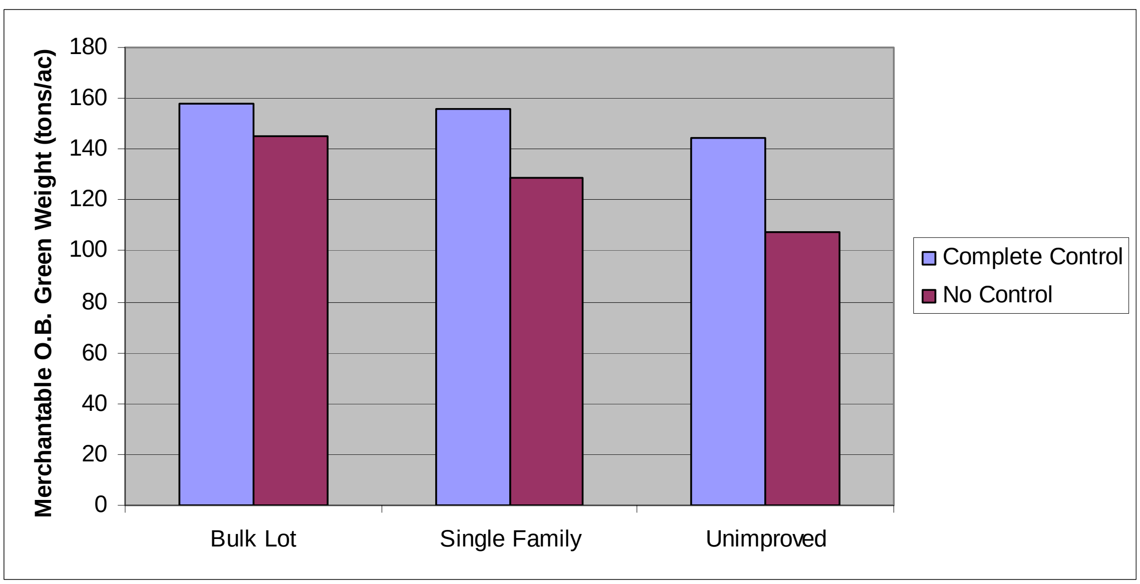

Figure 14. Merchantable green weight (2-in. top) per acre by treatment for 21-yr-old loblolly pine in the Piedmont.

3.8 Pulpwood Green Weight

3.8.1 Coastal Plain

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 30). Pulpwood green weight was greater with improved than unimproved stock (Table 31, Figure 15) and statistically similar for improved bulk lot and single family plantings. Across competition control levels, pulpwood green weight was 98 tons/ac for unimproved stock and averaged 110 tons/ac for the improved stock treatments, a 12 ton/ac gain (11.8%) relative to unimproved stock. Complete competition control increased yield an average 12 tons/ac (11.5%) across genetic treatments.

Table 30. Test of fixed effects (reproduced from SAS® output) for pulpwood green weight o.b. to a 2-in. top o.b. (tons/ac) of loblolly pine at age 21 in the Coastal Plain.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	29.5	6.36	0.0050
Competition Control	1	8.4	7.52	0.0242
Genetics* Competition Control	2	29.8	0.96	0.3935

Table 31. Summary of least squares means for pulpwood green weight o.b. to a 2-in. top o.b. (tons/ac) of loblolly pine at age 21 in the Coastal Plain.

	No Control	Complete Control	Average
Unimproved	95.8	101.0	98.4
Bulk Lot	101.4	116.0	108.7
Single Family	104.4	119.3	111.8
Average	100.5	112.1	106.3

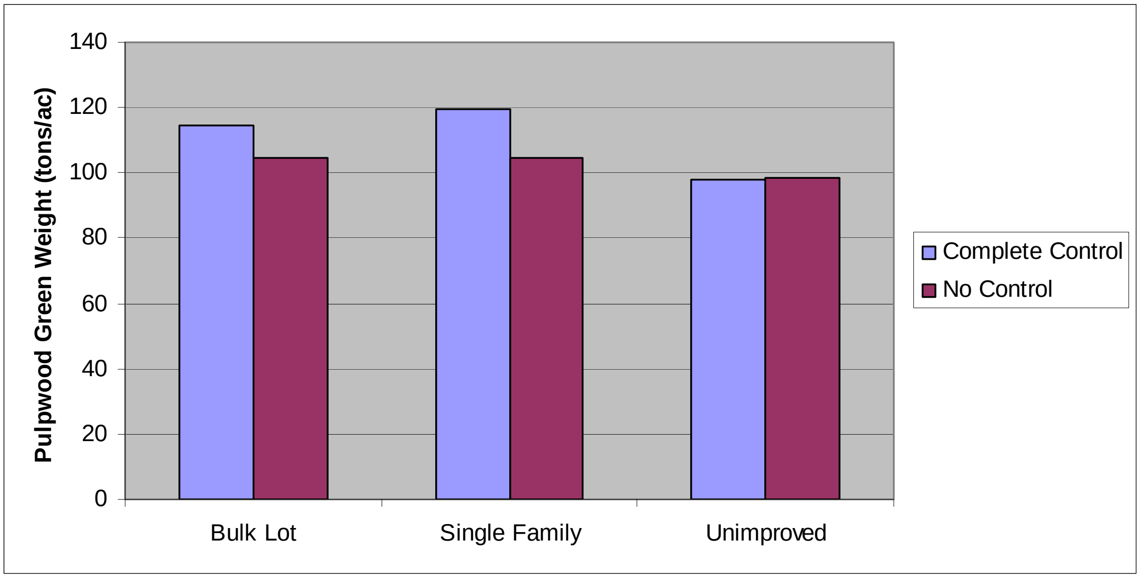

Figure 15. Pulpwood green weight (2-in. top) per acre by treatment for 21-yr-old loblolly pine in the Coastal Plain.

3.8.2 Piedmont

As seen for the Coastal Plain installations, results for pulpwood green weight in the Piedmont show the same trends as observed in the total green weight analysis; genetic and competition control treatments significantly affecting pulpwood green weight and there was the absence of interactions (Table 32). Pulpwood green weight was greater with improved than unimproved stock (Table 33, Figure 16) and statistically similar for improved bulk lot and improved single family plantings. Across competition control levels, pulpwood green weight was 96 tons/ac for unimproved stock and averaged 109 tons/ac for the improved stock treatments, a 13 ton/ac gain (13.3%) relative to unimproved stock. Complete competition control increased yield an average 13 tons/ac (12.8%) across genetic treatments.

Table 32. Test of fixed effects (reproduced from SAS® output) for pulpwood green weight o.b. to a 2-in. top o.b. (tons/ac) of loblolly pine at age 21 in the Piedmont.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	18.6	4.67	0.0227
Competition Control	1	9.0	7.27	0.0246
Genetics* Competition Control	2	17.7	0.61	0.5527

Table 33. Summary of least squares means for pulpwood green weight o.b. to a 2-in. top o.b. (tons/ac) of loblolly pine at age 21 in the Piedmont.

	No Control	Complete Control	Average
Unimproved	87.4	104.4	95.9
Bulk Lot	103.0	113.4	108.2
Single Family	104.0	114.2	109.1
Average	98.1	110.7	104.4

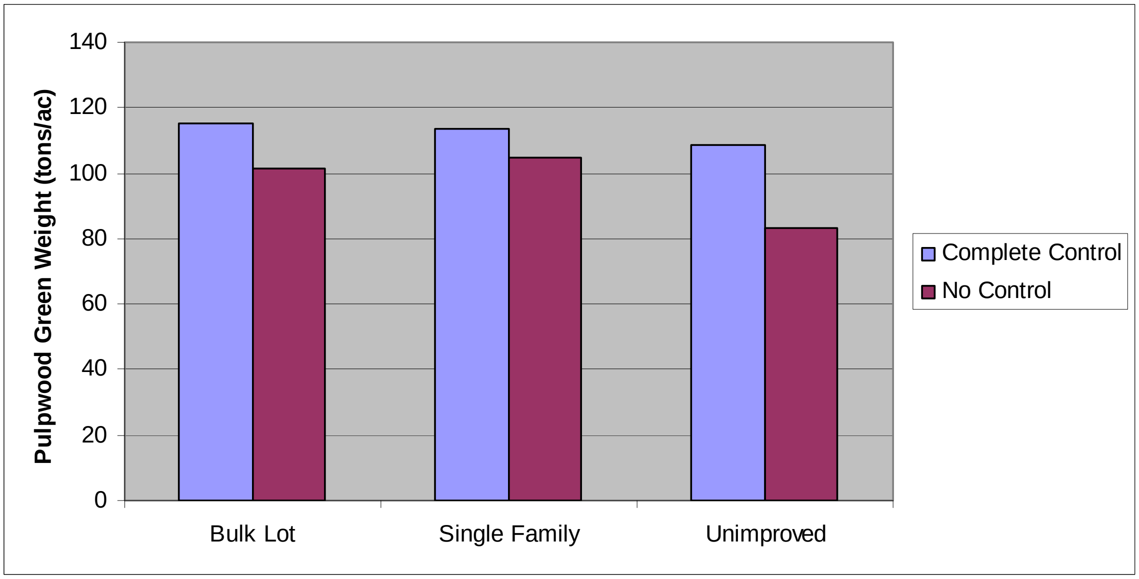

Figure 16. Pulpwood green weight (2-in. top) per acre by treatment for 21-yr-old loblolly pine in the Piedmont.

3.8 Chip-N-Saw Green Weight

3.8.1 Coastal Plain

Chip-n-saw green weight was significantly increased by complete competition control but not by genetic improvement (Table 34). The genetic by competition control interaction was not significant. Complete vegetation control increased chip-n-saw volume by 18 tons/ac (102%) across genetic treatments (Table 35). For the genetic treatments, chip-n-saw green weights ranged from 25.4 tons/ac for the unimproved planting to 28.3 tons/ac for the improved, single family planting (Figure 17). Note that the chip-n-saw calculation only takes into account tree size and not tree quality.

Table 34. Test of fixed effects (reproduced from SAS® output) for chip-n-saw green weight o.b. to a 6-in. top o.b. (tons/ac) of loblolly pine at age 21 in the Coastal Plain.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	17.6	0.57	0.5743
Competition Control	1	9.1	23.18	0.0009
Genetics* Competition Control	2	19.4	1.00	0.3864

Table 35. Summary of least squares means for chip-n-saw green weight o.b. to a 6-in. top o.b. (tons/ac) of loblolly pine at age 21 in the Coastal Plain.

	No Control	Complete Control	Average
Unimproved	16.3	34.6	25.4
Bulk Lot	18.7	33.2	26.0
Single Family	17.8	38.8	28.3
Average	17.6	35.5	26.6

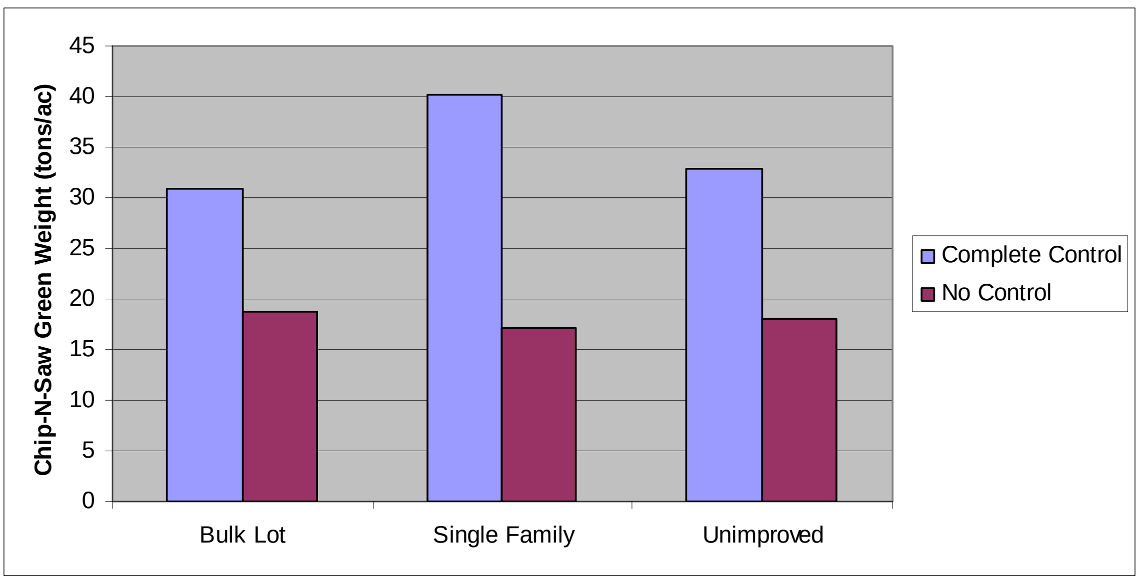

Figure 17. Chip-n-saw green weight (6-in. top) per acre by treatment for 21-yr-old loblolly pine in the Coastal Plain.

3.8.2 Piedmont

Genetic treatments and complete vegetation control significantly affected age 21 chip-n-saw green weight (Table 36). Genetic treatment by vegetation control interactions were not statistically significant. The improved bulk lot planting had the greatest chip-n-saw green weights under both vegetation management treatments, significantly more that either the unimproved planting or the improved single family planting (Table 37, Figure 18). Chip-n-saw green weights were somewhat larger for the improved single family planting than the unimproved planting but this difference was not significant. Although the interaction was not significant, the increase in chip-n-saw green weight from unimproved to improved bulk lot plantings was more pronounced on plots that did not receive complete vegetation control than on those that did. Across the two competition control treatments, the improved bulk lot planting had a 13 ton/ac gain (42.0%) in chip-n-saw green weight as compared to the unimproved planting. This is of a similar magnitude as the 11 ton/ac gain (37.1%) in chip-n-saw green weight from complete vegetation control across genetic treatments.

Table 36. Test of fixed effects (reproduced from SAS® output) for chip-n-saw green weight o.b. to a 6-in. top o.b. (tons/ac) of loblolly pine at age 21 in the Piedmont.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	15.4	9.65	0.0019
Competition Control	1	7.7	22.75	0.0015
Genetics* Competition Control	2	18.3	1.81	0.1926

Table 37. Summary of least squares means for chip-n-saw green weight o.b. to a 6-in. top o.b. (tons/ac) of loblolly pine at age 21 in the Piedmont.

	No Control	Complete Control	Average
Unimproved	23.1	37.3	30.2
Bulk Lot	40.5	45.4	42.9
Single Family	26.1	40.5	33.3
Average	29.9	41.0	35.4

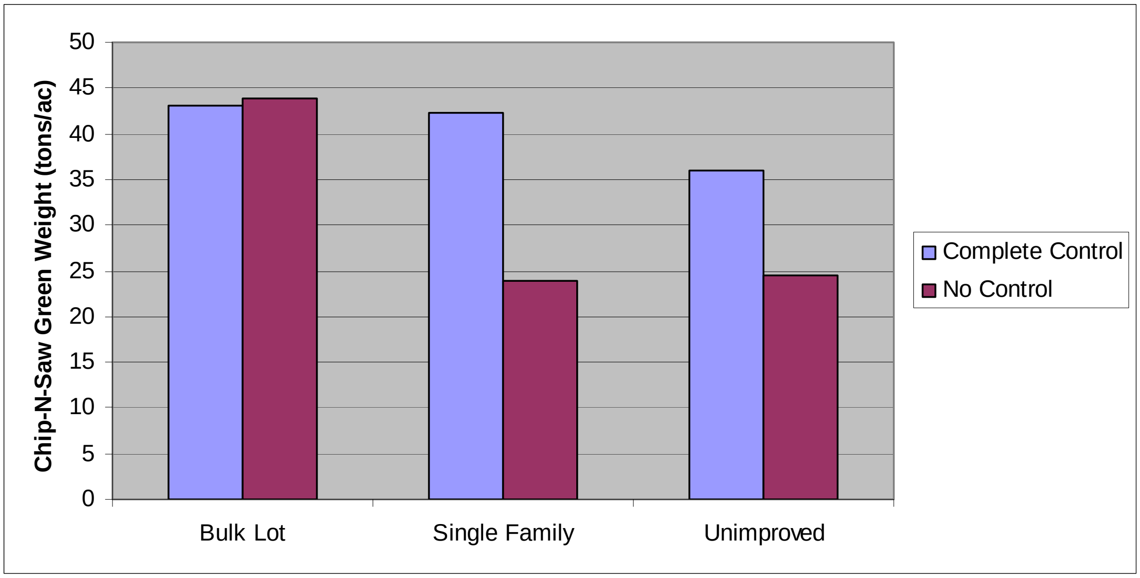

Figure 18. Chip-n-saw green weight (6-in. top) per acre by treatment for 21-yr-old loblolly pine in the Piedmont.

3.9 Trees per Acre

3.9.1 Coastal Plain

There were significantly less trees per acre on plots receiving complete competition control (587 TPA) than on plots without complete competition control (616 TPA) (Tables 38 and 39, Figure 19). Genetic treatment and the genetic by competition control interaction were not significant. This finding of lower trees per acre for the complete vegetation control plot at age 21 was not observed in analysis at earlier ages (Harrison and Shiver, 2005; Logan and Shiver, 2002).

Table 38. Test of fixed effects (reproduced from SAS® output) for trees per acre of loblolly pine at age 21 in the Coastal Plain.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	18.3	1.24	0.3121
Competition Control	1	9.15	7.90	0.0200
Genetics* Competition Control	2	44.2	0.07	0.9331

Table 39. Summary of least squares means for trees per acre of loblolly pine at age 21 in the Coastal Plain.

	No Control	Complete Control	Average
Unimproved	604	576	590
Bulk Lot	622	598	610
Single Family	621	589	605
Average	616	587	602

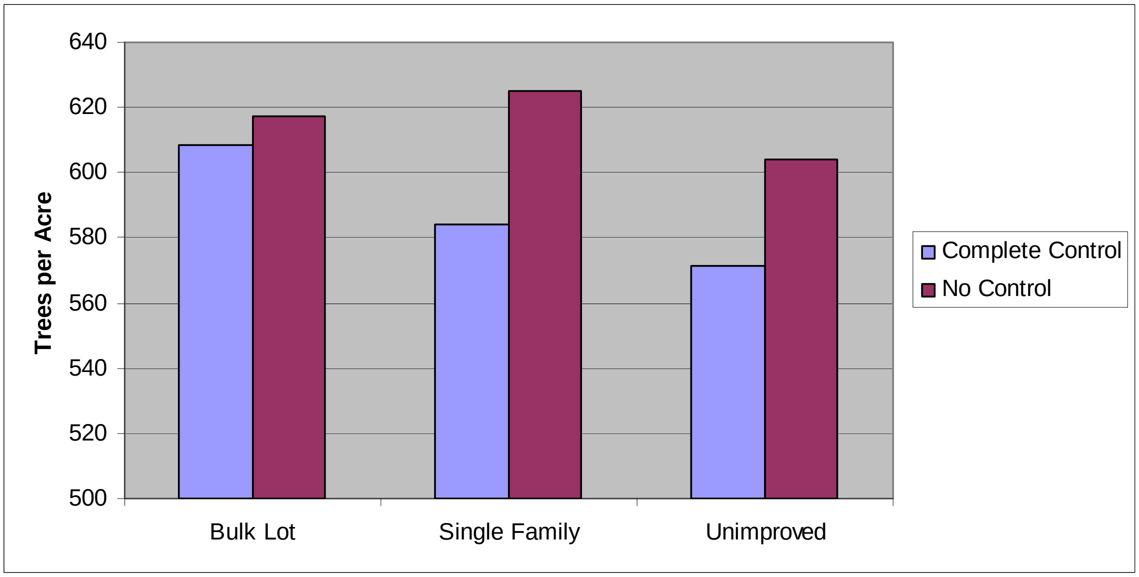

Figure 19. Trees per acre by treatment for 21-yr-old loblolly pine in the Coastal Plain.

3.9.2 Piedmont

There were no significant differences in trees per acre due to genetics or competition control or their interaction in the Piedmont (Table 40). Trees per acre ranged from 521 on plots with improved, bulk lot plantings without complete competition control to 568 on plots with improved, single family plantings without complete competition control (Figure 20).

Table 40. Test of fixed effects (reproduced from SAS® output) for trees per acre of loblolly pine at age 21 in the Piedmont.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	18.9	0.82	0.4564
Competition Control	1	8.5	0.08	0.7902
Genetics* Competition Control	2	41.4	1.40	0.2589

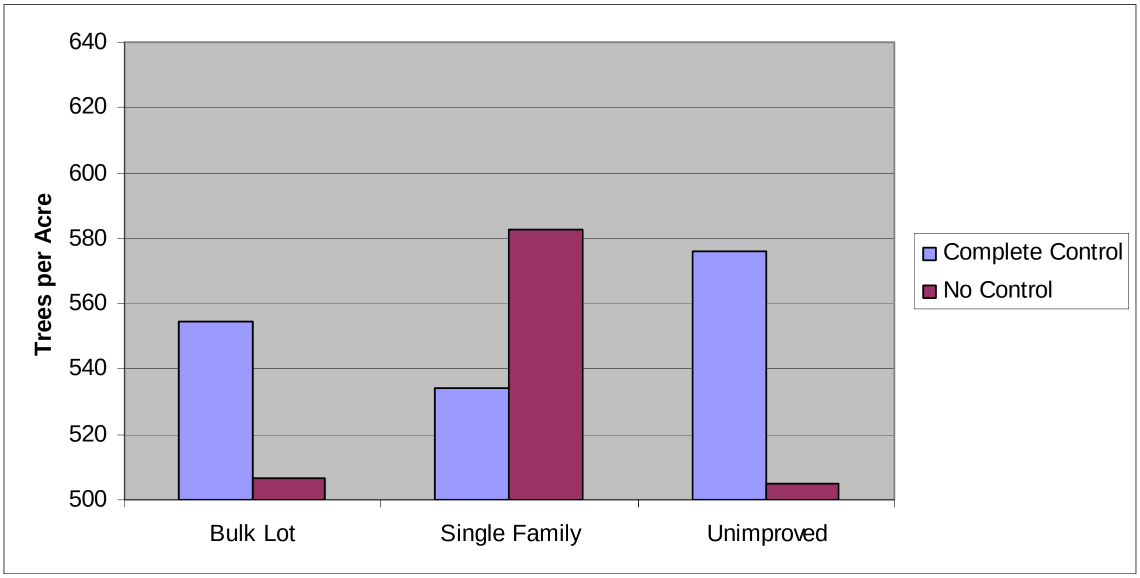

Figure 20. Trees per acre by treatment for 21-yr-old loblolly pine in the Piedmont.

3.10 Percent Fusiform Infection

3.10.1 Coastal Plain

Genetic improvement significantly reduced infection rates (Table 41). There were no significant differences between improved genetics treatments, both of which reduced percent fusiform infections from the 20.6% observed for unimproved stock. Rust rates were slightly greater on plantings receiving complete vegetation control (14%) as compared to those without complete vegetation control (12%). There being no interactions, main effect trends were consistently observed (Table 42, Figure 21).

Table 41. Test of fixed effects (reproduced from SAS® output) for percent fusiform infection on loblolly pine at age 21 in the Coastal Plain.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	16.4	37.82	<0.0001
Competition Control	1	7.8	4.38	0.0707
Genetics* Competition Control	2	41.6	0.39	0.6819

Table 42. Summary of least squares means for percent fusiform infection of loblolly pine at age 21 in the Coastal Plain.

	No Control	Complete Control	Average
Unimproved	19.2%	22.0%	20.6%
Bulk Lot	8.2%	9.7%	8.9%
Single Family	9.3%	10.5%	9.9%
Average	12.2%	14.0%	13.1%

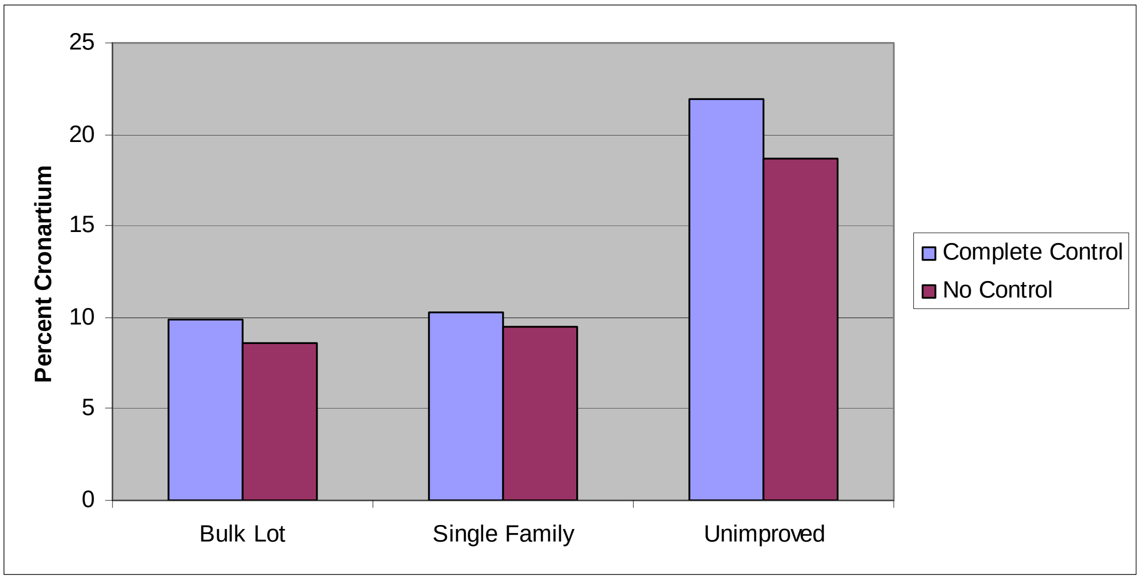

Figure 21. Percent fusiform rust infection by treatment for 21-yr-old loblolly pine in the Coastal Plain.

3.10. 2 Piedmont

Genetic improvement significantly reduced fusiform infection (Table 43). There were no significant differences between bulk lot and single family plantings, each of which decreased percent fusiform infections from the 22.4% for unimproved plantings (Table 44, Figure 22). Rust infection was 13.1% for improved, bulk lot plantings and 16.4% for improved, single family plantings. Rust infection rate did not vary significantly by competition control treatment.

Table 43. Test of fixed effects (reproduced from SAS® output) for percent fusiform infection on loblolly pine at age 21 in the Piedmont.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	18.2	10.13	0.0011
Competition Control	1	9.2	0.83	0.3844
Genetics* Competition Control	2	42.9	1.68	0.1978

Table 44. Summary of least squares means for percent fusiform infection on loblolly pine at age 21 in the Piedmont.

	No Control	Complete Control	Average
Unimproved	20.8%	24.0%	22.4%
Bulk Lot	13.3%	12.9%	13.1%
Single Family	16.4%	16.3%	16.4%
Average	16.8%	17.7%	17.2%

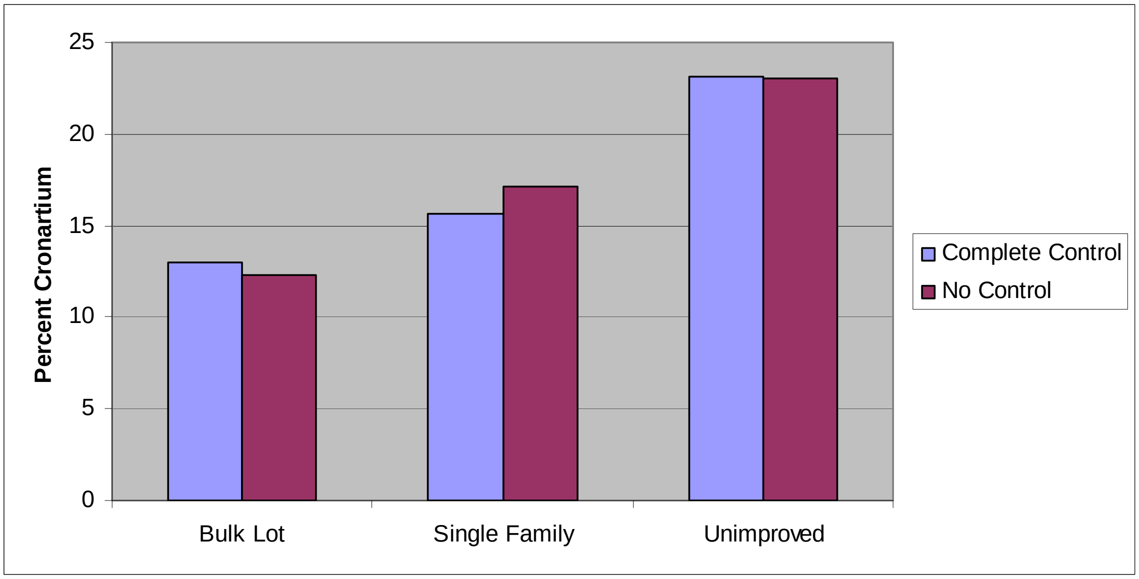

Figure 22. Percent fusiform rust infection by treatment for 21-yr-old loblolly pine in the Piedmont.

3.11 Percent Defect-Free Trees

3.11.1 Coastal Plain

Genetic improvement led to significant increases in the proportion of trees without major defects (Table 45). For the unimproved treatment, 23.1% of trees were defect-free while improved, bulk lot plots had an average of 42.6% and improved, single family plots had an average of 42.2% defect-free trees (Table 46, Figure 23). Vegetation control did not significantly affect the proportion of defect-free trees.

Table 45. Test of fixed effects (reproduced from SAS® output) for percent defect-free trees of loblolly pine at age 21 in the Coastal Plain.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	21.4	20.81	<0.0001
Competition Control	1	12.7	1.79	0.2050
Genetics* Competition Control	2	19.2	1.00	0.3867

Table 46. Summary of least squares means for percent defect-free trees of loblolly pine at age 21 in the Coastal Plain.

	No Control	Complete Control	Average
Unimproved	24.6%	21.6%	23.1%
Bulk Lot	46.5%	38.6%	42.6%
Single Family	42.6%	41.8%	42.2%
Average	37.9%	34.0%	36.0%

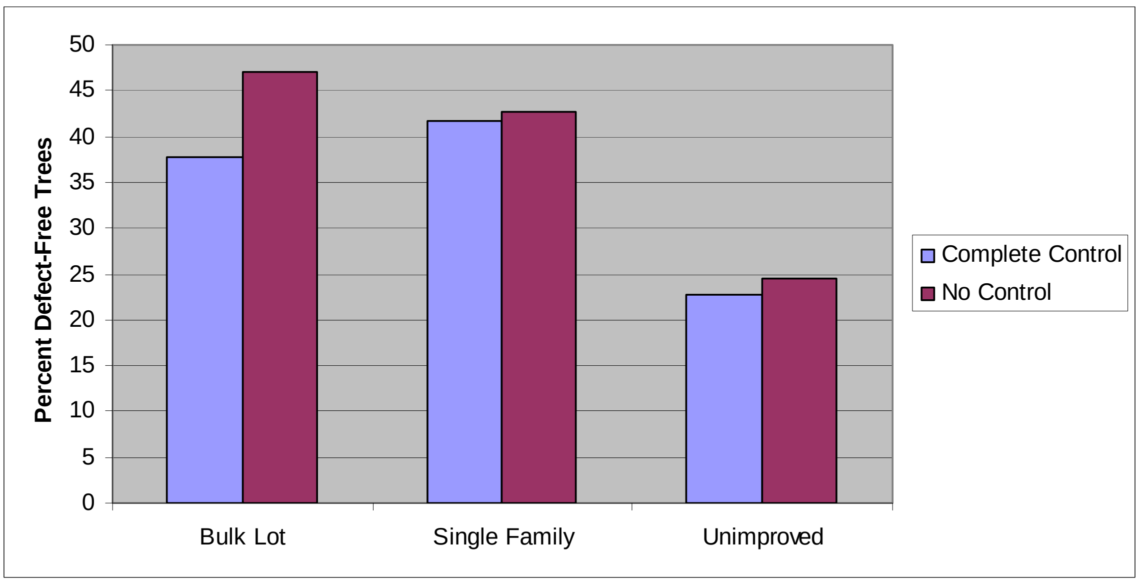

Figure 23. Percent defect-free trees by treatment for 21-yr-old loblolly pine in the Coastal Plain.

3.11. 2 Piedmont

Results for the Piedmont analysis are very similar to those for the Coastal Plain. Genetic improvement significantly contributed to increased proportion of defect-free trees (Table 47). Defect-free trees comprised about 36% of improved plantings as compared to only 22.7% of unimproved plantings (Table 48). There were no significant differences between bulk lot and single family plantings. Vegetation control significantly affected the proportion of defect-free trees at alpha=0.06. There was a consistent trend of a lower percentage of defect-free trees on plots receiving complete vegetation control as compared to plots not receiving complete vegetation control (Figure 24).

Table 47. Test of fixed effects (reproduced from SAS® output) for percent defect-free trees of loblolly pine at age 21 in the Piedmont.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	18.4	9.14	0.0018
Competition Control	1	8.9	4.85	0.0555
Genetics* Competition Control	2	17.5	0.73	0.4963

Table 48. Summary of least squares means for percent defect-free trees of loblolly pine at age 21 in the Piedmont.

	No Control	Complete Control	Average
Unimproved	27.6%	17.8%	22.7%
Bulk Lot	38.7%	33.6%	36.2%
Single Family	37.8%	34.0%	36.0%
Average	34.7%	28.5%	31.6%

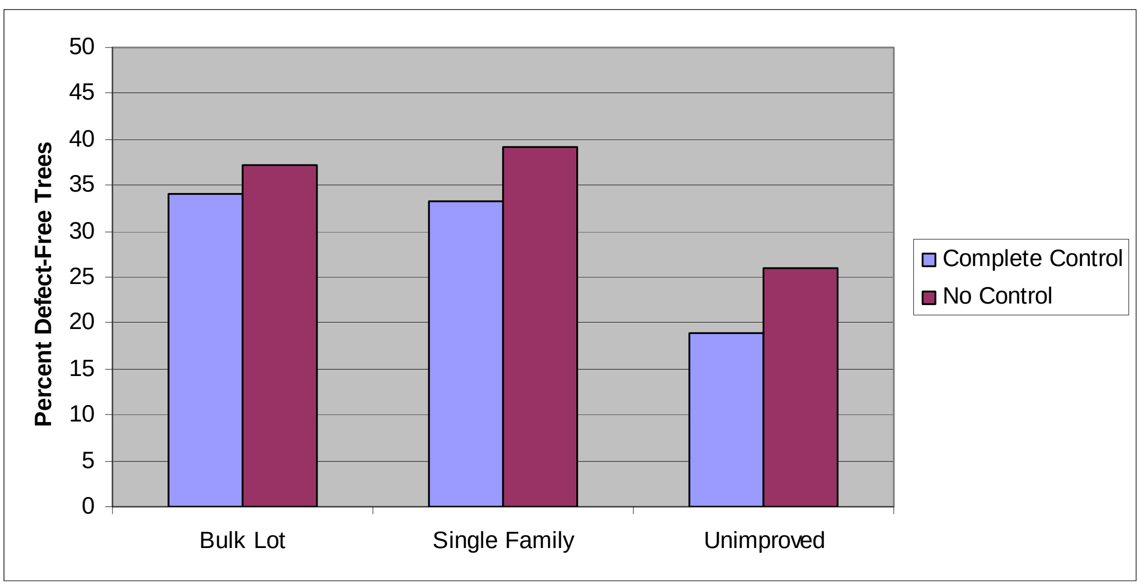

Figure 24. Percent defect-free trees by treatment for 21-yr-old loblolly pine in the Piedmont.

3.12 Percent Forked Trees

3.12.1 Coastal Plain

Genetic improvement significantly affected the proportion of forked trees in the Coastal Plain (Table 49) with the improved, bulk lot planting having a significantly higher (2.8%) proportion of forked trees as compared to the unimproved planting (Table 50 and Figure 25). The vegetation control treatment did not significantly impact the percent of forked trees.

Table 49. Test of fixed effects (reproduced from SAS® output) for percent forked trees of loblolly pine at age 21 in the Coastal Plain.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	16.3	4.01	0.0383
Competition Control	1	10.8	2.37	0.1528
Genetics* Competition Control	2	17.1	1.73	0.2063

Table 50. Summary of least squares means for percent forked trees of loblolly pine at age 21 in the Coastal Plain.

	No Control	Complete Control	Average
Unimproved	1.3%	1.2%	1.3%
Bulk Lot	2.1%	3.5%	2.8%
Single Family	1.6%	2.2%	1.9%
Average	1.7%	2.3%	2.0%

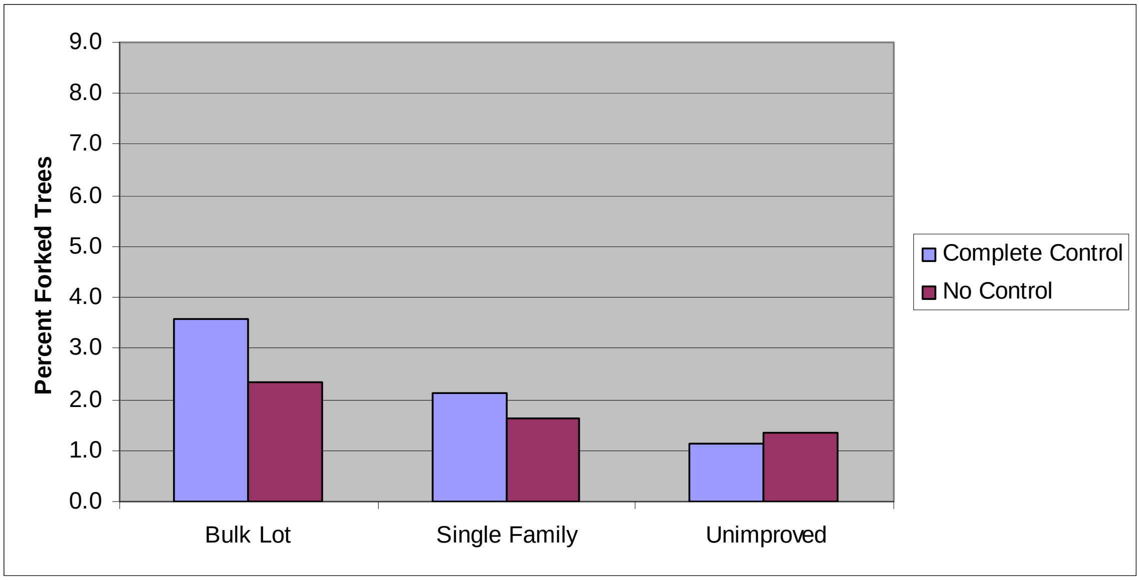

Figure 25. Percent forked trees by treatment for 21-yr-old loblolly pine in the Coastal Plain.

3.12. 2 Piedmont

In the Piedmont region, vegetation control had the only significant effect on the percentage of forked trees (Table 51). Forked trees comprised 6.3% of trees on plots receiving complete vegetation control as compared with 2.9% on plots without complete vegetation control (Table 52 and Figure 26). Forking tended to be greater for improved than unimproved stock but differences among genetic treatments were not significant.

Table 51. Test of fixed effects (reproduced from SAS® output) for percent forked trees of loblolly pine at age 21 in the Piedmont.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	17.1	1.63	0.2241
Competition Control	1	9.0	17.92	0.0022
Genetics* Competition Control	2	43.1	0.28	0.7583

Table 52. Summary of least squares means for percent forked trees of loblolly pine at age 21 in the Piedmont.

	No Control	Complete Control	Average
Unimproved	2.4%	5.0%	3.7%
Bulk Lot	3.5%	7.5%	5.5%
Single Family	2.9%	6.4%	4.6%
Average	2.9%	6.3%	4.6%

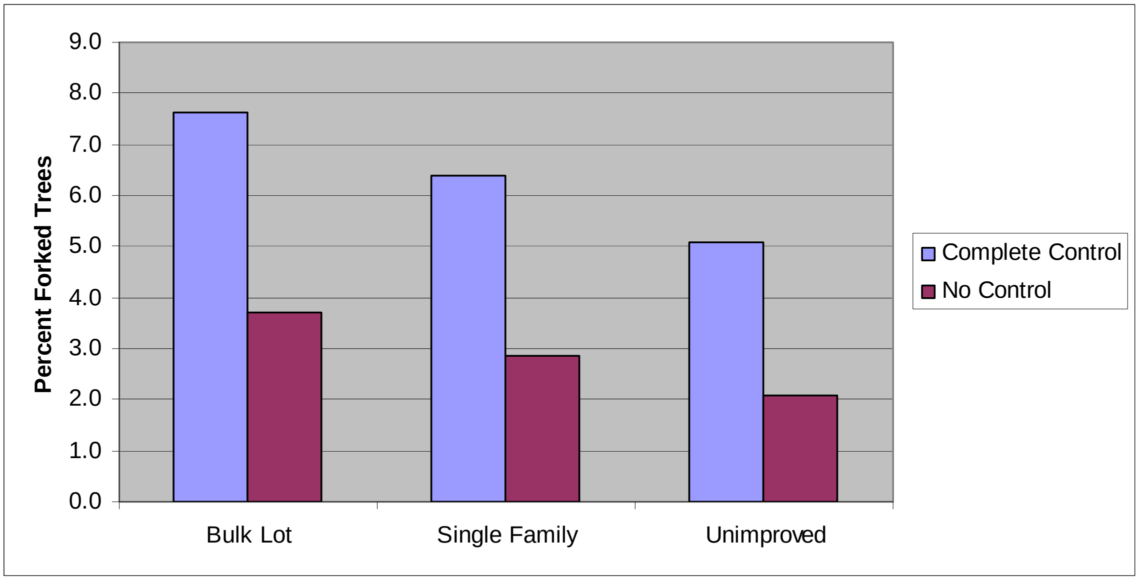

Figure 26. Percent forked trees by treatment for 21-yr-old loblolly pine in the Piedmont.

3.13 Percent of Trees with Crook or Sweep

3.13.1 Coastal Plain

Genetic improvement significantly contributed to reduce the percent of trees with crook or sweep in the Coastal Plain (Tables 53 and 54, Figure 27). Improved stock had a substantially lower percentage of trees with crook or sweep (50.6% for bulk lot plantings and 52.3% for single family plantings) as compared to unimproved stock (68.5%). Bulk lot plantings and single family plantings did not differ significantly in crook or sweep proportion. Vegetation control did not significantly affect the percent of trees with crook or sweep.

Table 53. Test of fixed effects (reproduced from SAS® output) for percent of trees with crook or sweep for loblolly pine at age 21 in the Coastal Plain.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	20.5	17.14	<0.0001
Competition Control	1	14.6	0.33	0.5749
Genetics* Competition Control	2	19.1	0.80	0.4651

Table 54. Summary of least squares means for percent of trees with crook or sweep for loblolly pine at age 21 in the Coastal Plain.

	No Control	Complete Control	Average
Unimproved	68.0%	69.0%	68.5%
Bulk Lot	47.6%	53.6%	50.6%
Single Family	53.0%	51.7%	52.3%
Average	56.2%	58.1%	57.2%

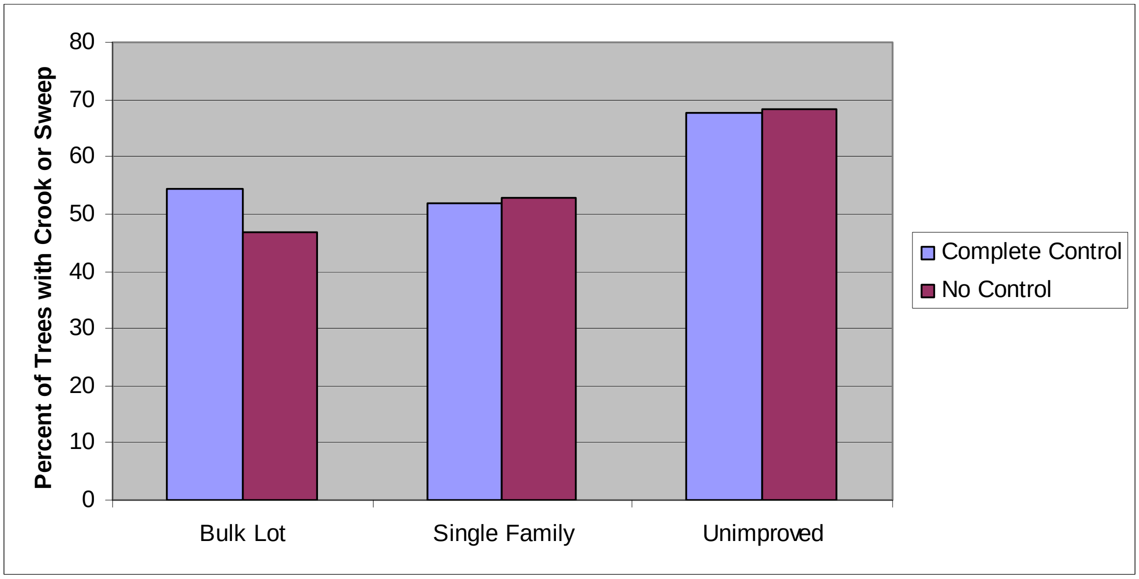

Figure 27. Percent of trees with crook or sweep by treatment for 21-yr-old loblolly pine in the Coastal Plain.

3.13. 2 Piedmont

Results for the Piedmont analysis are very similar to those for the Coastal Plain. Genetic improvement significantly contributed to a reduced percent of trees with crook or sweep (Tables 55 and 56, Figure 28). Improved stock had a substantially lower percentage of trees with crook or sweep (53.4% for bulk lot plantings and 52.6% for single family plantings) as compared to unimproved stock (69.7%). Bulk lot plantings and single family plantings did not differ significantly in crook or sweep proportion. Vegetation control did not significantly affect the percent of trees with crook or sweep.

Table 55. Test of fixed effects (reproduced from SAS® output) for percent of trees with crook or sweep for loblolly pine at age 21 in the Piedmont.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	18.4	4.89	0.0198
Competition Control	1	8.8	1.07	0.3279
Genetics* Competition Control	2	41.9	1.08	0.3493

Table 56. Summary of least squares means for percent of trees with crook or sweep for loblolly pine at age 21 in the Piedmont.

	No Control	Complete Control	Average
Unimproved	61.6%	69.7%	69.7%
Bulk Lot	52.2%	54.6%	53.4%
Single Family	53.4%	52.6%	52.6%
Average	55.7%	59.0%	57.4%

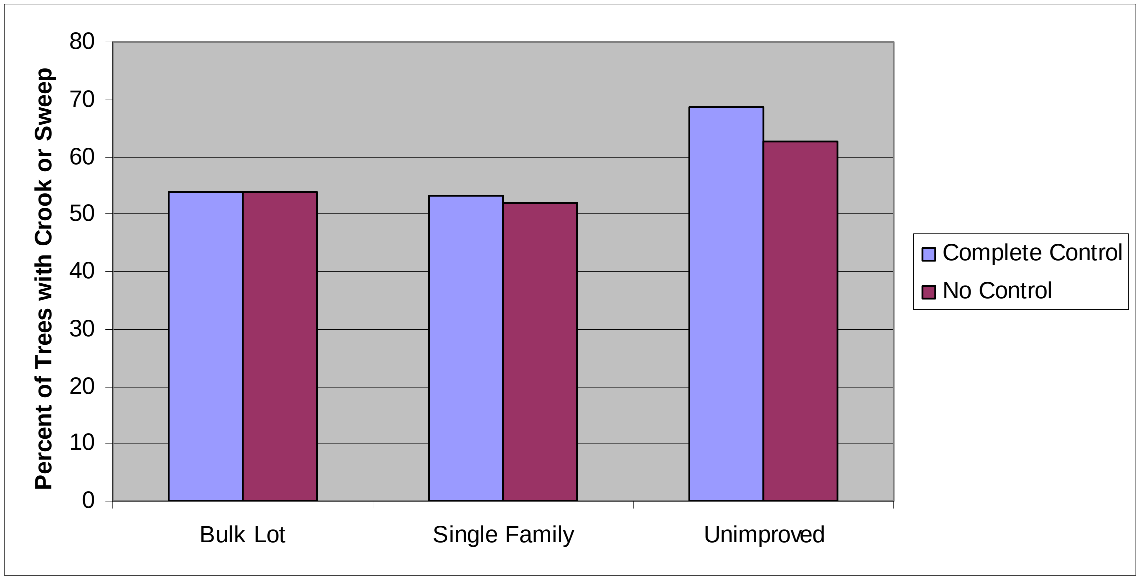

Figure 28. Percent of trees with crook or sweep by treatment for 21-yr-old loblolly pine in the Piedmont.

3.14 Stand Density Index

3.14.1 Coastal Plain

Competition control significantly affected stand density index (Table 57). Stand density index was consistently greater on plots receiving complete vegetation control as compared to plots not receiving complete vegetation control (Table 58, Figure 29). Stand density index tended to be greater for improved plantings as compared with unimproved plantings but genetic treatment differences were not significant.

Table 57. Test of fixed effects (reproduced from SAS® output) for stand density index of loblolly pine at age 21 in the Coastal Plain.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	28.5	2.01	0.1523
Competition Control	1	8.2	29.31	0.0006
Genetics* Competition Control	2	28.9	1.29	0.2915

Table 58. Summary of least squares means for stand density index of loblolly pine at age 21 in the Coastal Plain.

	No Control	Complete Control	Average
Unimproved	329	353	341
Bulk Lot	332	366	349
Single Family	332	376	354
Average	331	365	348

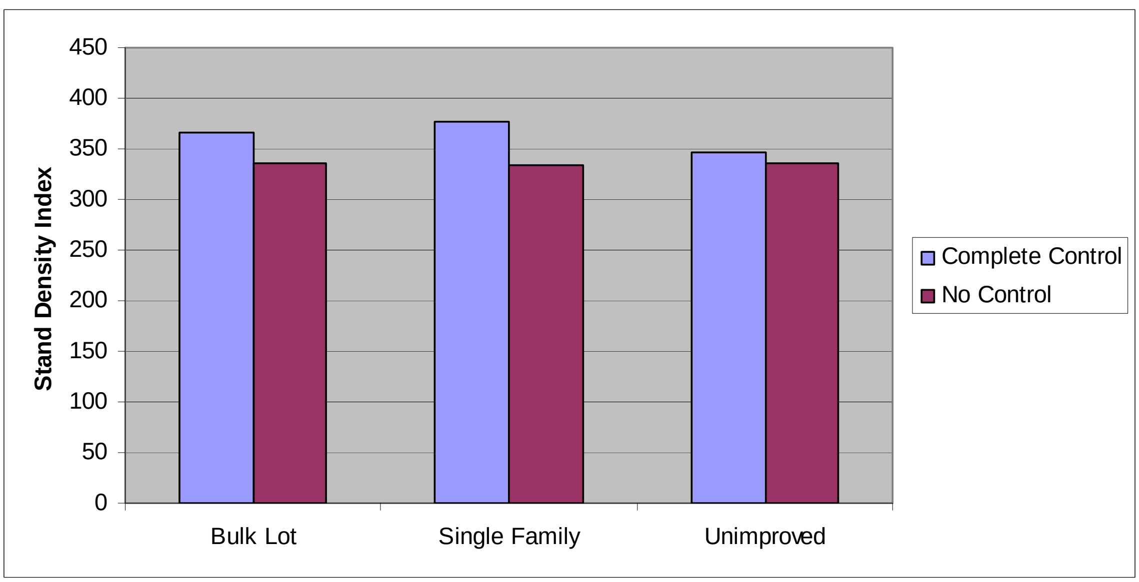

Figure 29. Stand density index by treatment for 21-yr-old loblolly pine in the Coastal Plain.

3.14. 2 Piedmont

Results in the Piedmont mirrored those observed in the Coastal Plain. Competition control significantly affected stand density index (Table 59). Stand density index was consistently greater on plots receiving complete vegetation control as compared to plots not receiving complete vegetation control (Table 60, Figure 30). Stand density index tended to be greater for improved plantings as compared with unimproved plantings but treatment differences were not significant.

Table 59. Test of fixed effects (reproduced from SAS® output) for stand density index of loblolly pine at age 21 in the Piedmont.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	18.1	1.12	0.3494
Competition Control	1	9.0	12.14	0.0068
Genetics* Competition Control	2	17.3	1.38	0.2775

Table 60. Summary of least squares means for stand density index of loblolly pine at age 21 in the Piedmont.

	No Control	Complete Control	Average
Unimproved	322	377	350
Bulk Lot	353	382	368
Single Family	347	378	363
Average	341	379	360

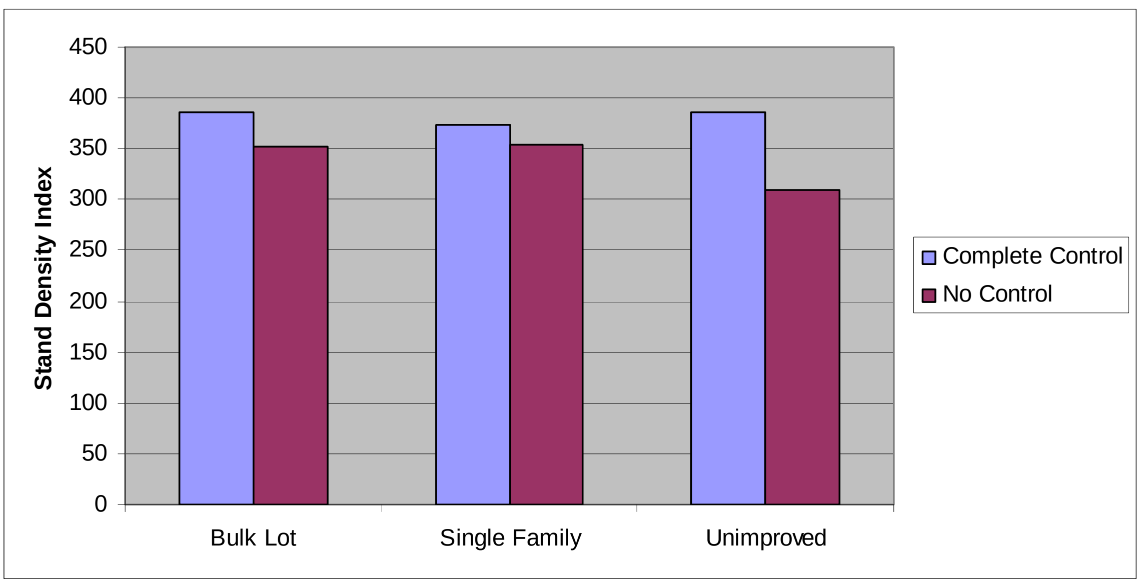

Figure 30. Stand density index by treatment for 21-yr-old loblolly pine in the Piedmont.

3.15 Relative Spacing

3.15.1 Coastal Plain

Both genetics and competition main effects for relative spacing were significant (Table 61). Improved planting stock plots had significantly lower relative densities, 0.143 for bulk lot plantings and 0.141 for single family plantings, as compared to unimproved stock plots with 0.151 (Table 62). Bulk lot and single family improved plantings did not differ significantly in relative spacing. Relative spacing was significantly less on complete vegetation control plots (0.141) in comparison with that on plots not receiving complete vegetation control (0.149). Although the genetic by vegetation control treatment interaction was not significant, the reduction in relative density associated with complete vegetation control was more pronounced for improved than unimproved plantings (Figure 31).

Table 61. Test of fixed effects (reproduced from SAS® output) for relative spacing of loblolly pine at age 21 in the Coastal Plain.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	26.6	6.59	0.0047
Competition Control	1	28.3	11.20	0.0023
Genetics* Competition Control	2	27.5	2.03	0.1510

Table 62. Summary of least squares means for relative spacing of loblolly pine at age 21 in the Coastal Plain.

	No Control	Complete Control	Average
Unimproved	0.1515	0.1503	0.1509
Bulk Lot	0.1489	0.1373	0.1431
Single Family	0.1465	0.1350	0.1407
Average	0.1490	0.1409	0.1450

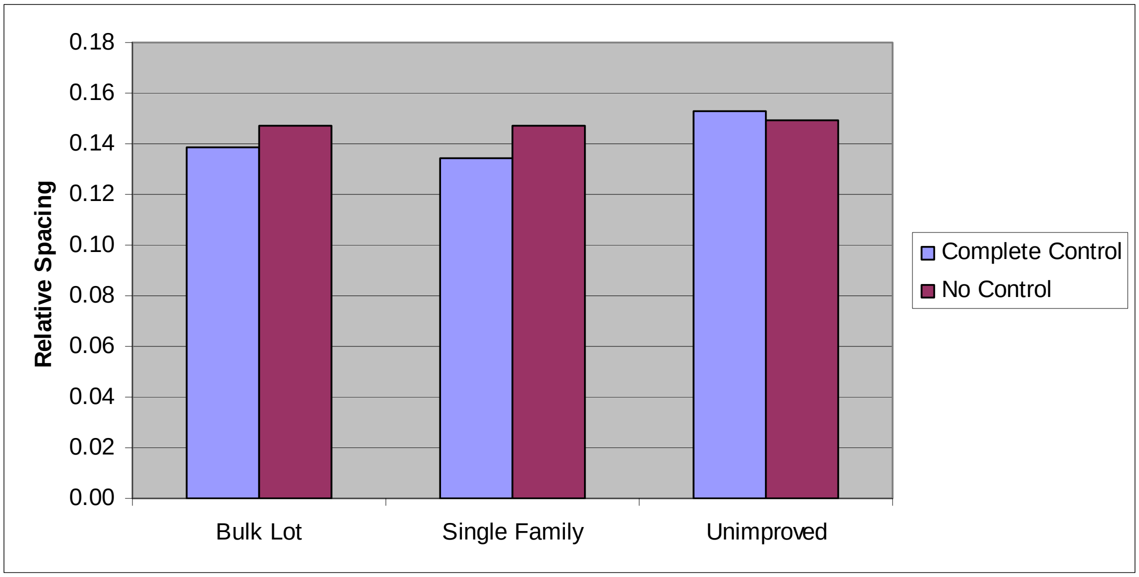

Figure 31. Relative spacing by treatment for 21-yr-old loblolly pine in the Coastal Plain.

3.15. 2 Piedmont

As in the Coastal Plain, both genetics and competition main effects for relative spacing were significant in the Piedmont (Table 63). Improved planting stock plots had significantly lower relative densities, 0.141 for bulk lot plantings and 0.143 for single family plantings, as compared to unimproved stock plots with 0.156 (Table 64). Bulk lot and single family improved plantings did not differ significantly in relative spacing. Relative spacing was significantly less on complete vegetation control plots (0.142) in comparison with that on plots not receiving complete vegetation control (0.152). The reduction in relative density associated with complete vegetation control was consistently observed across genetic treatments (Figure 31).

Table 63. Test of fixed effects (reproduced from SAS® output) for relative spacing of loblolly pine at age 21 in the Piedmont.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	18.4	8.35	0.0026
Competition Control	1	9.0	6.18	0.0345
Genetics* Competition Control	2	17.6	1.15	0.3398

Table 64. Summary of least squares means for relative spacing of loblolly pine at age 21 in the Piedmont.

	No Control	Complete Control	Average
Unimproved	0.1630	0.1494	0.1562
Bulk Lot	0.1438	0.1385	0.1411
Single Family	0.1477	0.1383	0.1430
Average	0.1515	0.1421	0.1468

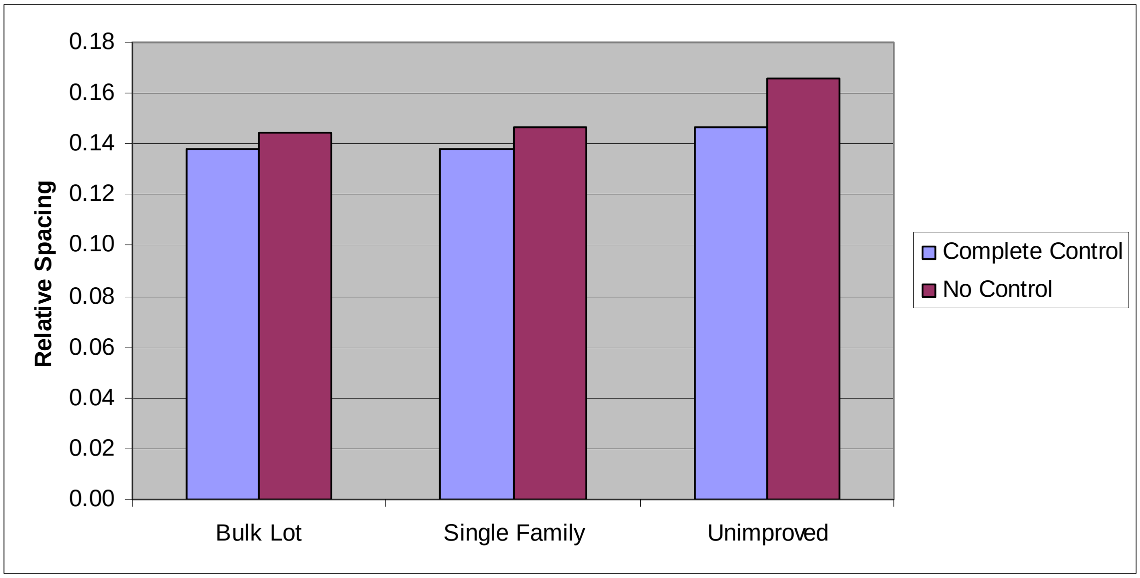

Figure 32. Relative spacing by treatment for 21-yr-old loblolly pine in the Piedmont.

3.16 Average Crown Length

3.16.1 Coastal Plain

Main effects of genetic and vegetation control treatments were significant at alpha=0.10 (Table 65). Average crown length ranged from 19.9 ft for plots without genetic improvement or complete vegetation control to 21.5 ft for plots with improved single family stock and complete competition control (Table 66 and Figure 33). Crown length was least for unimproved stock (20.0 ft), intermediate for improved, bulk lot plantings (20.4 ft), and greatest for improved, single family plantings (21.0 ft) and greater on plots receiving complete competition control (20.7 ft) as compared to plots not receiving complete competition control (20.2 ft).

Table 65. Test of fixed effects (reproduced from SAS® output) for average crown length of loblolly pine at age 21 in the Coastal Plain.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	16.9	3.04	0.0745
Competition Control	1	51.2	3.02	0.0882
Genetics* Competition Control	2	51.8	0.96	0.3884

Table 66. Summary of least squares means for average crown length of loblolly pine in the Coastal Plain.

	No Control	Complete Control	Average
Unimproved	19.9	20.0	20.0
Bulk Lot	20.2	20.6	20.4
Single Family	20.4	21.5	21.0
Average	20.2	20.7	20.4

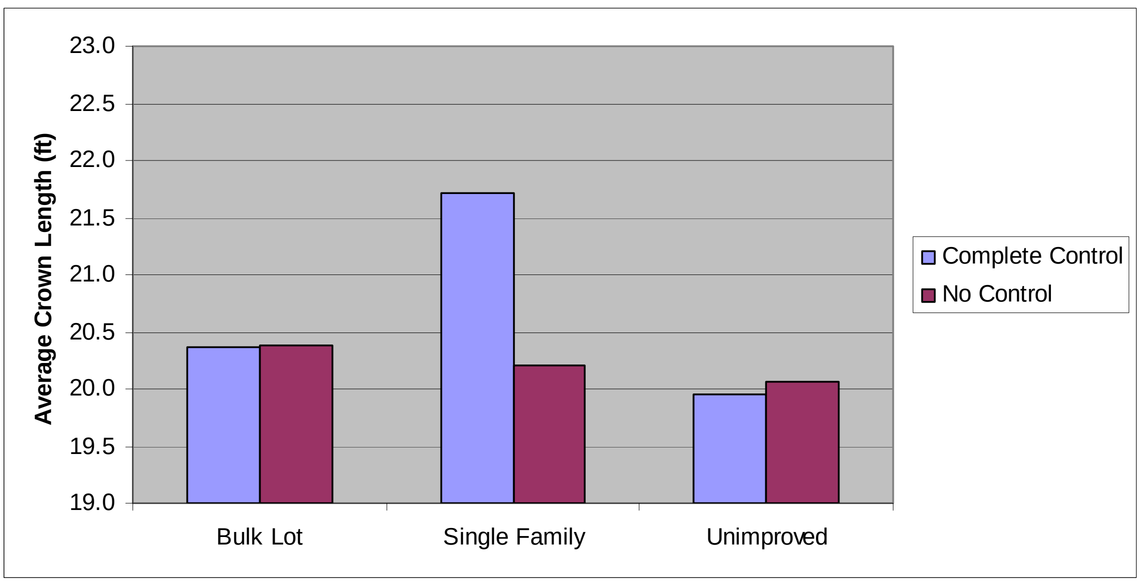

Figure 33. Average crown length by treatment for 21-yr-old loblolly pine in the Coastal Plain.

3.16. 2 Piedmont

Average crown length was not significantly affected by genetic or competition control treatments (Table 67). Average crown length ranged from 21.4 ft on plots with unimproved stock and without complete competition control to 22.5 ft on plots with improved bulk lot plantings with complete competition control (Table 68 and Figure 34).

Table 67. Test of fixed effects (reproduced from SAS® output) for average crown length of loblolly pine at age 21 in the Piedmont.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	16.5	0.78	0.4748
Competition Control	1	49.8	0.35	0.5548
Genetics* Competition Control	2	49.8	0.01	0.9893

Table 68. Summary of least squares means for average crown length of loblolly pine at age 21 in the Piedmont.

	No Control	Complete Control	Average
Unimproved	21.4	21.6	21.5
Bulk Lot	22.3	22.5	22.4
Single Family	21.8	22.2	22.0
Average	21.8	22.1	22.0

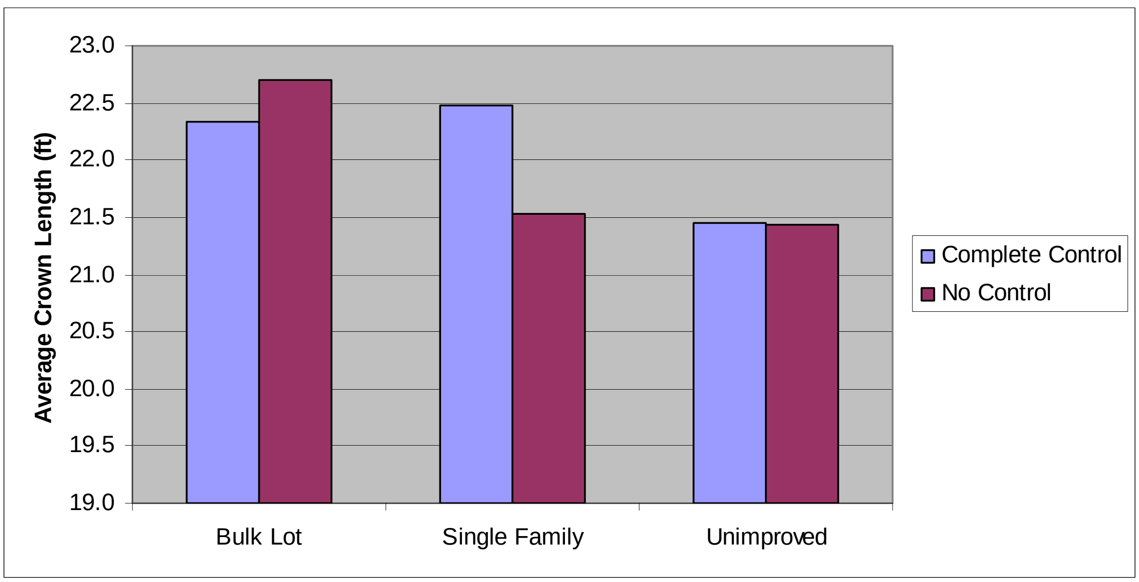

Figure 34. Average crown length by treatment for 21-yr-old loblolly pine in the Piedmont.

3.17 Average Crown Ratio

3.17.1 Coastal Plain

Average crown ratio was significantly affected by competition control treatments (Table 69). Average crown ratio was significantly less on plots receiving complete competition control (0.34) than on plots not receiving complete vegetation control (0.36) (Table 70). The lower crown ratio with complete vegetation control was observed for each of the three genetics treatments (Figure 35). The main genetic treatment effect was significant at alpha=0.10. Average crown ratio was greatest for unimproved plantings (0.355), intermediate for improved, single family plantings (0.345), and least for improved, bulk lot plantings (0.343).

Table 69. Test of fixed effects (reproduced from SAS® output) for average crown ratio of loblolly pine at age 21 in the Coastal Plain.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	15.0	2.71	0.0990
Competition Control	1	8.1	14.08	0.0055
Genetics* Competition Control	2	37.5	0.24	0.7904

Table 70. Summary of least squares means for average crown ratio of loblolly pine at age 21 in the Coastal Plain.

	No Control	Complete Control	Average
Unimproved	0.36	0.35	0.35
Bulk Lot	0.36	0.33	0.34
Single Family	0.36	0.34	0.35
Average	0.36	0.34	0.35

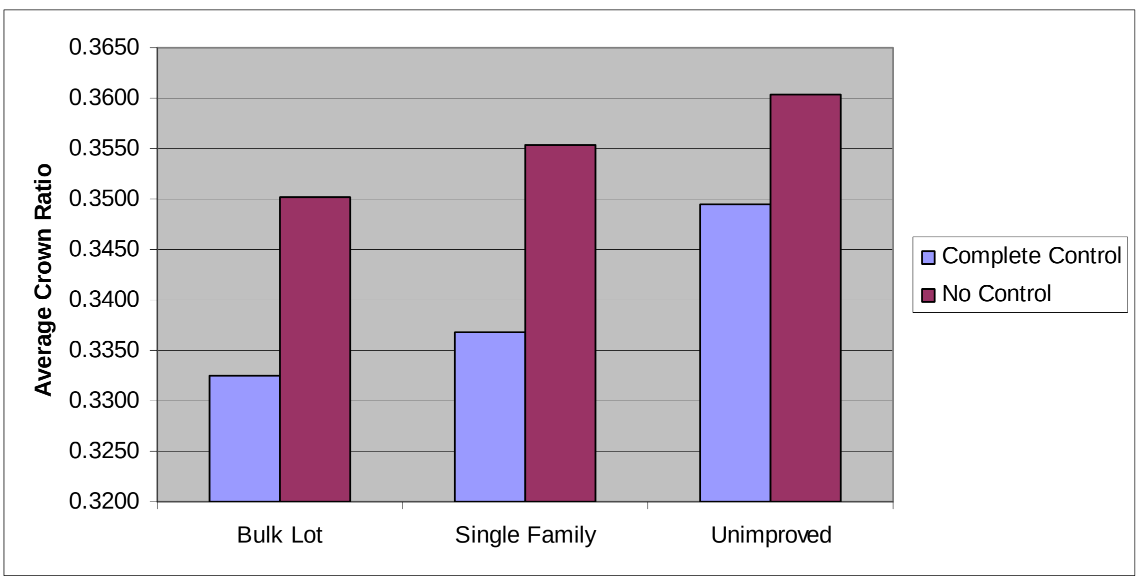

Figure 35. Average crown ratio by treatment for 21-yr-old loblolly pine in the Coastal Plain.

3.17. 2 Piedmont

Results in the Piedmont were similar to those observed for the Coastal Plain. Average crown ratio was significantly affected by competition control treatments (Table 71). Average crown ratio was significantly less on plots receiving complete competition control (0.35) than on plots not receiving complete vegetation control (0.36) (Table 72). The lower crown ratio with complete vegetation control was observed for each of the three genetics treatments (Figure 36). The main genetic treatment effect was significant at alpha=0.10. Average crown ratio was greatest for unimproved plantings (0.371), intermediate for improved, single family plantings (0.348), and least for improved, bulk lot plantings (0.346).

Table 71. Test of fixed effects (reproduced from SAS® output) for average crown ratio of loblolly pine at age 21 in the Piedmont.

Source	Numerator Df	Denominator Df	Type III F	Pr > F
Genetics	2	17.8	2.90	0.0814
Competition Control	1	48.8	8.25	0.0060
Genetics* Competition Control	2	48.9	1.15	0.3242

Table 72. Summary of least squares means for average crown ratio of loblolly pine at age 21 in the Piedmont.

	No Control	Complete Control	Average
Unimproved	0.38	0.36	0.37
Bulk Lot	0.35	0.34	0.34
Single Family	0.36	0.34	0.35
Average	0.36	0.35	0.36

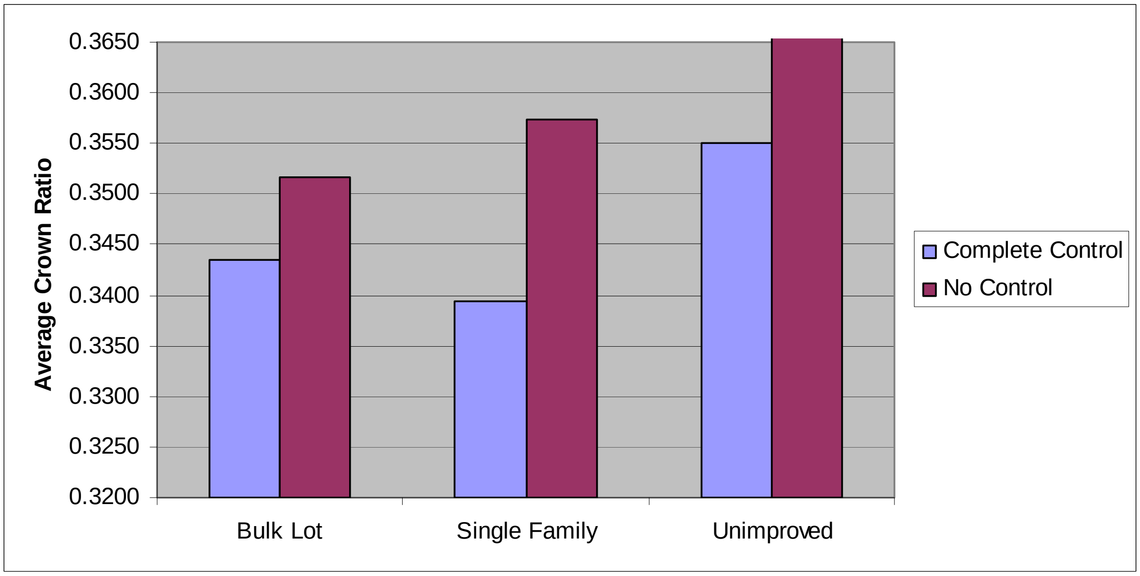

Figure 36. Average crown ratio by treatment for 21-yr-old loblolly pine in the Piedmont.

4. PERIODIC INCREMENT FROM AGE 18 TO AGE 21

4.1 Coastal Plain

For the age 18 to 21 year period, improved genetic plantings exhibited greater increment in volume and weight than unimproved plantings (Table 73). During this period, basal area per acre increment on plots receiving complete competition control was less than that on plots with operational site preparation only, continuing a trend observed since age 12 (Harrison and Shiver, 2005; Logan and Shiver, 2003). There were no genetic by competition control treatment interactions.

Table 73. Summary of results from statistical analysis of periodic increment of loblolly pine from age 18 to age 21 in the Coastal Plain.

	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	*	NS	Complete vegetation control had less growth than not complete control.
Total O.B. Volume per Acre	*	NS	NS	Improved genetics had greater periodic growth than unimproved.
Merchantable O.B. Volume per Acre	NT	NT	NT	
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=0.05; NT indicates unable to test with mixed model.

4.2 Piedmont

There were no significant effects of genetic and competition control treatments on periodic growth from age 18 to 21 years (Table 74).

Table 74. Summary of results from statistical analysis of periodic increment of loblolly pine from age 18 to age 21 in the Piedmont.

	Effect			
Periodic Growth Attribute	Genetics (G)	Competition Control (CC)	G x CC Interaction	Comment
	Prob. > F[a]			
Average DBH	NS	0.12	NS	Complete competition control plots had less periodic growth than plots not receiving complete competition control
Average Dominant Height	NS	NS	NS	
Average Basal Area per Acre	0.14	NS	NS	Improved genetics had less growth than unimproved planting.
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=0.05

5. GROWTH THROUGH AGE 21

5.1 Average Dbh

5.1.1 Coastal Plain

Patterns of average dbh with age are presented by genetics main effects (Figure 37), competition control main effects (Figure 38), and for each genetic by competition control treatment combination (Figure 39).

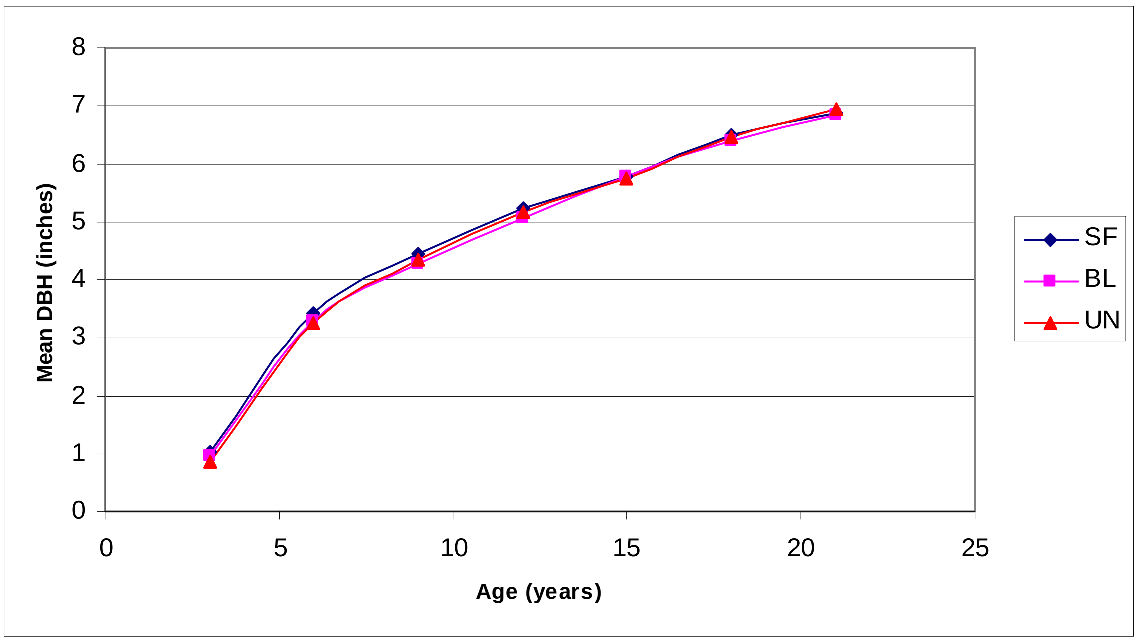

Figure 37. Mean dbh of loblolly pine by age for improved single family (SF), improved bulk lot (BL) and unimproved plantings in the Coastal Plain through age 21

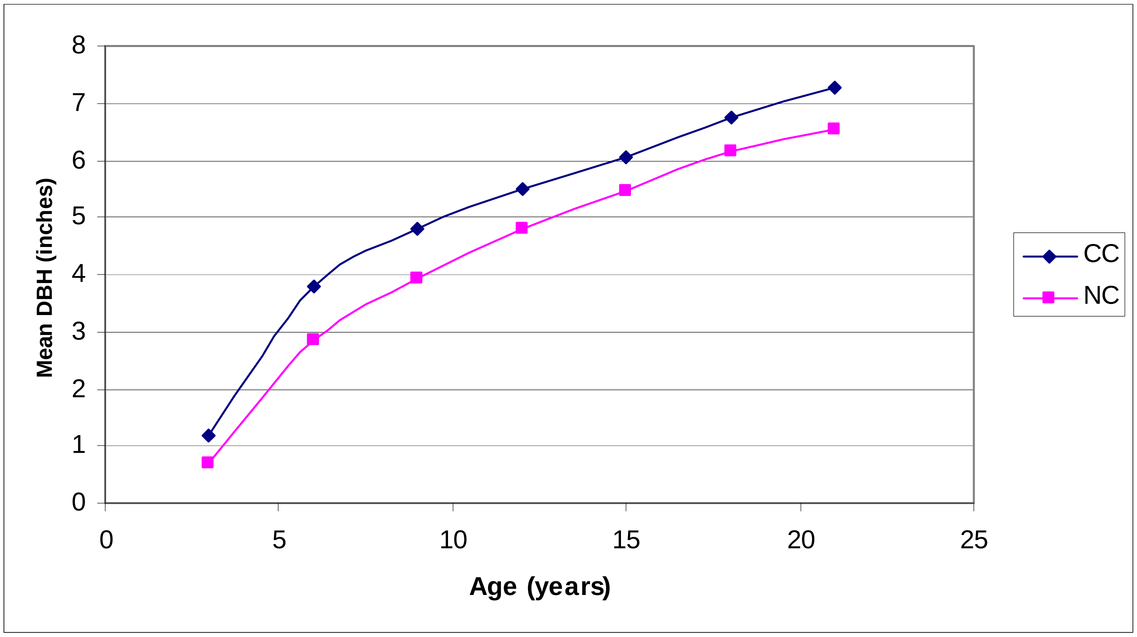

Figure 38. Mean dbh of loblolly pine by age for complete competition control (CC) and without complete competition control (NC) in the Coastal Plain through age 21.

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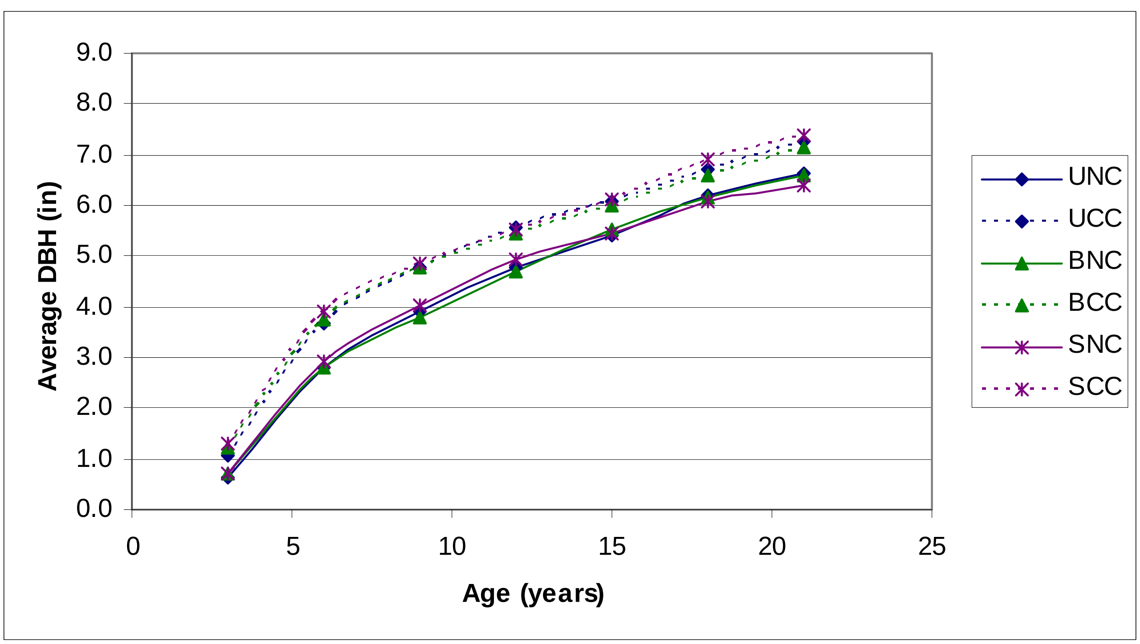

Figure 39. Mean dbh of loblolly pine by age for the six genetic by competition control treatment combinations in the Coastal Plain through age 21.

5.1.2 Piedmont

Patterns of average dbh with age are presented by genetics main effects (Figure 40), competition control main effects (Figure 41), and for each genetic by competition control treatment combination (Figure 42).

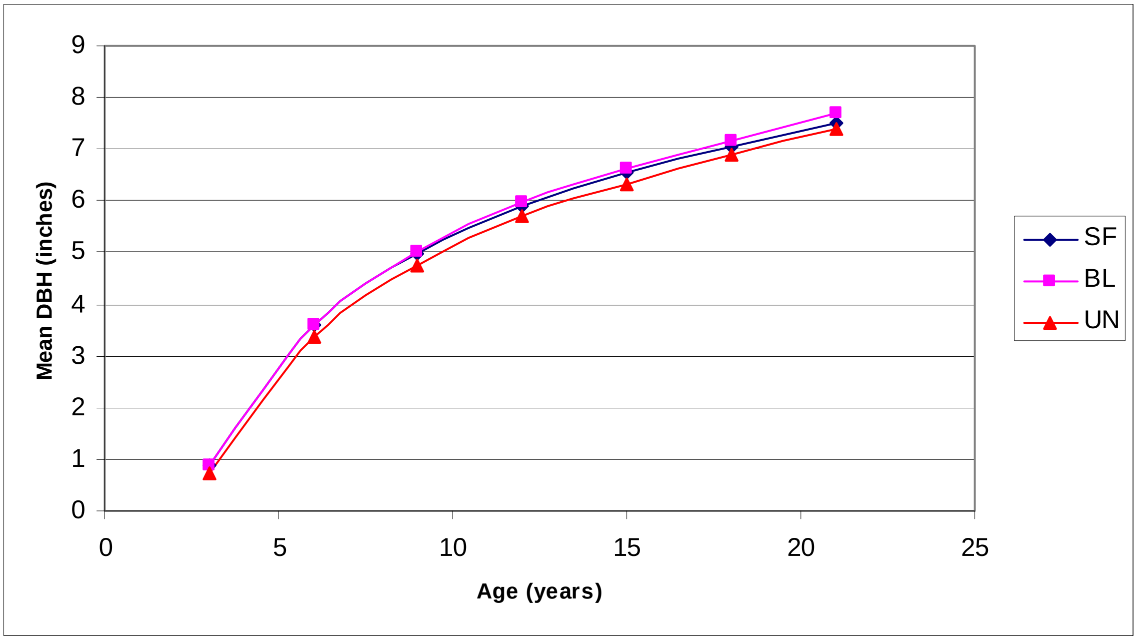

Figure 40. Mean dbh of loblolly pine by age for improved single family (SF), improved bulk lot (BL) and unimproved plantings in the Piedmont through age 21.

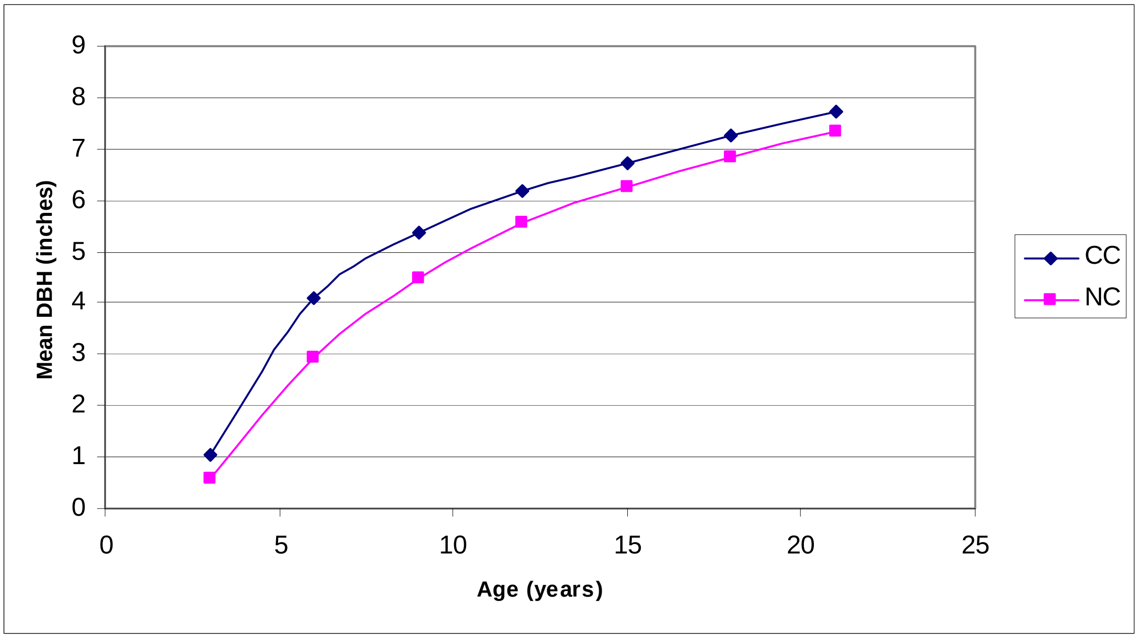

Figure 41. Mean dbh of loblolly pine by age for complete competition control (CC) and without complete competition control (NC) age in the Piedmont through age 21.

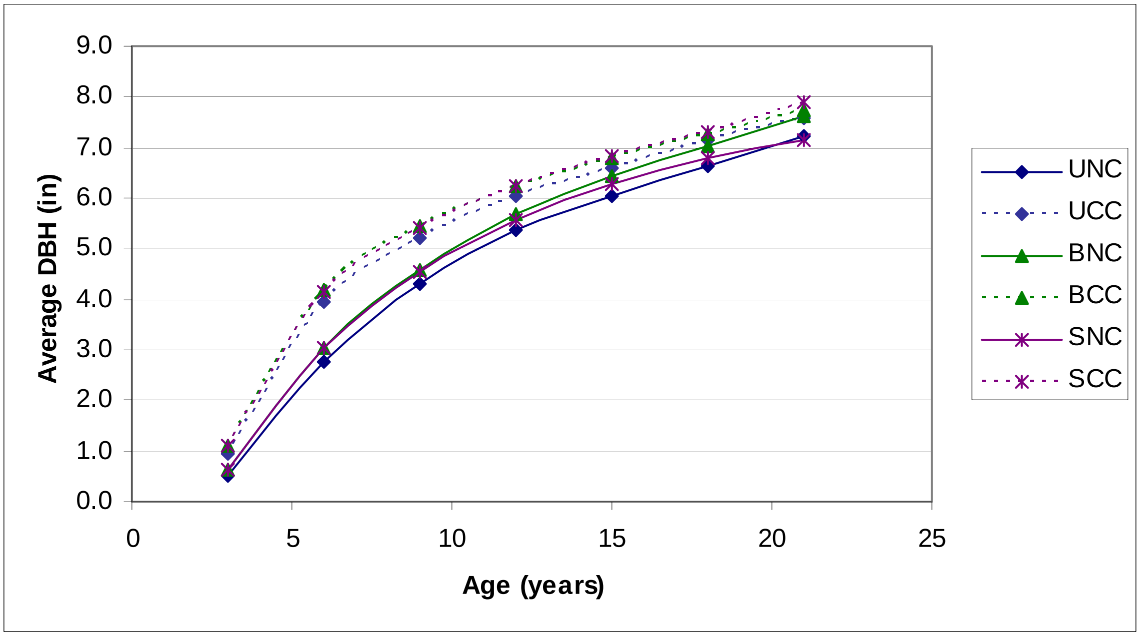

Figure 42. Mean dbh of loblolly pine by age for the six genetic by competition control treatment combinations in the Piedmont through age 21.

5.2 Average Dominant Height

5.2.1 Coastal Plain

Patterns of average dominant height with age are presented by genetics main effects (Figure 43), competition control main effects (Figure 44), and for each genetic by competition control treatment combination (Figure 45).

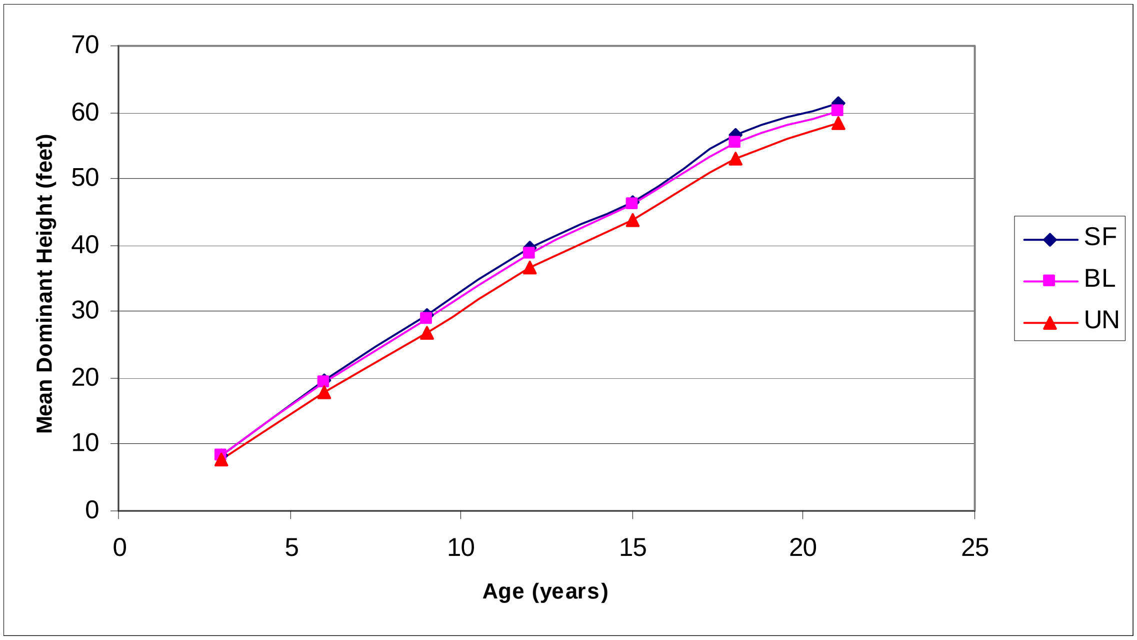

Figure 43. Mean dominant height of loblolly pine by age for improved single family (SF), improved bulk lot (BL) and unimproved plantings in the Coastal Plain through age 21.

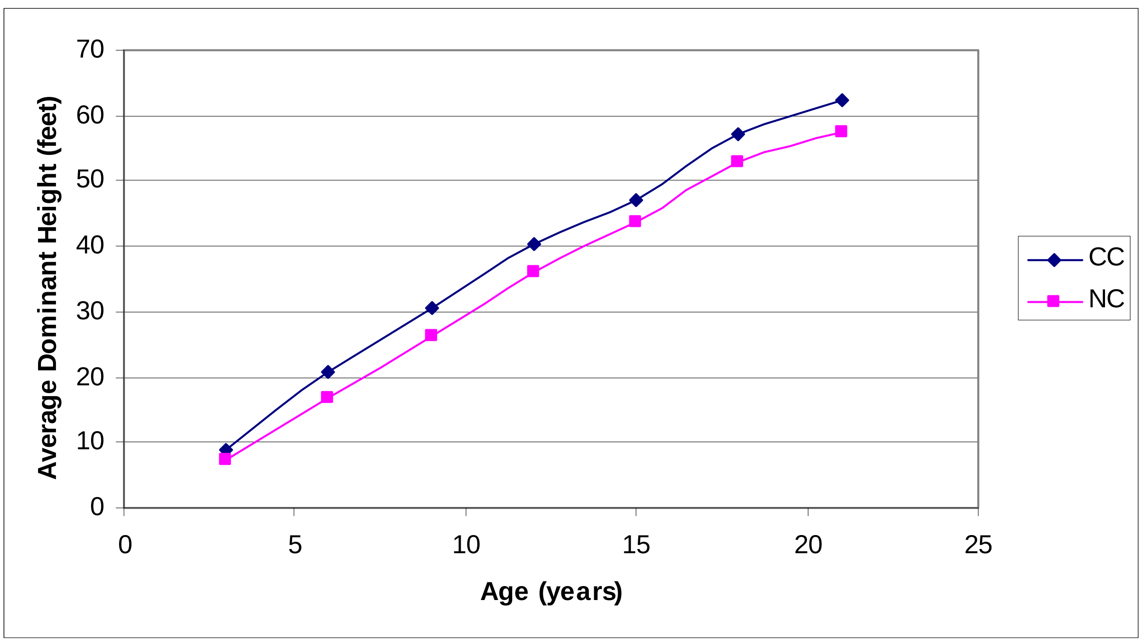

Figure 44. Mean dominant height of loblolly pine by age for complete competition control (CC) and without complete competition control (NC) in the Coastal Plain through age 21.

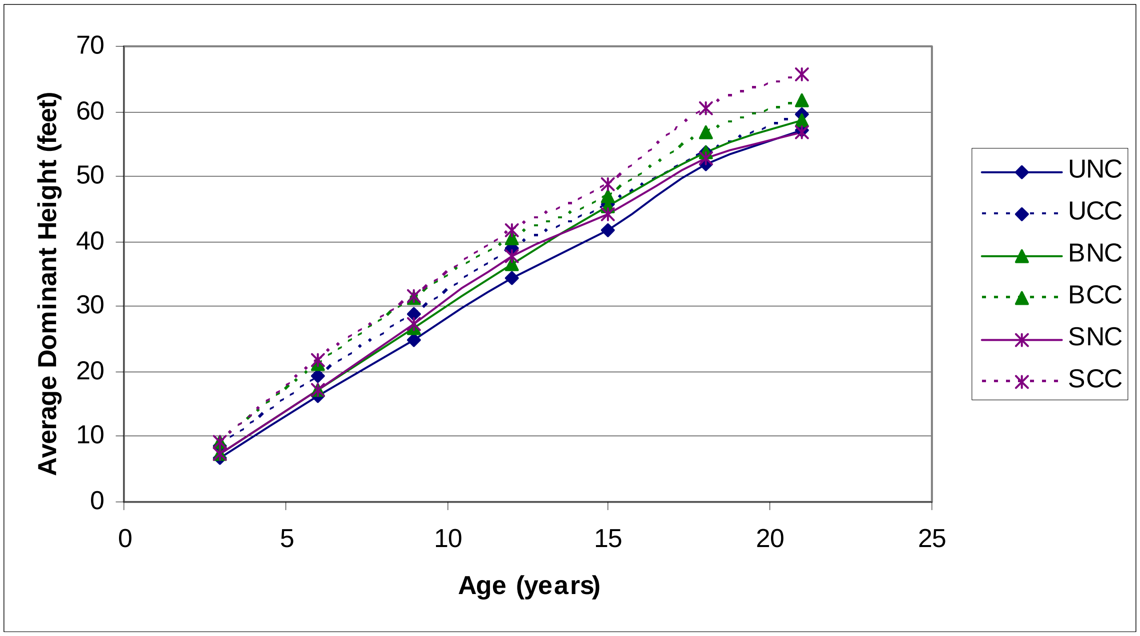

Figure 45. Mean dominant height of loblolly pine by age for the six genetic by competition control treatment combinations in the Coastal Plain through age 21.

5.2.2 Piedmont

Patterns of average dominant height with age are presented by genetics main effects (Figure 46), competition control main effects (Figure 47), and for each genetic by competition control treatment combination (Figure 48).

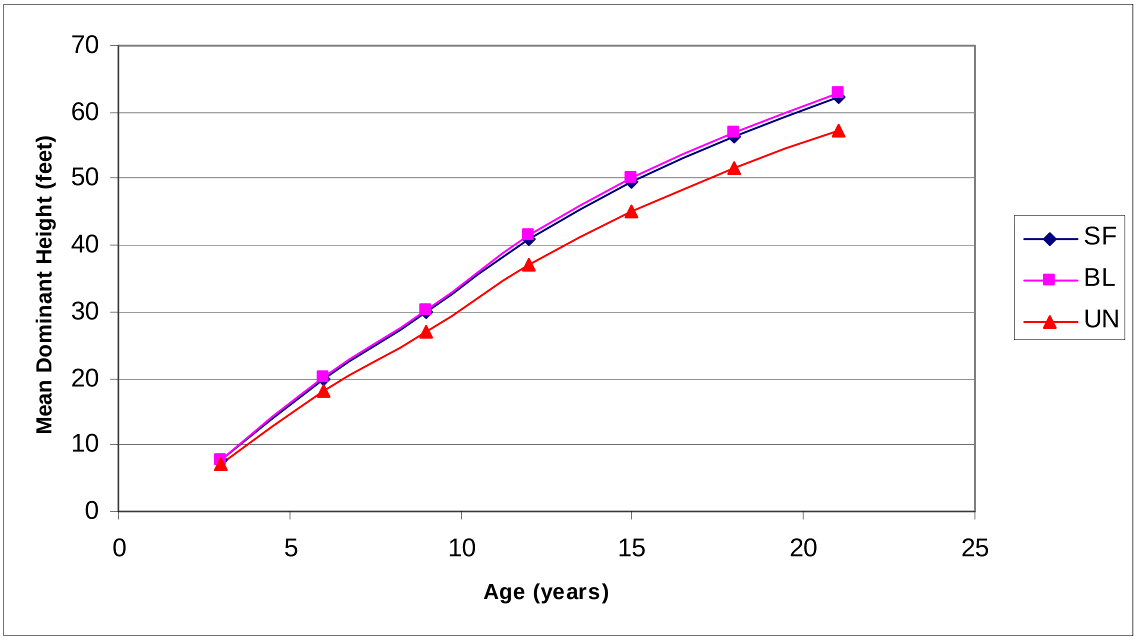

Figure 46. Mean dominant height of loblolly pine by age for improved single family (SF), improved bulk lot (BL) and unimproved plantings in the Piedmont through age 21.

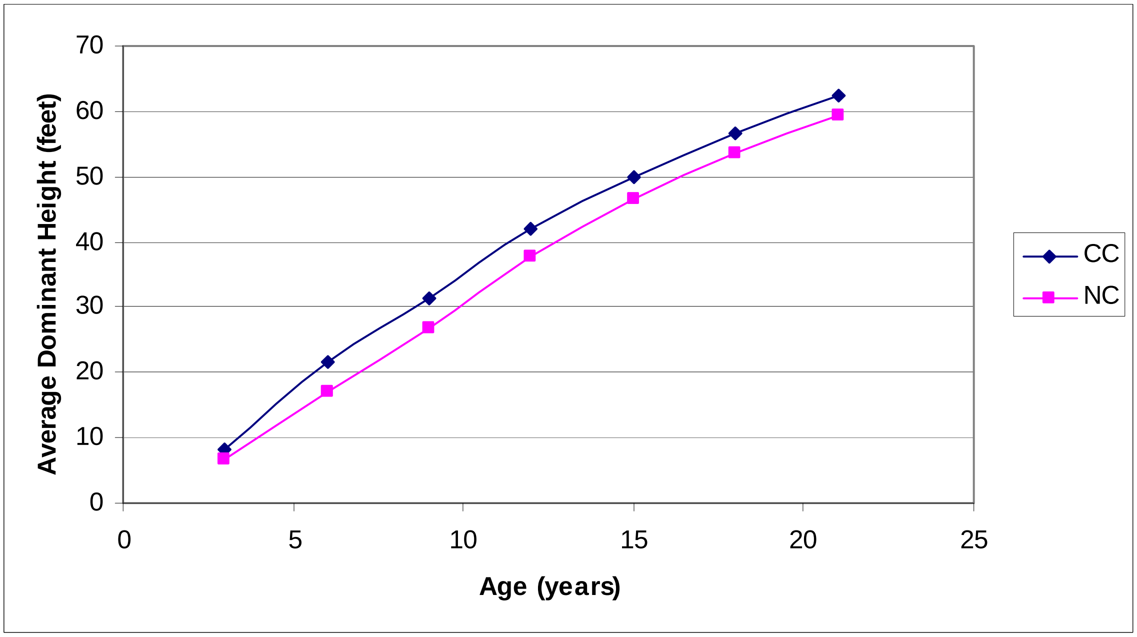

Figure 47. Mean dominant height of loblolly pine by age for complete competition control (CC) and without complete competition control (NC) in the Piedmont through age 21.

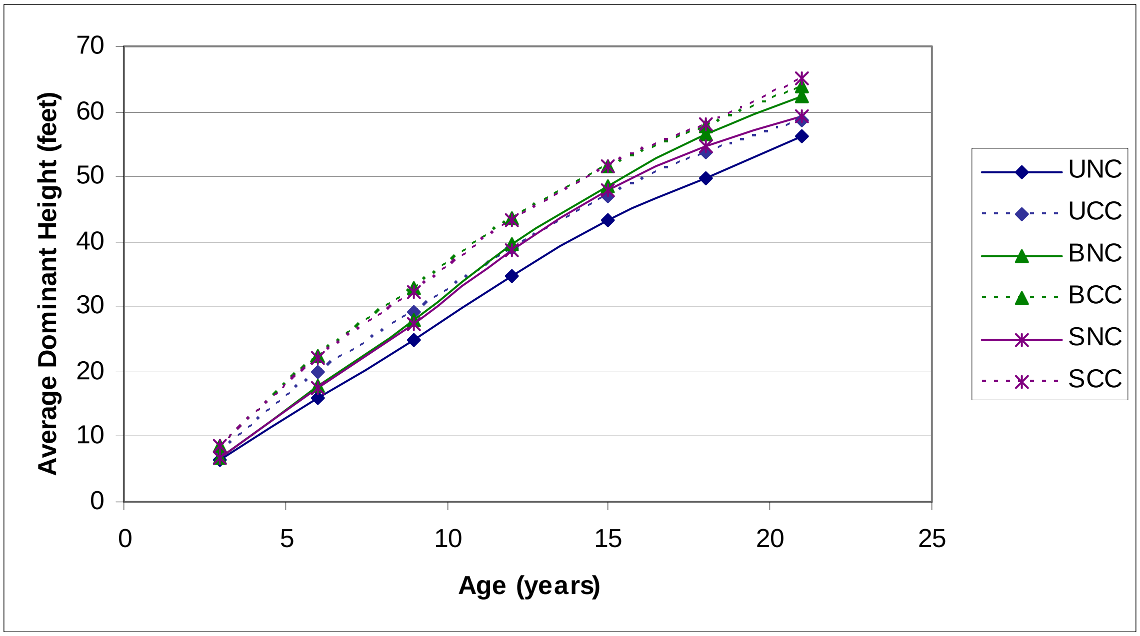

Figure 48. Mean dominant height of loblolly pine by age for the six genetic by competition control treatment combinations in the Piedmont through age 21.

5.3 Basal Area per Acre

5.3.1 Coastal Plain

Patterns of basal area per acre with age are presented by genetics main effects (Figure 49), competition control main effects (Figure 50), and for each genetic by competition control treatment combination (Figure 51).

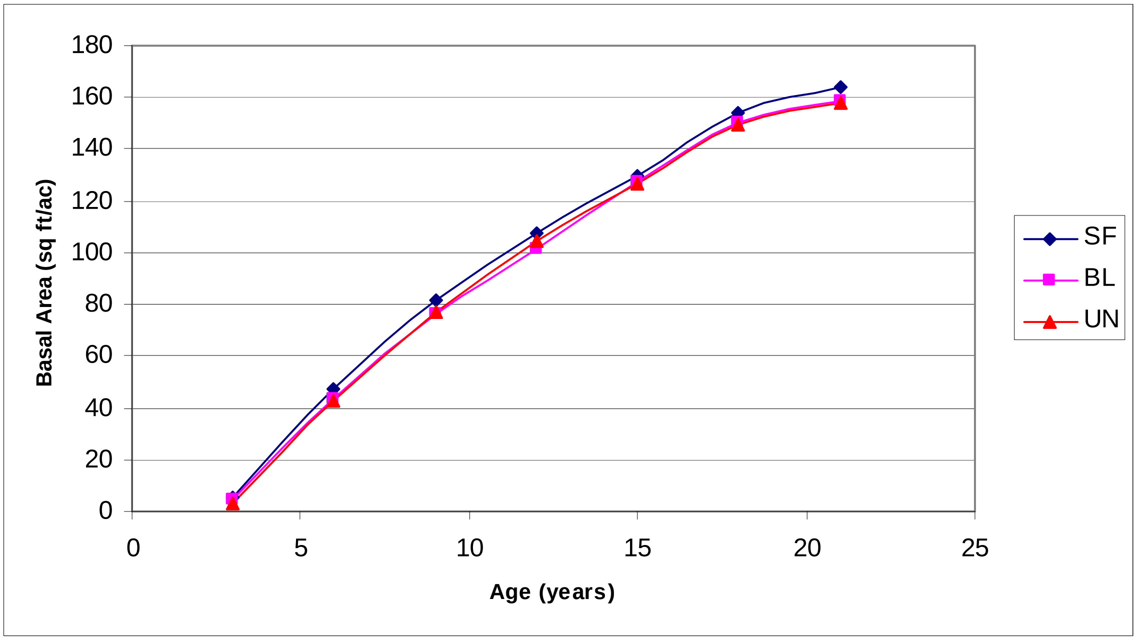

Figure 49. Mean basal area per acre of loblolly pine by age for improved single family (SF), improved bulk lot (BL) and unimproved plantings in the Coastal Plain through age 21.

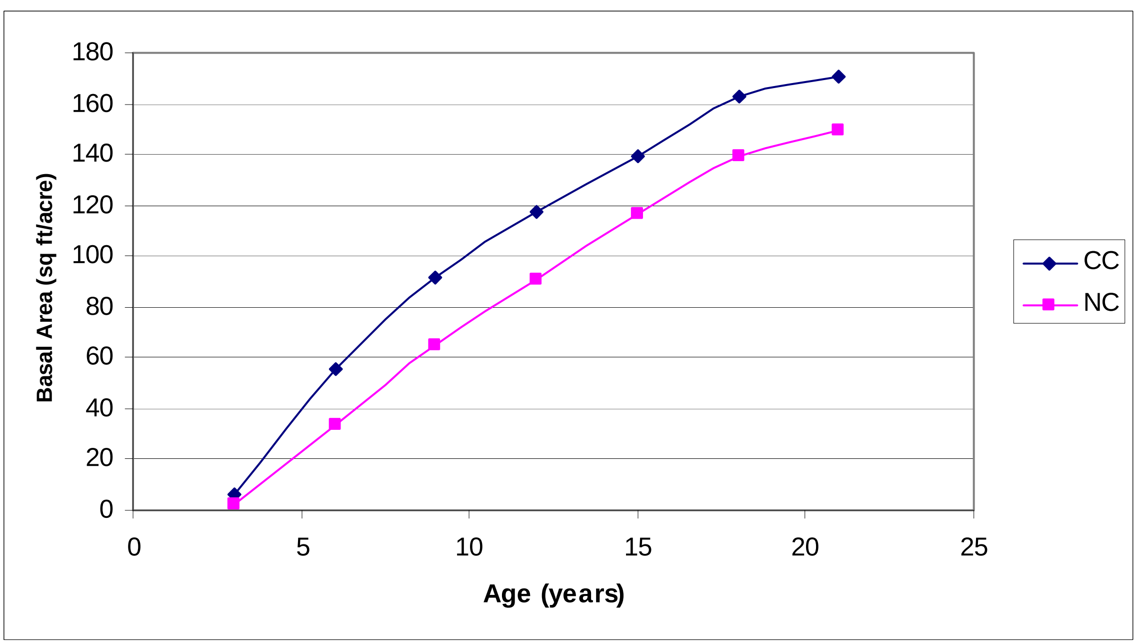

Figure 50. Mean basal area per acre of loblolly pine by age for complete competition control (CC) and without complete competition control (NC) in the Coastal Plain through age 21.

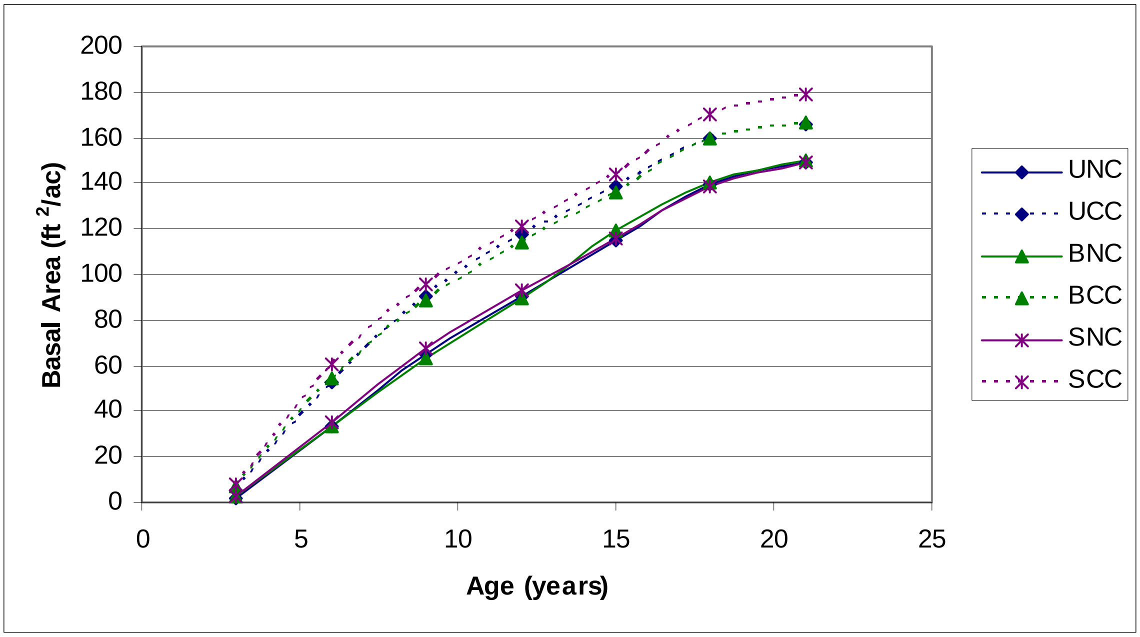

Figure 51. Mean basal area per acre of loblolly pine by age for the six genetic by competition control treatment combinations in the Coastal Plain through age 21.

5.3.2 Piedmont

Patterns of average basal area per acre with age are presented by genetics main effects (Figure 52), competition control main effects (Figure 53), and for each genetic by competition control treatment combination (Figure 54).

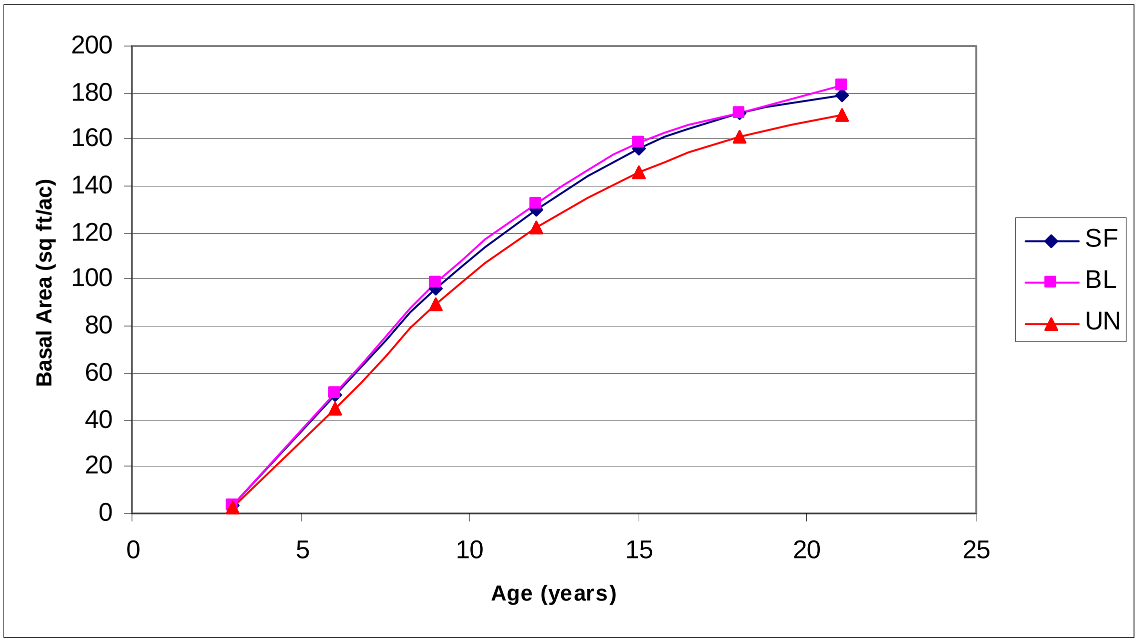

Figure 52. Mean basal area per acre of loblolly pine by age for improved single family (SF), improved bulk lot (BL) and unimproved plantings in the Piedmont through age 21.

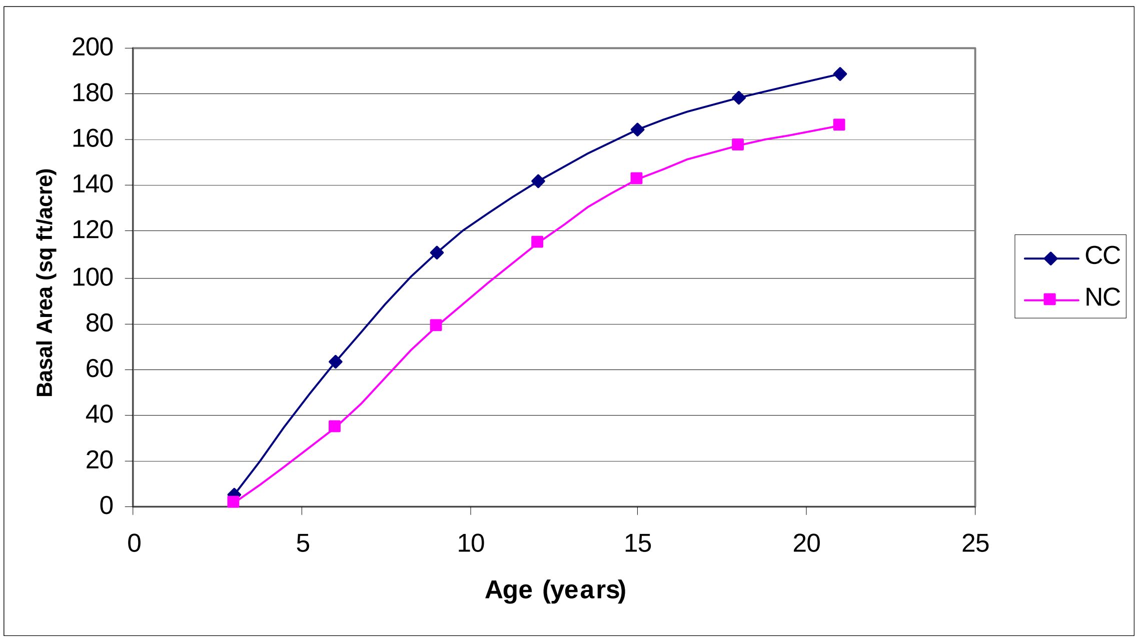

Figure 53. Mean basal area per acre of loblolly pine by age for complete competition control (CC) and without complete competition control (NC) in the Piedmont through age 21.

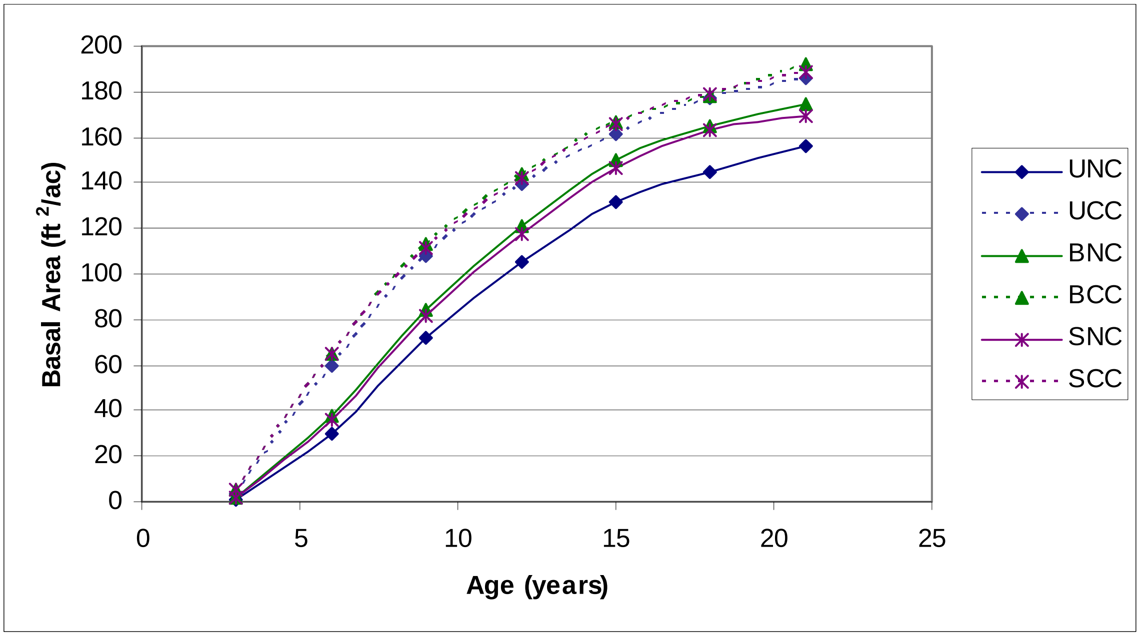

Figure 54. Mean basal area per acre of loblolly pine by age for the six genetic by competition control treatment combinations in the Piedmont through age 21.

5.4 Total Volume per Acre

5.4.1 Coastal Plain

Patterns of mean total green weight per acre with age are presented by genetics main effects (Figure 55), competition control main effects (Figure 55), and for each genetic by competition control treatment combination (Figure 56).

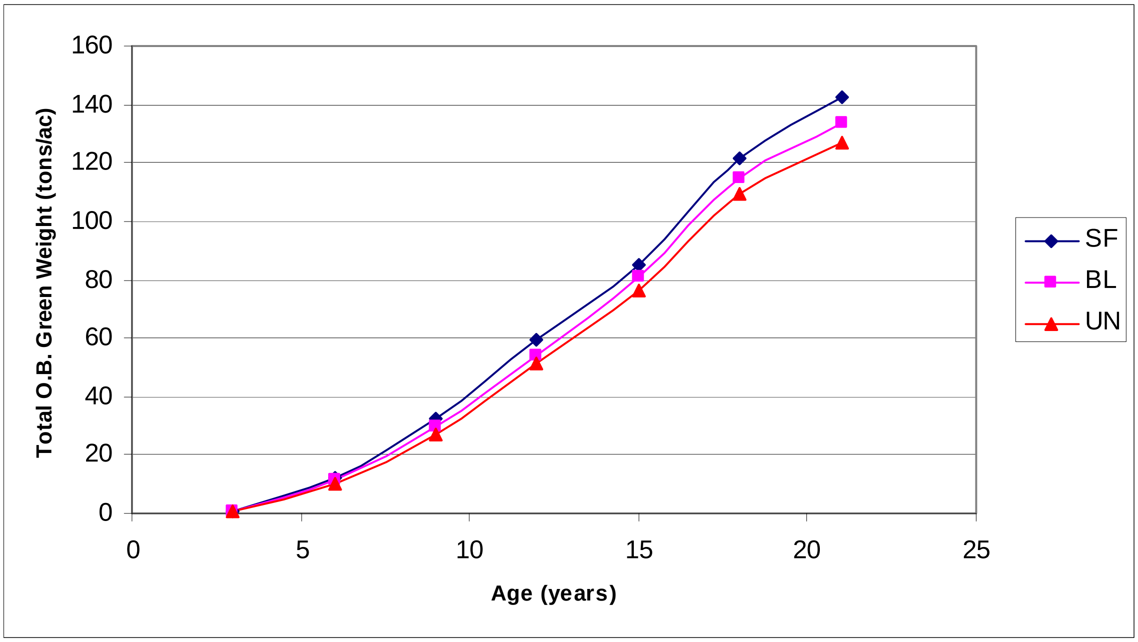

Figure 55. Mean total green weight per acre of loblolly pine by age for improved single family (SF), improved bulk lot (BL) and unimproved plantings in the Coastal Plain through age 21.

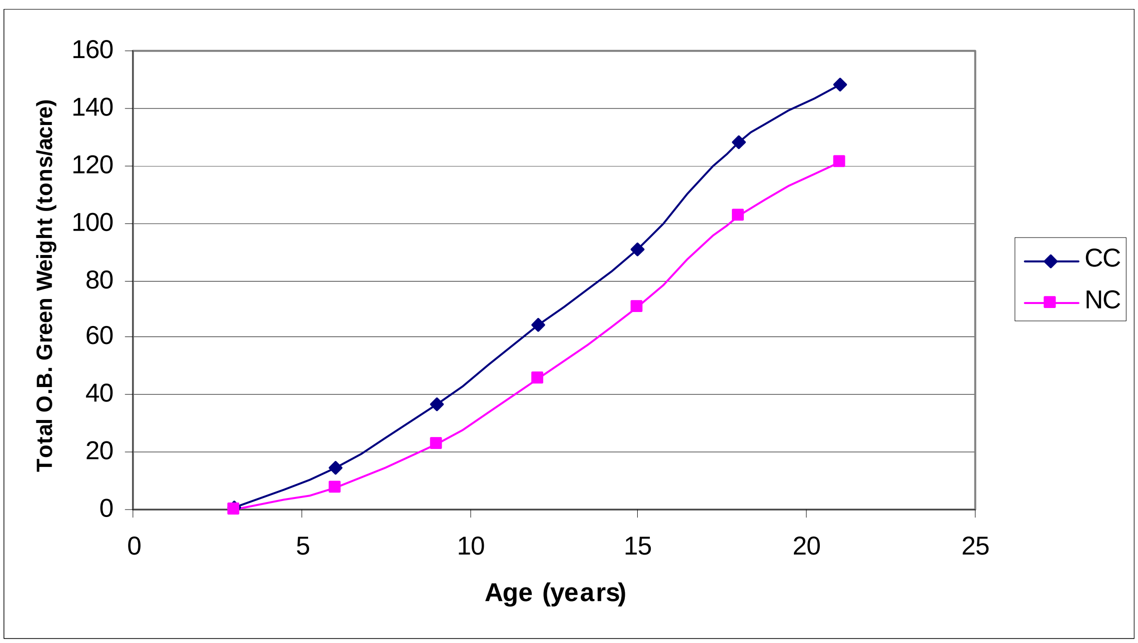

Figure 56. Mean total green weight per acre of loblolly pine by age for complete competition control (CC) and without complete competition control (NC) in the Coastal Plain through age 21.

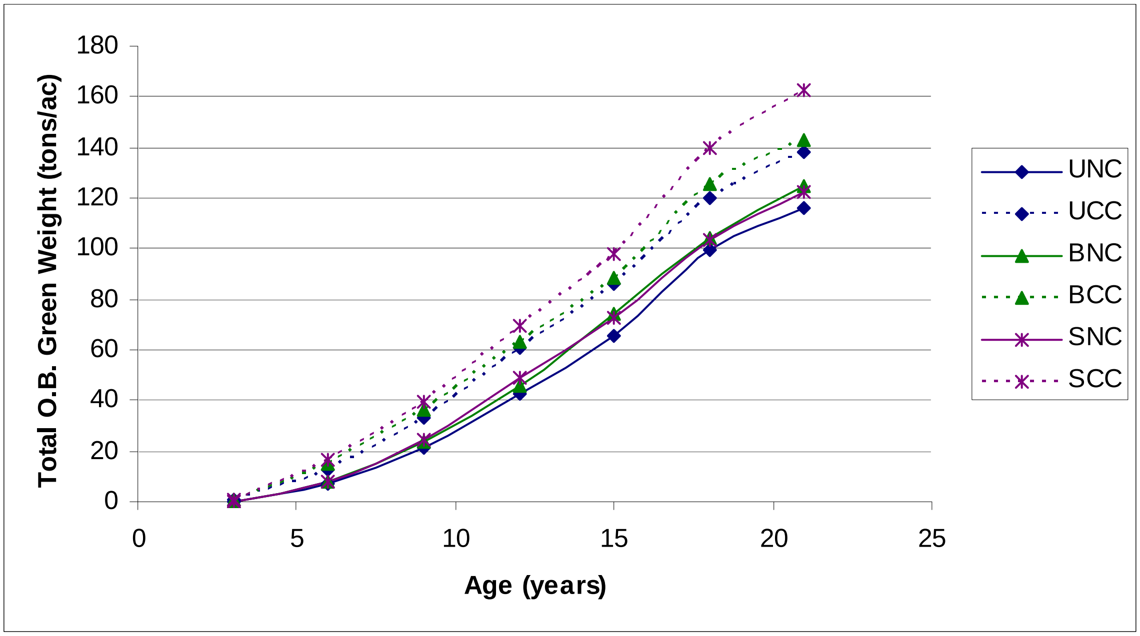

Figure 57. Mean total green weight per acre of loblolly pine by age for the six genetic by competition control treatment combinations in the Coastal Plain through age 21.

5.4.2 Piedmont

Patterns of mean total green weight per acre with age are presented by genetics main effects (Figure 58), competition control main effects (Figure 59), and for each genetic by competition control treatment combination (Figure 60).

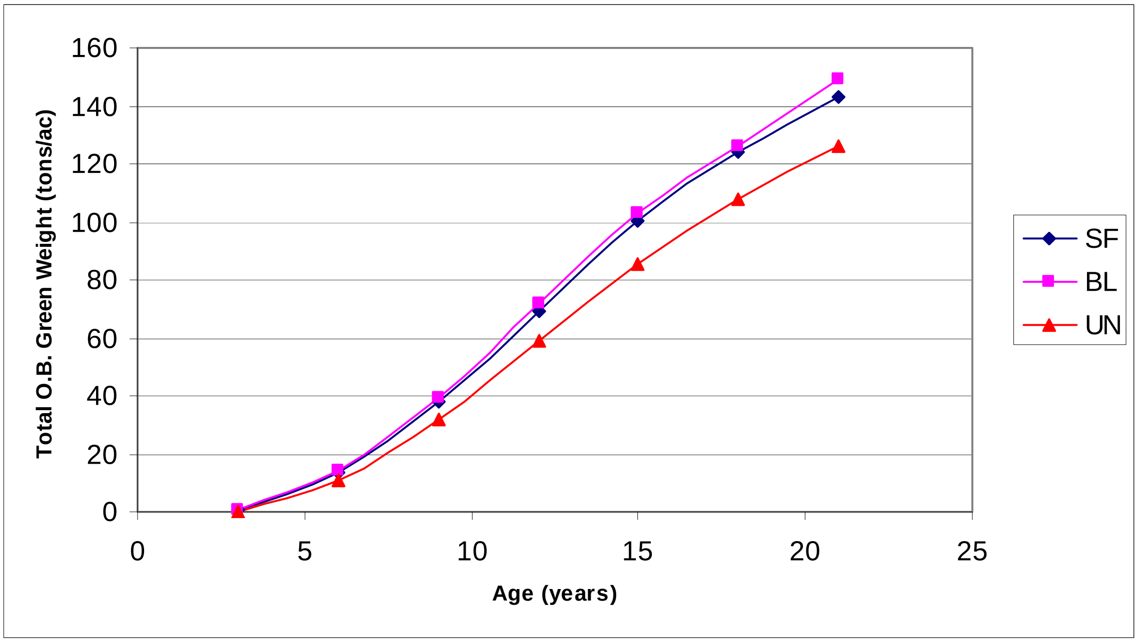

Figure 58. Mean total green weight per acre of loblolly pine by age for improved single family (SF), improved bulk lot (BL) and unimproved plantings in the Piedmont through age 21.

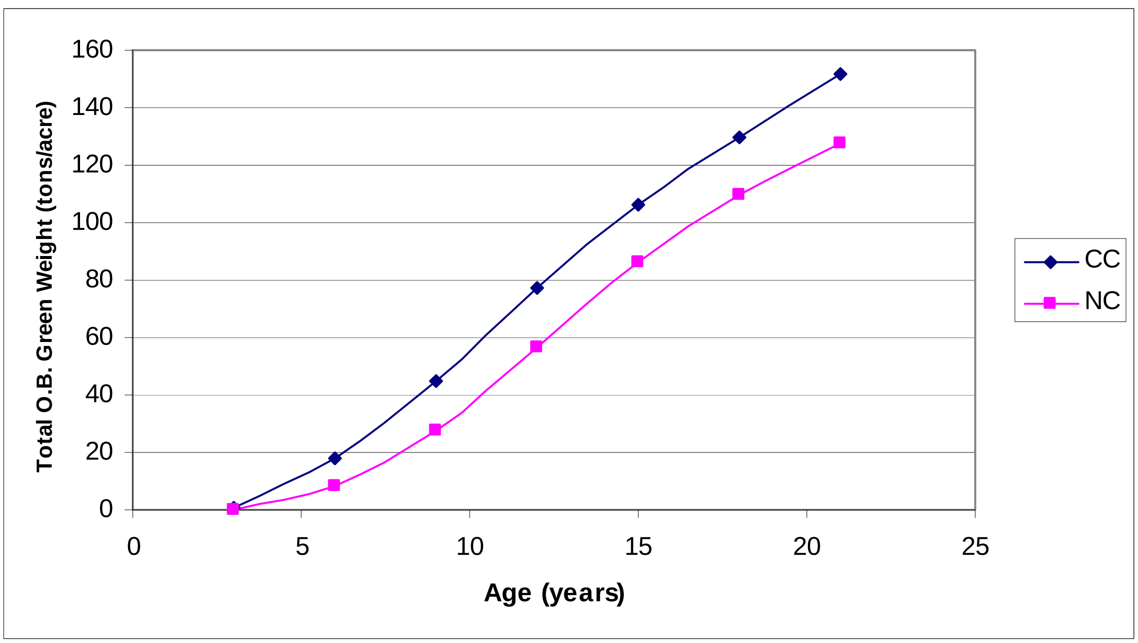

Figure 59. Mean total green weight per acre of loblolly pine by age for complete competition control (CC) and without complete competition control (NC) in the Piedmont through age 21.

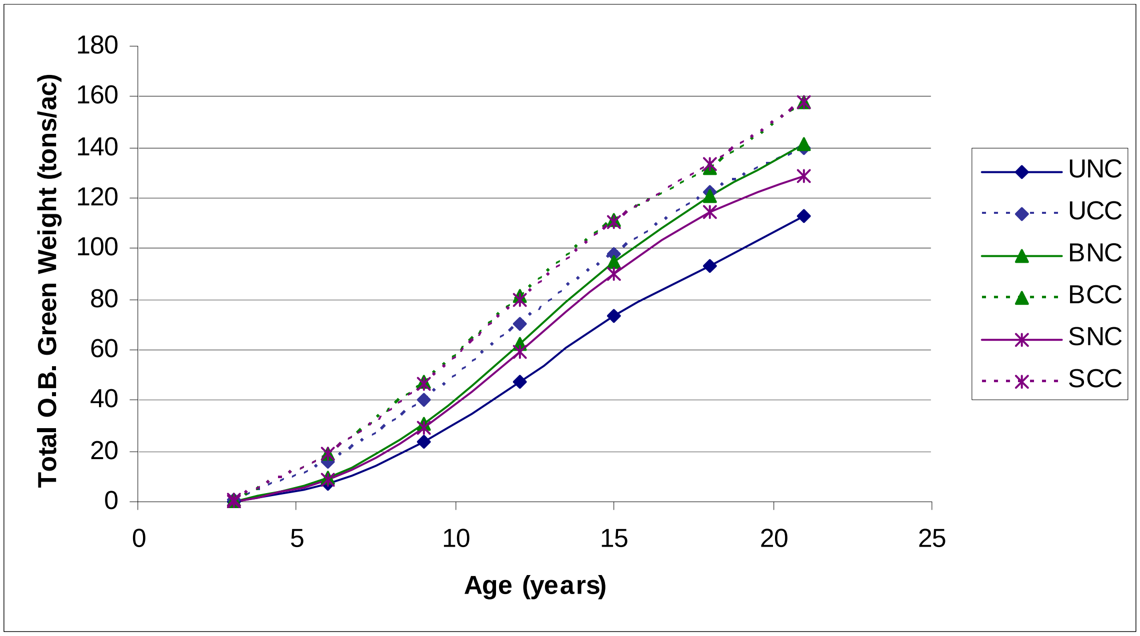

Figure 60. Mean total green weight per acre of loblolly pine by age for the six genetic by competition control treatment combinations in the Piedmont through age 21.

6. STAND DENSITY AND LIMITING DENSITY RELATIONSHIPS THROUGH AGE 21

6.1 Trees per Acre

6.1.1 Coastal Plain

Tree per acre trends through age 21 by genetics main effects (Figure 61), competition control main effects (Figure 62), and for each genetic by competition control treatment combination (Figure 63) are presented below.

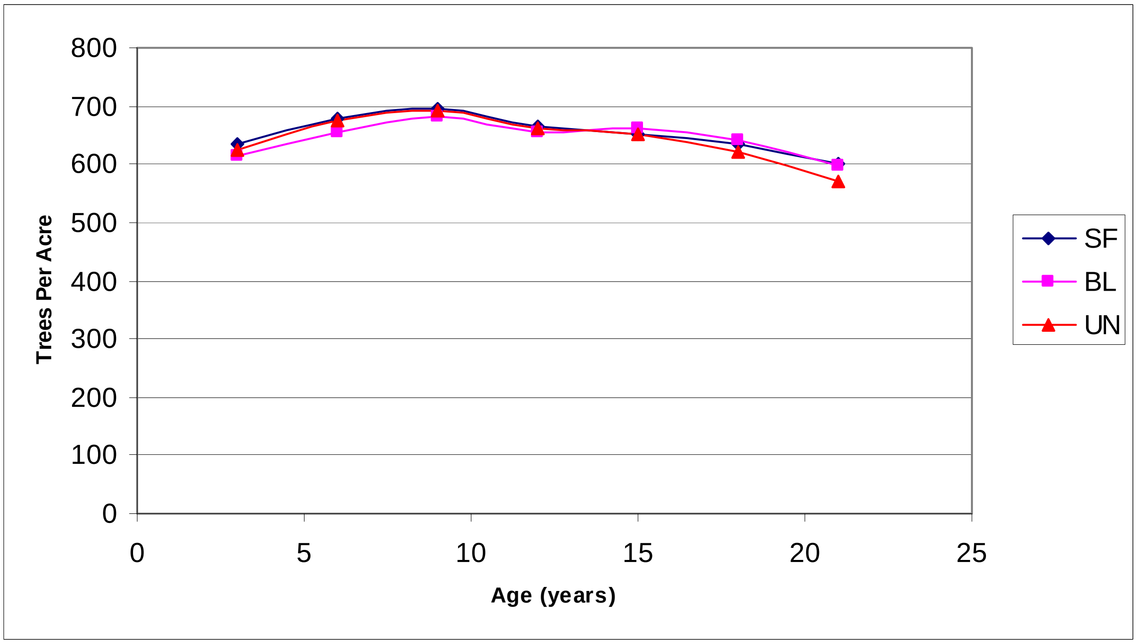

Figure 61. Mean trees per acre of loblolly pine by age for improved single family (SF), improved bulk lot (BL) and unimproved plantings in the Coastal Plain through age 21.

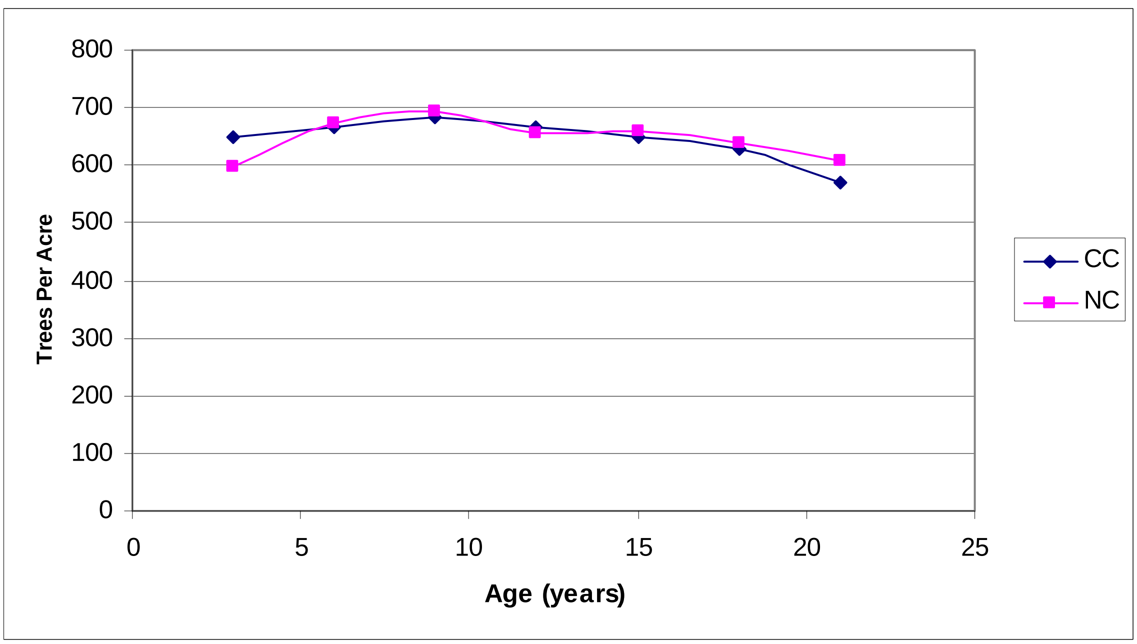

Figure 62. Mean trees per acre of loblolly pine by age for complete competition control (CC) and without complete competition control (NC) in the Coastal Plain through age 21.

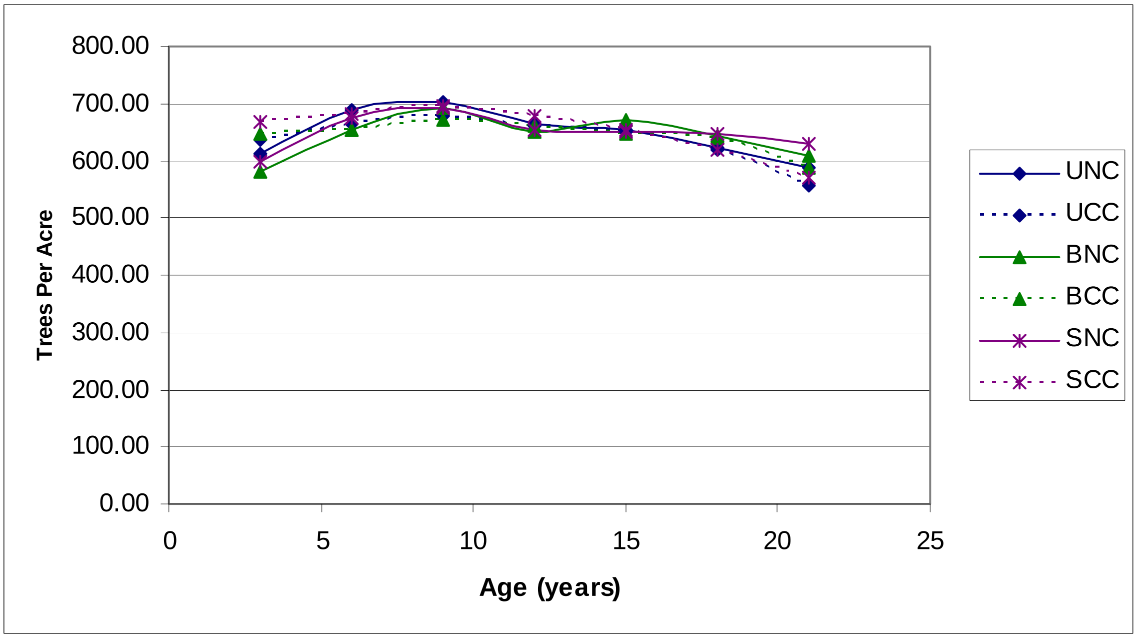

Figure 63. Mean trees per acre of loblolly pine by age for the six genetic by competition control treatment combinations in the Coastal Plain through age 21.

6.1.2 Piedmont

Trees per acre trends through age 21 by genetics main effects (Figure 64), competition control main effects (Figure 65), and for each genetic by competition control treatment combination (Figure 66) are shown below.

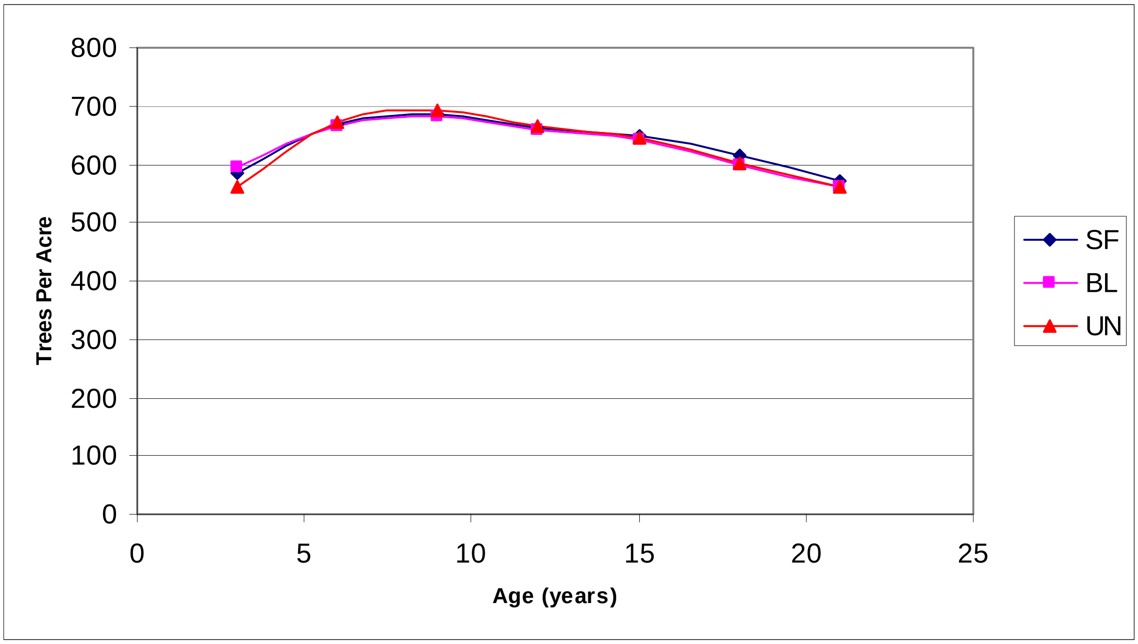

Figure 64. Mean trees per acre of loblolly pine by age for improved single family (SF), improved bulk lot (BL) and unimproved plantings in the Piedmont through age 21.

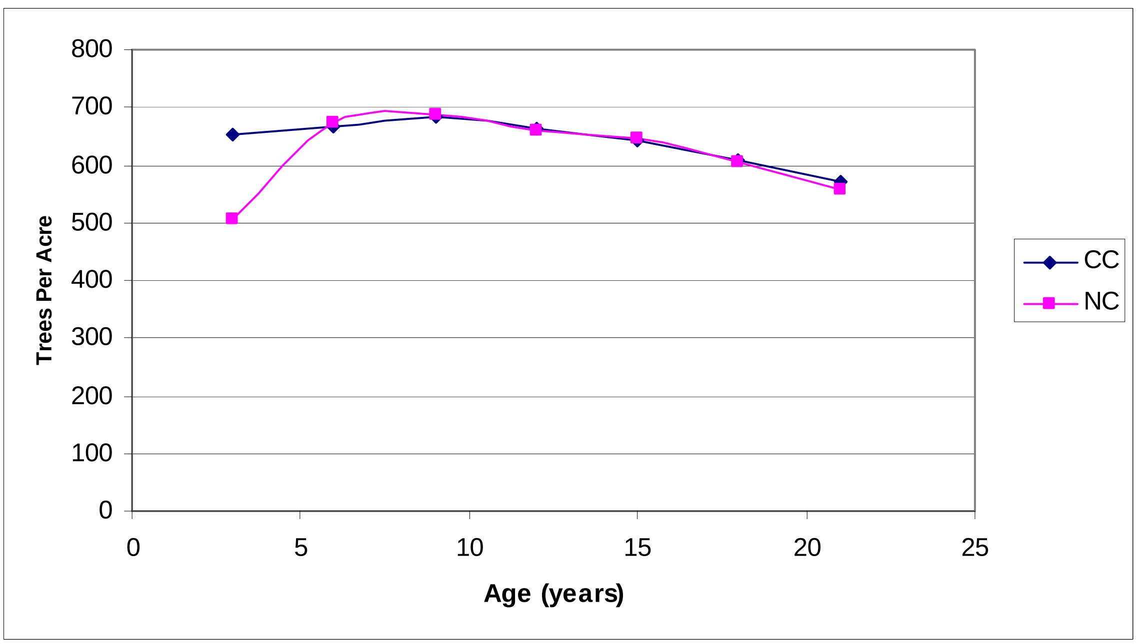

Figure 65. Mean trees per acre of loblolly pine by age for complete competition control (CC) and without complete competition control (NC) in the Piedmont through age 21.

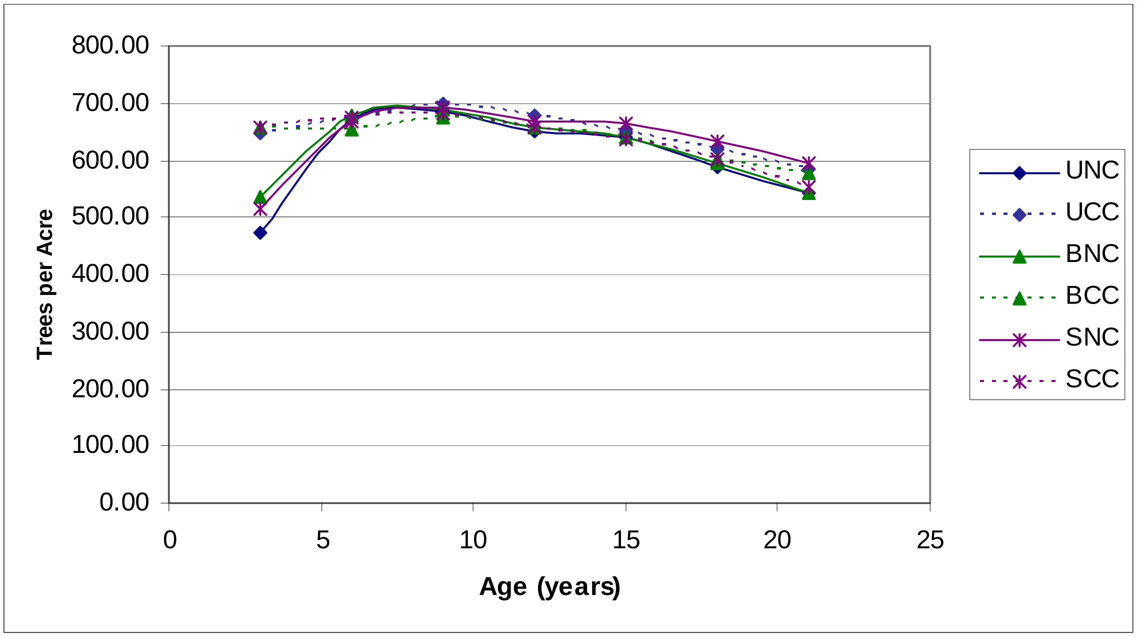

Figure 66. Mean trees per acre of loblolly pine by age for the six genetic by competition control treatment combinations in the Piedmont through age 21.

6.2 Stand Density Index

6.2.1 Coastal Plain

Stand density index trends through age 21 by genetics main effects (Figure 67), competition control main effects (Figure 68), and for each genetic by competition control treatment combination (Figure 69) are shown below.

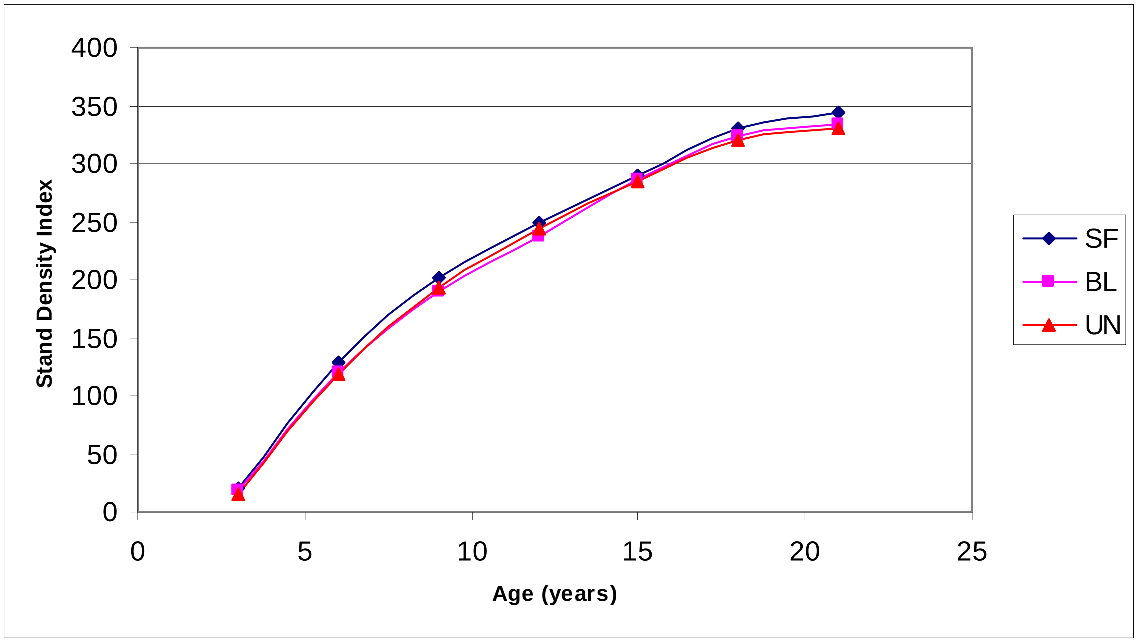

Figure 67. Stand density index of loblolly pine by age for improved single family (SF), improved bulk lot (BL) and unimproved plantings in the Coastal Plain through age 21.

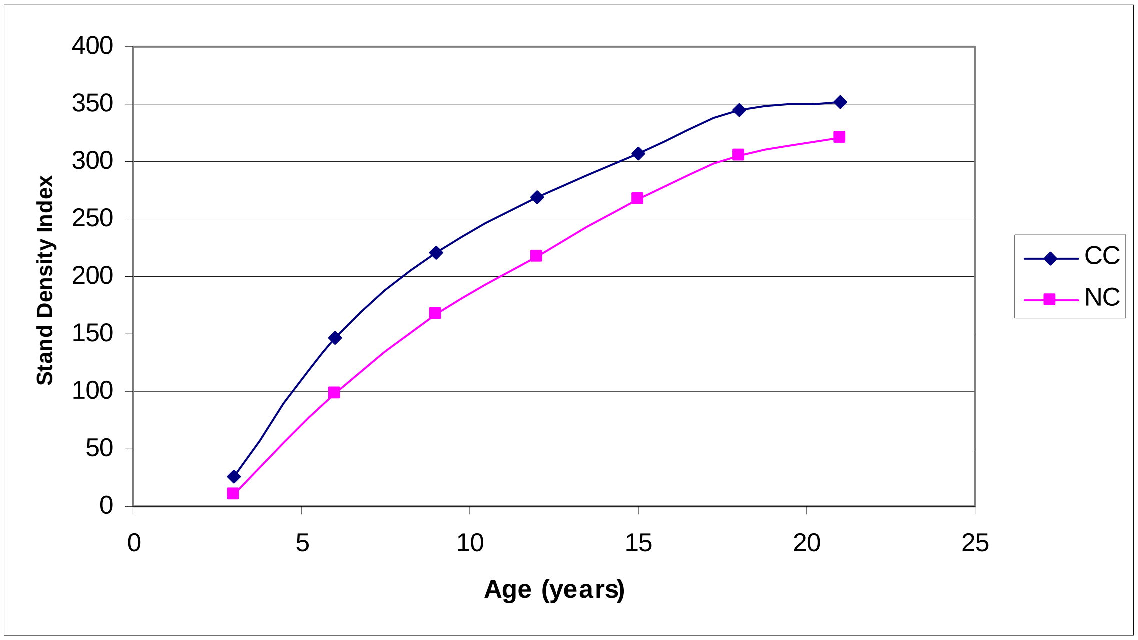

Figure 68. Stand density index of loblolly pine by age for complete competition control (CC) and without complete competition control (NC) in the Coastal Plain through age 21.

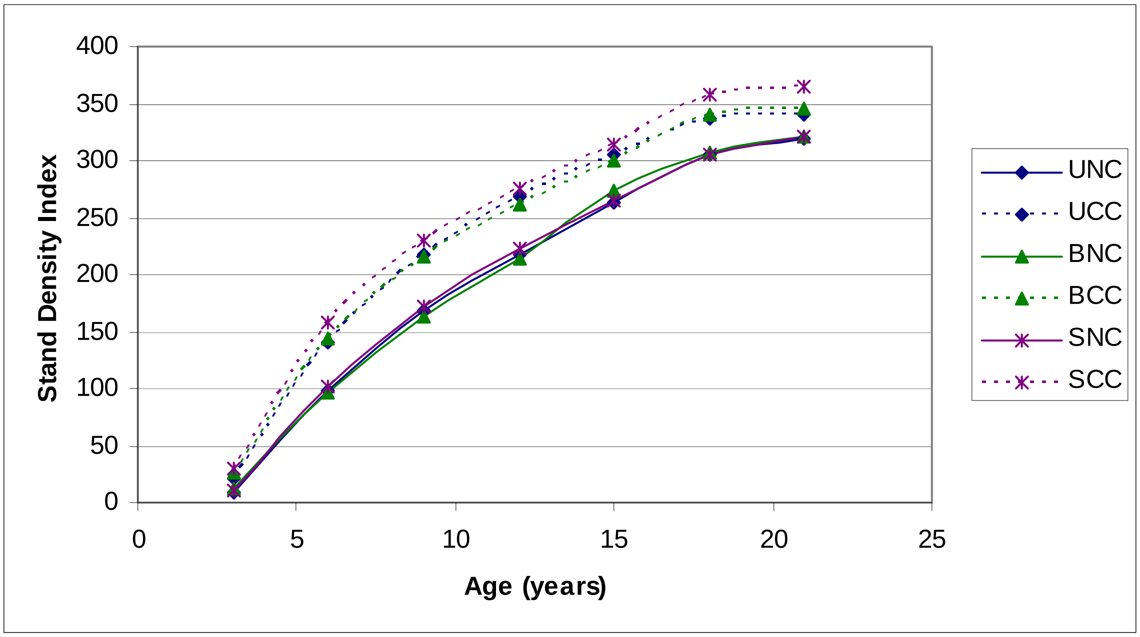

Figure 69. Mean stand density index of loblolly pine by age for the six genetic by competition control treatment combinations in the Coastal Plain through age 21.

6.2.2 Piedmont

Stand density index trends through age 21 by genetics main effects (Figure 70), competition control main effects (Figure 71), and for each genetic by competition control treatment combination (Figure 72) are presented below.

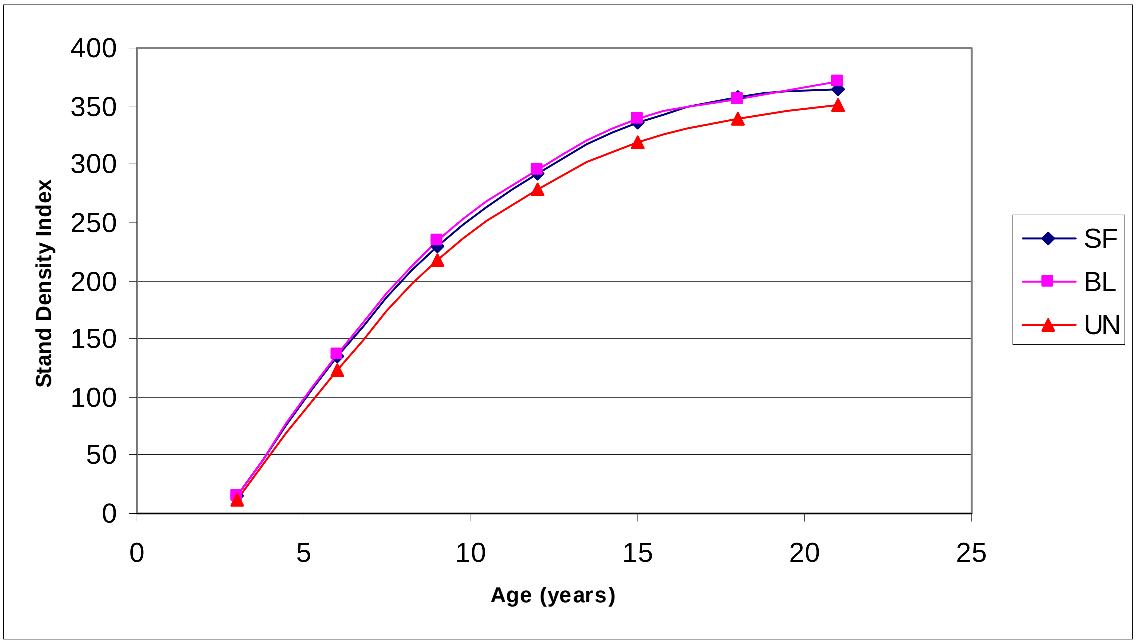

Figure 70. Stand density index of loblolly pine by age for improved single family (SF), improved bulk lot (BL) and unimproved plantings in the Piedmont through age 21.

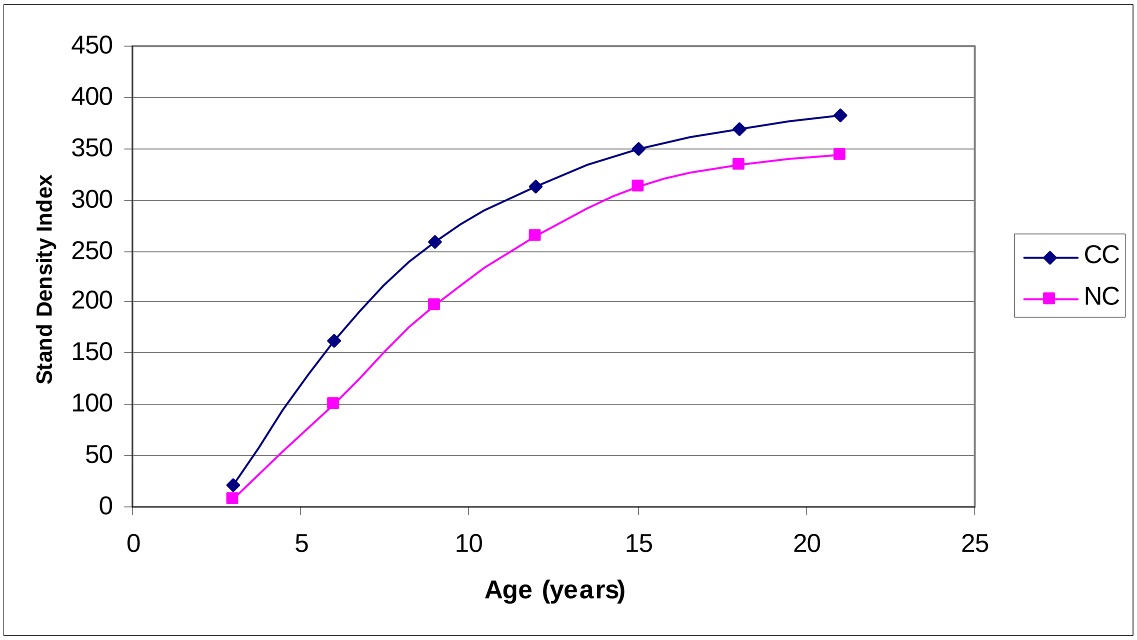

Figure 71. Stand density index of loblolly pine by age for complete competition control (CC) and without complete competition control (NC) in the Piedmont through age 21.

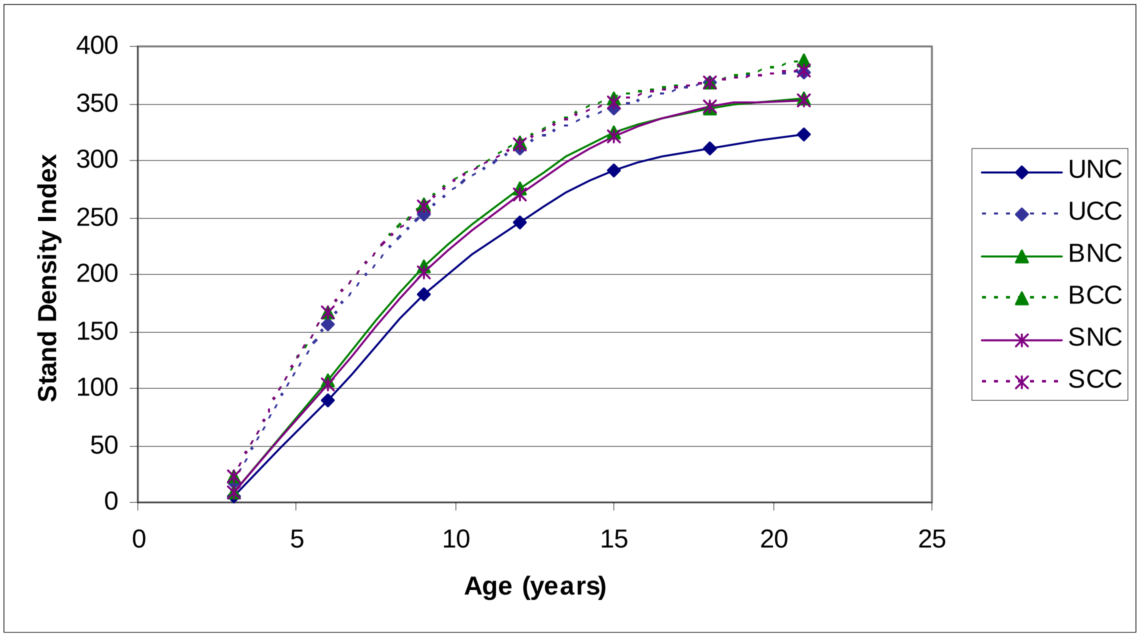

Figure 72. Mean stand density index of loblolly pine by age for the six genetic by competition control treatment combinations in the Piedmont through age 21.

6.3 Relative Spacing

6.3.1 Coastal Plain

Relative spacing trends through age 21 by genetics main effects (Figure 73), competition control main effects (Figure 74), and for each genetic by competition control treatment combination (Figure 75) are shown below. Since genetics did not have an impact on survival and the impact of vegetation control, though significant at age 21, has been modest, and both had significant effects on average dominant height, the relative spacing values, in the early years, should reflect the differences in average dominant height. This is illustrated in Figures 73, 74, and 75 as relative spacing at age six decreases with increasing treatment intensity. By age nine, the relative spacing values had begun to converge and this trend has continued through age 21. Clutter et.al. (1983) point out that regardless of site quality, stands of a given species tend to approach a common, minimum relative spacing level over time.

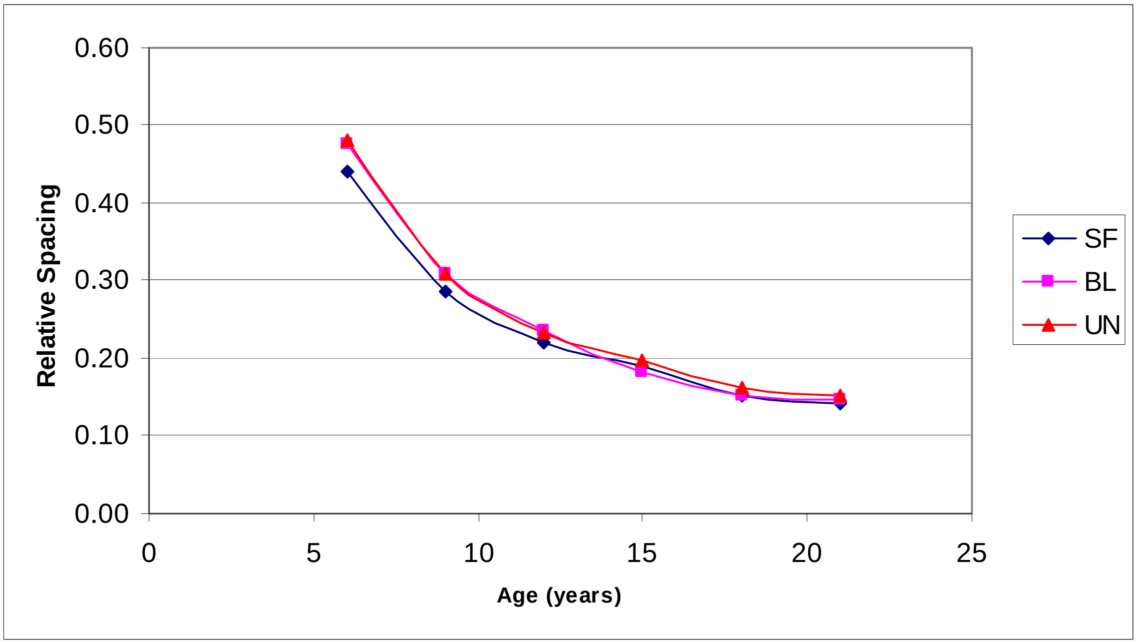

Figure 73. Relative spacing of loblolly pine by age for improved single family (SF), improved bulk lot (BL) and unimproved plantings in the Coastal Plain through age 21.

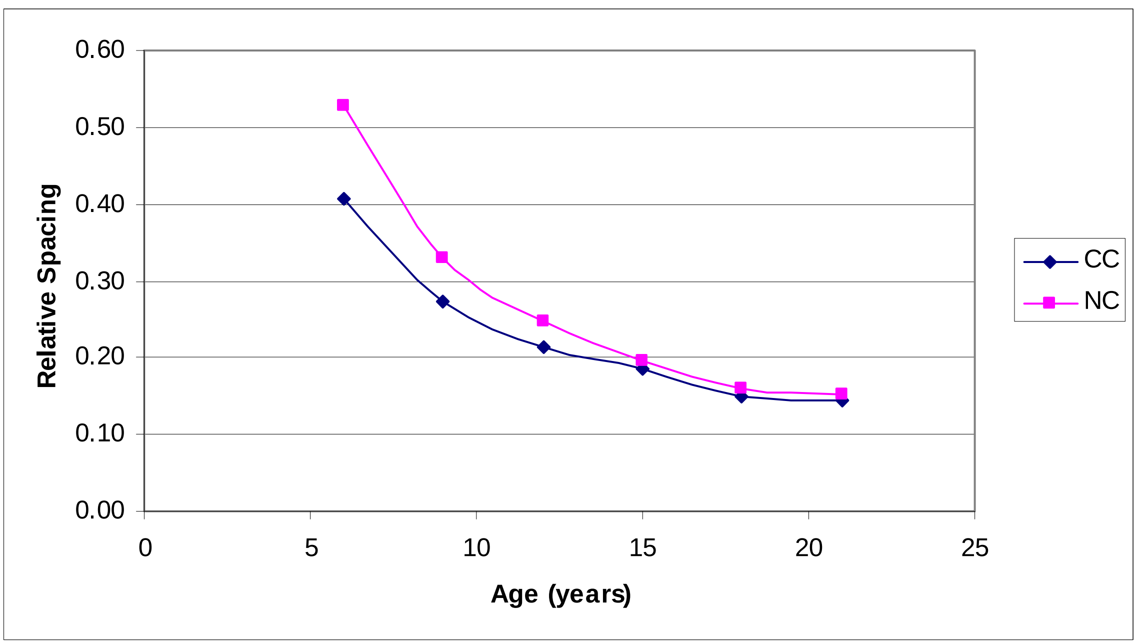

Figure 74. Relative spacing of loblolly pine by age for complete competition control (CC) and without complete competition control (NC) in the Coastal Plain through age 21.

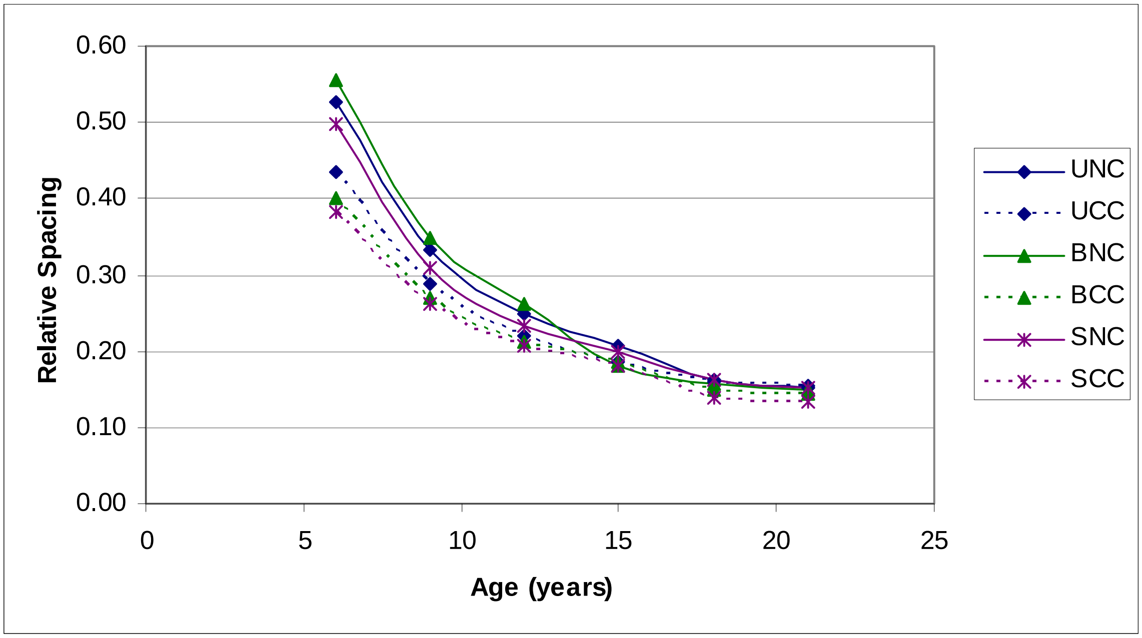

Figure 75. Mean relative spacing of loblolly pine by age for the six genetic by competition control treatment combinations in the Coastal Plain through age 21.

6.3.2 Piedmont

Relative spacing trends through age 21 by genetics main effects (Figure 76), competition control main effects (Figure 77), and for each genetic by competition control treatment combination (Figure 78) are presented below. Results are similar to those highlighted for the Coastal Plain.

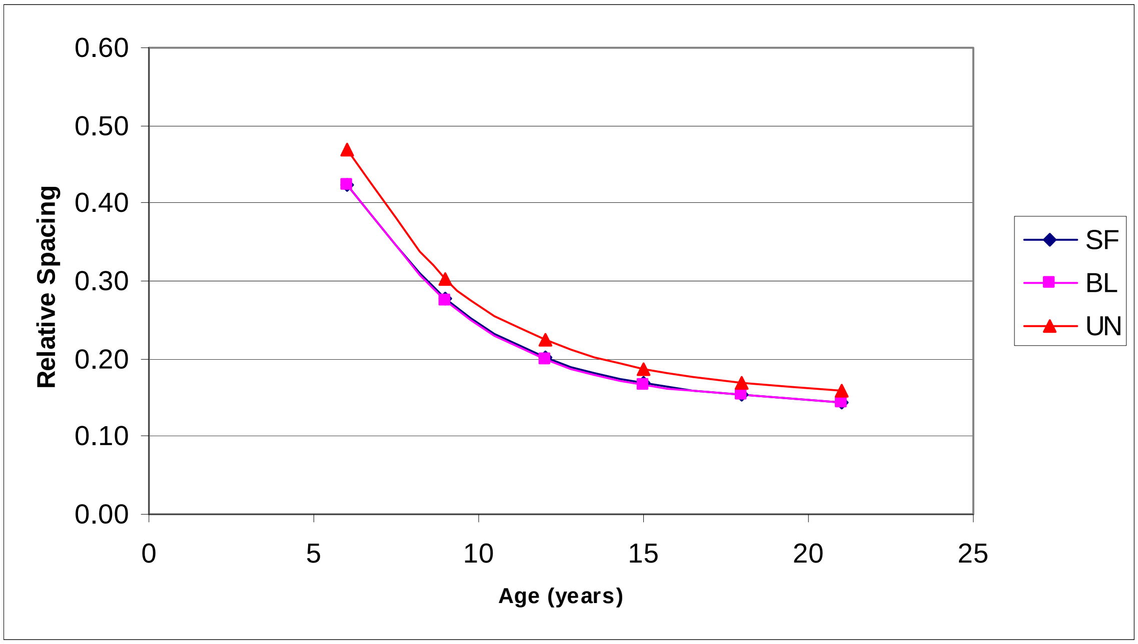

Figure 76. Relative spacing of loblolly pine by age for improved single family (SF), improved bulk lot (BL) and unimproved plantings in the Piedmont through age 21.

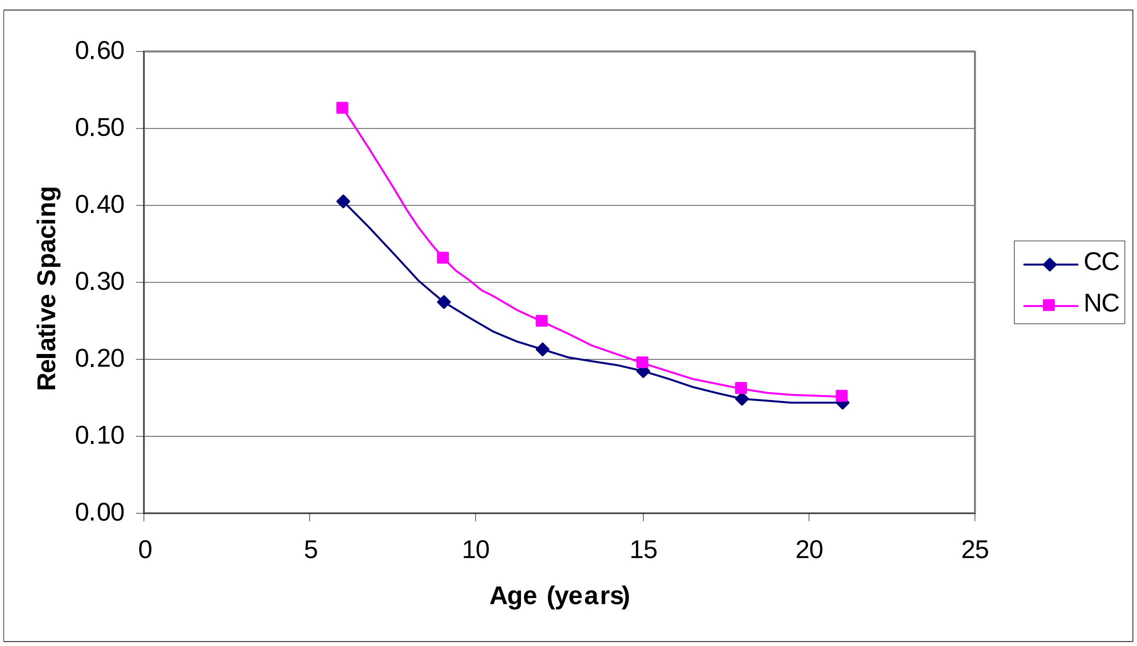

Figure 77. Relative spacing of loblolly pine by age for complete competition control (CC) and without complete competition control (NC) in the Piedmont through age 21.

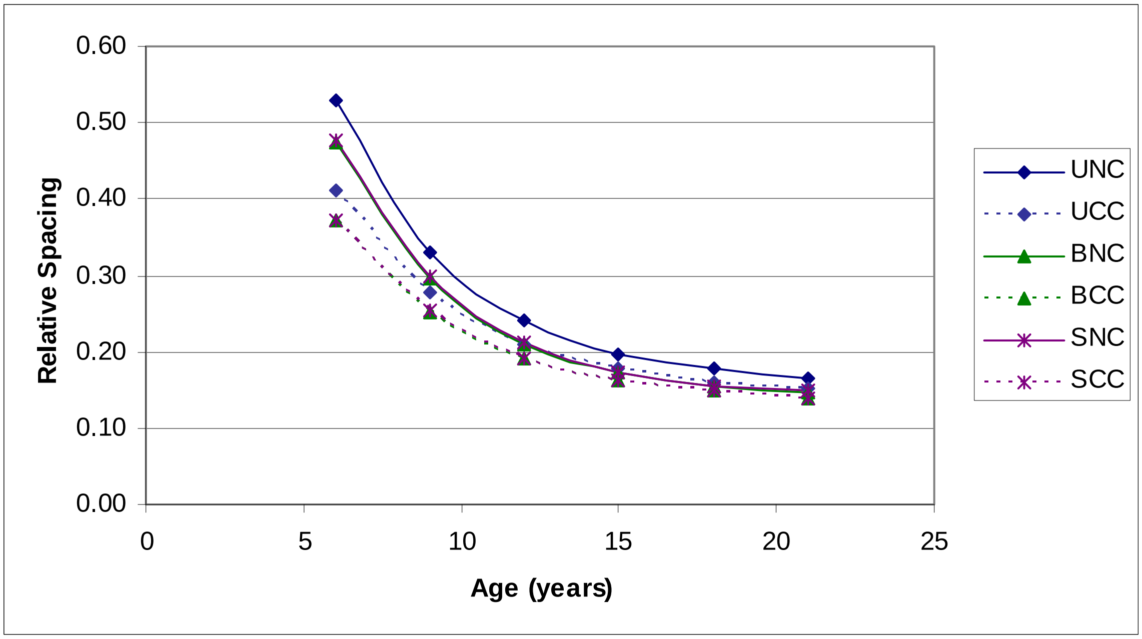

Figure 78. Mean relative spacing of loblolly pine by age for the six genetic by competition control treatment combinations in the Piedmont through age 21.

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7. PATTERNS OF PERIODIC GROWTH RESPONSES

7.1 Coastal Plain

Temporal response patterns in the Coastal Plain varied for genetic and competition control effects (Table 75). The improved stock used in this study increased height growth and volume and weight yields but did not increase tree dbh or per acre basal area. Gains from improved genetics increased through age 12 and were maintained through age 21. In contrast, complete competition control increased tree height and dbh growth as well as per acre basal area, volume, and weight. Responses to complete competition control generally approached their maximum for dbh and height at age 6, for per acre basal area at age 9, and for per acre volume and weight at age 12. Thereafter, cumulative responses tended to decline somewhat with the exception of per acre volume and weight which showed no significant decline in cumulative response with increasing age.

Table 75. Summary of response patterns to genetic improvement and complete competition control in periodic growth through age 21 in the Coastal Plain[a].

	Treatment	
Periodic Growth Attribute	Genetic Improvement	Complete Competition Control
	Period and Treatment Performance	
Average Dbh	0 to 21 yrs; Improved = Unimproved	0 to 6 yrs; Complete > Not Complete 6 to 18 yrs; Complete < Not Complete 18 to 21 yrs; Complete = Not Complete
Average Dominant Height	0 to 12 yrs; Improved > Unimproved 12 to 21 yrs; Improved = Unimproved	0 to 6 yrs; Complete > Not Complete 6 to 12 yrs; Complete = Not Complete 12 to 18 yrs; Complete < Not Complete 18 to 21 yrs; Complete = Not Complete
Basal Area per Acre	0 to 21 yrs; Improved = Unimproved	0 to 9 yrs; Complete > Not Complete 9 to 12 yrs; Complete = Not Complete 12 to 21 yrs; Complete < Not Complete
Volume or Weight per Acre	0 to 12 yrs; Improved > Unimproved 12 to 18 yrs; Improved = Unimproved 18 to 21 yrs; Improved > Unimproved	0 to 12 yrs; Complete > Not Complete 12 to 21 yrs; Complete = Not Complete

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

7.2 Piedmont

Temporal response patterns in the Piedmont (Table 76) were quite similar to those in the Coastal Plain. The improved stock used in this study increased tree height and dbh growth and per acre basal area, volume and weight. Gains from improved genetics increased through age 6 for dbh and basal area per acre, through age 12 for height, and through age 15 for volume and weight per acre. These gains from improved stock were maintained through age 21. Complete competition control also increased tree height and dbh growth as well as per acre basal area, volume and weight. As observed in the Coastal Plain, Piedmont responses to complete competition control generally reached their maximum for dbh and height at age 6, for per acre basal area at age 9, and for per acre volume and weight at age 12. Thereafter, cumulative responses tended to decline somewhat with the exception of per acre volume and weight which showed no significant decline in cumulative response with increasing age.

Table 76. Summary of response patterns to genetic improvement and complete competition control in periodic growth through age 21 in the Piedmont.

	Treatment	
Periodic Growth Attribute	Genetic Improvement	Complete Competition Control
	Period and Treatment Performance	
Average Dbh	0 to 6 yrs; Improved > Unimproved 6 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 21 yrs; improved = Unimproved	0 to 6 yrs; Complete > Not Complete 6 to 12 yrs; Complete = Not Complete 12 to 18 yrs; Complete < Not Complete 18 to 21 yrs; Complete = Not Complete
Basal Area per Acre	0 to 6 yrs; Improved > Unimproved 6 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
Volume or Weight per Acre	0 to 15 yrs; Improved > Unimproved 15 to 21 yrs; Improved = Unimproved	0 to 12 yrs; Complete > Not Complete 12 to 21 yrs; Complete = Not Complete

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

8. CONCLUSIONS

These updated results confirm the following earlier findings:

- Gains from improved stock in block plots were within the range estimated from progeny trial results
- Single family and mixed block plots show similar productivity patterns suggesting that considerable flexibility in deployment strategies is possible for stock with this level of genetic improvement
- Effective and sustained competition control provides consistent, substantial and persistent productivity gains
- The general lack of interaction suggests that, for this and similar levels of genetic improvement, gains from genetics and significant competition control are additive.

At age 21, both genetic improvement and competition control significantly increased loblolly pine plantation productivity in both the Coastal Plain and the Piedmont. Effects of genetic improvement and competition control on tree and stand attributes at age 21 years were additive; responses to genetic improvement were similar for plantings with either only operational site preparation or with complete and sustained competition control and responses to complete vegetation control were similar across the genetic treatments tested. Deployment of improved, first generation stock in single family blocks or bulk lot family mixtures yielded similar plantation performance.

In the Coastal Plain, age 21 total green weight was 114, 137, 123, and 155 tons/acre for unimproved stock and operational site preparation, unimproved stock and complete competition control, improved stock and operational site preparation only, and improved stock and complete competition control treatments, respectively. The response to improved genetic stock across competition control treatments averaged 13 tons per acre (11%). The response to complete competition control across genetic treatments was 29 tons per acre (24%).

In the Piedmont, age 21 total green weight was 112, 143, 138, and 158 tons/acre for unimproved stock and operational site preparation, unimproved stock and complete competition control, improved stock and operational site preparation only, and improved stock and complete competition control treatments, respectively. The response to improved genetic stock across competition control treatments was 21 tons per acre (14%). The response to complete competition control across genetic treatments averaged 24 tons per acre (19%).

Genetic improvement significantly improved tree health and quality. In the Coastal Plain, plantings with improved stock had a lower incidence of trees with fusiform rust stem galls (9.4% vs 20.6%) and crook or sweep (51.5% vs 68.5%) and a higher proportion of defect-free trees (42.4% vs 23.1%) as compared to plantings with unimproved stock. In the Piedmont, plantings with improved stock had a lower incidence of trees with fusiform rust stem galls (14.8% vs 22.4%) and forks (53% vs 70%) and a higher proportion of defect-free trees (36% vs 23%) as compared to plantings with unimproved stock.

Complete competition control did not significantly affect tree quality attributes in the Coastal Plain and tended to lower tree quality in the Piedmont where a smaller percentage of defect-free trees (29% vs 35%) and a larger proportion of trees with crook or sweep (6% vs 3%) were found on complete competition control plots as compared with that on operational site preparation only plots.

Temporal patterns in response were different to genetic improvement and competition control. For genetic improvement, Coastal Plain gains increased through age 12 and where maintained thereafter through age 21. Similarly, Piedmont genetic gains increased through age 6 for dbh and basal area per acre, through age 12 for height, and through age 15 for volume and weight per acre and thereafter were maintained through age 21. In contrast, responses to complete competition control in both the Coastal Plain and Piedmont generally approached their maximum for dbh and height at age 6, for per acre basal area at age 9, and for per acre volume and weight at age 12 and thereafter, cumulative responses tended to decline somewhat with the exception of per acre volume and weight which showed no significant decline with increasing age.

The cumulative effect of early growth gains for both genetic improvement and competition control is that treated stands are at a more advanced stage of stand development with more intra-specific competition than stands with unimproved genetic stock and competition control only during operational site preparation. By age 21, basal area per acre was 181 and 190 ft^2/acre on improved and complete competition control plots in the Coastal Plain and Piedmont, respectively as compared to 155 ft^2/acre mean basal area for each region on unimproved stands receiving competition control only during operational site preparation. Stand density index on improved stock and complete vegetation control plots was 371 and 380 (82% and 84% of maximum SDI) in the Coastal Plain and Piedmont, respectively as compared to 329 and 322 SDI values on counterpart plots without genetic improvement and complete competition control.

The growth patterns reported are for nonthinned stands not receiving any fertilization following plantation establishment. By age 21, intra-specific competition was severe and nutrient limitations were likely limiting stand productivity at most locations.

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 followed a Type B response pattern; absolute gains in dominant height reached their maximum by about age 12 and were thereafter maintained. Responses to complete competition control followed a Type C response pattern; absolute gains in dominant height reached their maximum by about age 6 and thereafter declined somewhat.

9. LITERATURE CITED

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