LOBLOLLY PINE IMPROVED PLANTING STOCK-VEGETATION CONTROL STUDY-AGE 12 RESULTS

Plantation Management Research Cooperative

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EXECUTIVE SUMMARY

A designed experimental study was established at 16 locations in the Coastal Plain region of Georgia and northern Florida, and at 15 locations in 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 vegetation control on yields of loblolly pine. A mixed model approach was used to analyze the age 12 measurements for this study and the 3-yr periodic growth from ages 6 to 9, and 9 to 12 yr. 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 first generation improved stock or single family.

Competition control significantly increased average tree characteristics and basal area per acre in both the Piedmont and Coastal Plain regions. In the Piedmont region, improved genetics significantly increased average dbh. Average dominant height was significantly increased in both physiographic regions by improved genetics. For Coastal Plain loblolly pine, improved genetics significantly increased basal area per acre while, in the Piedmont region, there was a significant interaction between competition control and genetics with respect to basal area per acre and trees per acre. Total volume was significantly increased by both improved genetics and competition control. In terms of total volume, increases up to 45% and 39% can be obtained from using complete vegetation control in the Coastal Plain and Piedmont regions, respectively. Improved genetic stock can increase total volume an average of 11% to 16% in the Coastal Plain and 10% to 19% in the Piedmont. For both total and merchantable volume the effects of competition control and improved genetics were additive. This additive nature of the effects indicates that managers should obtain the full benefit of these treatments. In the Coastal Plain region, neither competition control nor genetics significantly affected surviving trees per acre. In both regions, improved genetics significantly reduced the percent fusiform infection. Additionally, no significant differences were detected between bulk lot and single family plantings across all dependent variables.

The results of the 3-yr periodic growth analysis indicated that the no competition control plots had significantly larger 3-yr growth in mean dbh in both the Piedmont and Coastal Plain regions than complete vegetation control plots. In terms of mean dominant height, improved genetic stock continued to outgrow the unimproved stock in both physiographic regions. During the 3-yr period between 9 and 12 yrs there were no significant differences in dominant height growth between the two levels of competition control in the Coastal Plain, while in the Piedmont region no control had significantly greater 3-yr growth than the complete control. In the Coastal Plain region, improved genetics and complete competition control continued to significantly increase volume growth during both periods. During the period from 6 to 9 yrs, both competition control and genetics additively increased volume growth in the Piedmont region, while during the period from 9 to 12, the interaction between genetics and competition control was significant.

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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 likely that these cultural treatments could confound and possibly exaggerate results from progeny tests. Data from these 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 estimate potential gains from using these 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 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 12 measurement analysis of loblolly pine for this study. Also included are the results of the analysis of the 3-yr growth between ages 6 to 9, and 9 to 12.

STUDY DESIGN

A designed experimental study was established at 16 locations in the Coastal Plain region of Georgia and northern Florida, and at 15 locations in the Piedmont region of South Carolina, Georgia and Alabama. 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 Industry 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. North Carolina State cooperative identification numbers identify the families chosen for the study in Table 1.

Table 1. North Carolina State University tree improvement cooperative 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. Some seed from each family was kept separate and grown in separate nursery beds for the single family plantings.

Eight 0.4 ac treatment 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.

Plots were randomly assigned to each of the six 2x3 factorial treatment combinations. Each 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 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.

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 sixth, ninth and twelfth growing seasons. After the ninth and twelfth growing seasons all trees on the measurement plots were measured for dbh and checked for stem cankers. 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.

Total and merchantable (3-in. top ob) tree volumes and weights were estimated using total and merchantable volume and weight equations developed by Pienaar, et al. (1987).

ANALYSIS and RESULTS

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 statistic of the dbh distribution, average dominant height, surviving trees per acre, basal area per acre, total and merchantable stem volume and percent fusiform rust infection. In the discussion of the results, effects of genetic improvement are calculated by averaging across both vegetation control treatments, and vegetation control effects are determined by averaging across all genetics treatments. All statistical tests were conducted at the α=0.05 significance level. To obtain the correct degrees of freedom (df) for this analysis the Satterthwaite option in SAS®'s PROC MIXED procedure was used. Unlike traditional analyses, the df may not be an integer.

Two outlier installations were removed from both the Coastal Plain and Piedmont analyses on all dependent variables because they exhibited extremely low growth rates.

Average DBH

Coastal Plain Analysis

Table 2 gives the results of the tests of fixed effects for average dbh in the Coastal Plain. Competition control significantly increased average dbh in the Coastal Plain an average of 0.7 in. across all levels of genetic stock. There were no significant effects of genetics on average dbh. Table 3 and Figure 1 summarize the least square means for average dbh (in.) by treatment.

Table 2. Test of fixed effects (reproduced from SAS® output) for average dbh (in.) in the Coastal Plain.

Source	Numerator Degrees of Freedom	Denominator Degrees of Freedom	Type III F	Pr > F
Genetics	2	80.1	2.91	0.0601
Competition Control	1	12.8	76.99	0.0001
Genetics* Competition Control	2	79.3	0.11	0.8996

Table 3. Summary of least squares means for average dbh (in.) in the Coastal Plain.

	No Control	Complete Control	Average
Unimproved	5.12	5.88	5.50
Bulk Lot	5.20	5.90	5.55
Single Family	5.28	6.01	5.65
Average	5.20	5.93	5.57

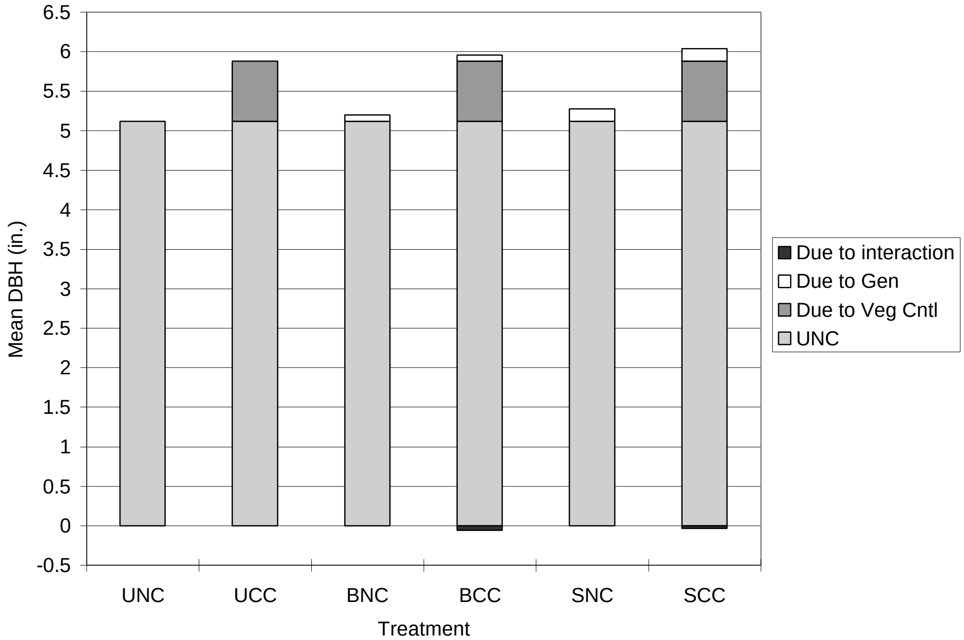

Figure 1. **Mean dbh by treatment for 12-yr-old loblolly pine in the Coastal Plain.**

Piedmont Analysis

The results of the tests of fixed effects for average dbh in the Piedmont are given in Table 4. Both vegetation control and genetics had significant effects on average dbh. Competition control significantly increased average dbh an average of 0.8 in. across all genetic stock. A t-test on the differences of least square means detected no significant difference between bulk lot and single family, but bulk lot increased average dbh 0.26 in. and single family 0.16 in. over unimproved stock. The interaction between genetic stock and competition control was not significant. Table 5 and Figure 2 summarize the least square means for average dbh (in.) by treatment.

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

Source	Numerator Degrees of Freedom	Denominator Degrees of Freedom	Type III F	Pr > F
Genetics	2	49.8	5.03	0.0102
Competition Control	1	12.2	73.50	0.0001
Genetics* Competition Control	2	50.4	0.77	0.4673

Table 5. Summary of least squares means for average dbh (in.) in the Piedmont.

	No Control	Complete Control	Average
Unimproved	5.40	6.23	5.81
Bulk Lot	5.76	6.40	6.08
Single Family	5.58	6.37	5.98
Average	5.58	6.33	5.96

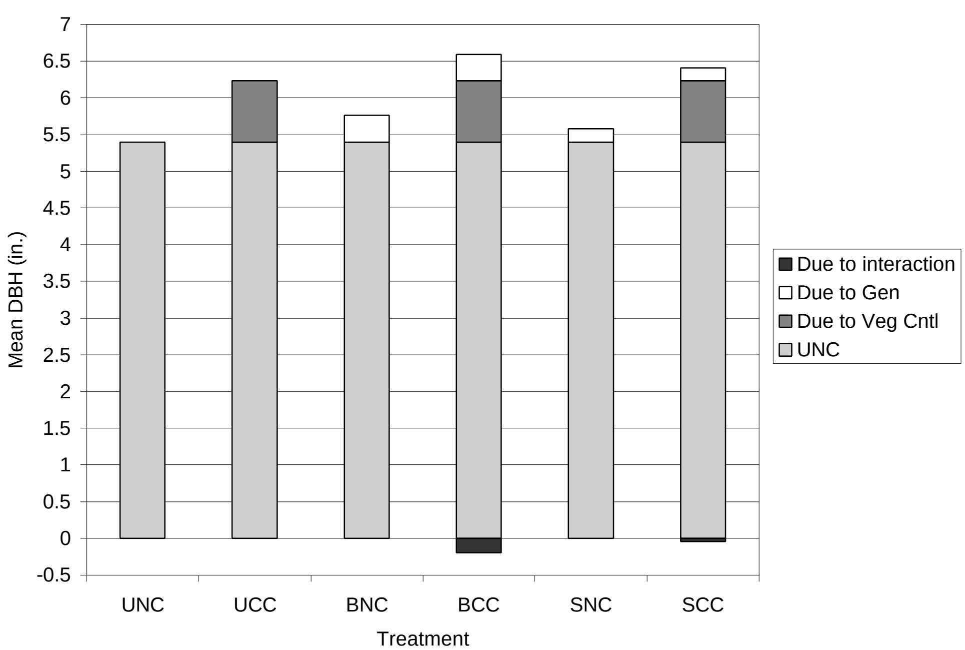

Figure 2. Mean dbh by treatment for 12-yr-old loblolly pine in the Piedmont.

Range and Skewness of the DBH Distribution

Coastal Plain Analysis

There were no significant differences between the mean range of the dbh distributions for each treatment combination due to genetics or competition control in the Coastal Plain. Genetics significantly affected the skewness of the distribution. While there were no differences between single family and bulk lot, both decreased the skewness statistic by 0.2 over unimproved stock indicating that improved genetics skewed the dbh distribution to the left. This means that the dbh distribution has fewer trees in smaller dbh classes and more trees in larger dbh classes.

Piedmont Analysis

In the Piedmont region, competition control significantly decreased the average range in dbh by 0.38 in., and the skewness statistic was not effected by either genetics or competition control.

Average Dominant Height

Coastal Plain Analysis

Table 6 gives the results of the tests of fixed effects for average dominant height in the Coastal Plain. Competition control significantly increased average dominant height in the Coastal Plain an average of 5.4 ft at age 12 across all levels of genetic stock. Genetic stock also significantly increased average dominant height. While there was no significant difference between single family and bulk lot, dominant height increased by 4.0 ft and 3.2 ft, respectively over unimproved stock. The interaction between competition control and genetic stock was not significant. Table 7 and Figure 3 summarize the least square means for average dominant height (ft) by treatment.

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

Source	Numerator Degrees of Freedom	Denominator Degrees of Freedom	Type III F	Pr > F
Genetics	2	80.5	24.54	0.0001
Competition Control	1	12.8	59.02	0.0001
Genetics* Competition Control	2	79.4	0.40	0.6743

Table 7. Summary of least squares means for average dominant height (ft) in the Coastal Plain.

	No Control	Complete Control	Average
Unimproved	36.7	41.5	39.1
Bulk Lot	39.5	45.1	42.3
Single Family	40.2	46.0	43.1
Average	38.8	44.2	41.5

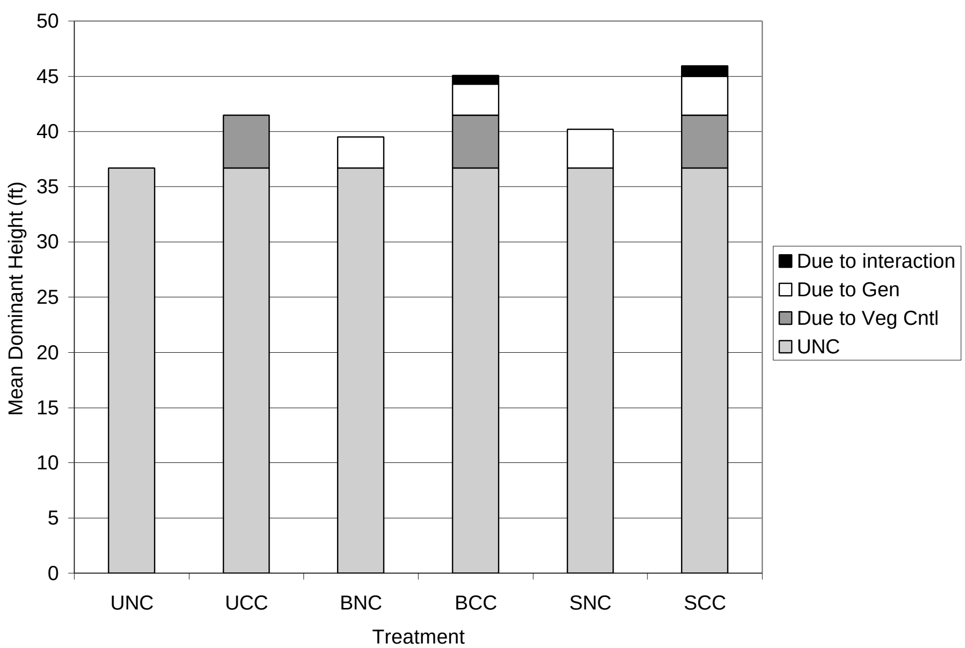

Figure 3. Mean dominant height by treatment for 12-yr-old loblolly pine in the Coastal Plain.

Piedmont Analysis

The results of the tests of fixed effects for average dominant height in the Piedmont are given in Table 8. Both vegetation control and improved genetic stock had significant effects on average dominant height. Competition control significantly increased average dominant height an average of 5.0 ft across all genetic stock. A t-test on the differences of least square means detected no significant differences between bulk lot and single family, but bulk lot increased average dominant height 4.9 ft and single family 3.6 ft over unimproved stock. The interaction between genetic stock and competition control was not significant. Table 9 and Figure 4 summarize the least square means for average dominant height (ft) by treatment.

Table 8. **Test of fixed effects (reproduced from SAS® output) for average dominant height (ft) in the Piedmont.**

Source	Numerator Degrees of Freedom	Denominator Degrees of Freedom	Type III F	Pr > F
Genetics	2	25	27.05	0.0001
Competition Control	1	11.7	63.77	0.0001
Genetics* Competition Control	2	57.1	1.23	0.2998

Table 9. **Summary of least squares means for average dominant height (ft) in the Piedmont.**

	No Control	Complete Control	Average
Unimproved	34.5	40.5	37.5
Bulk Lot	40.4	44.5	42.4
Single Family	38.7	43.5	41.1
Average	37.9	42.8	40.3

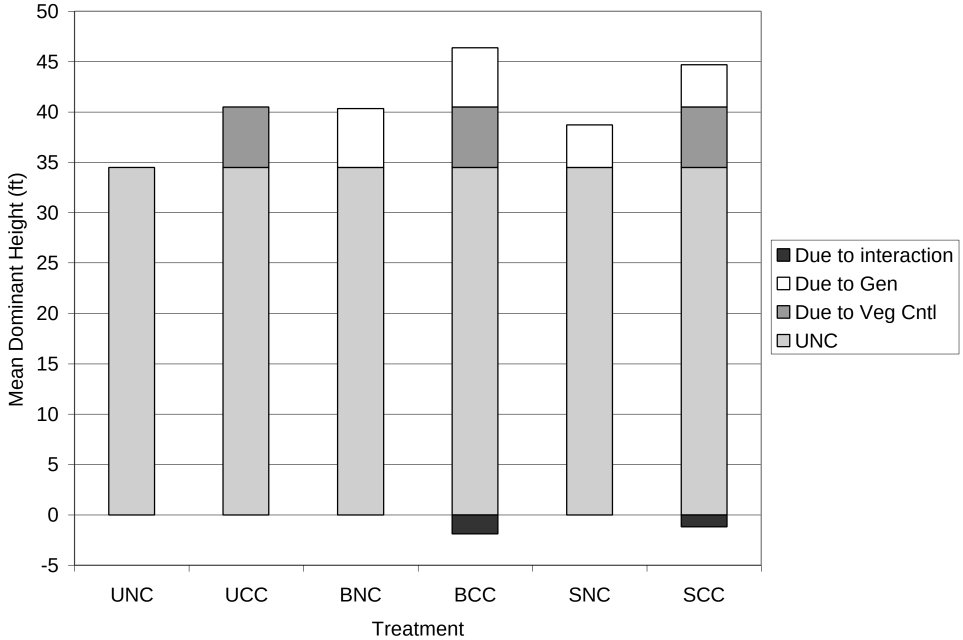

Figure 4. Mean dominant height by treatment for 12-yr-old loblolly pine in the Piedmont.

Basal Area per Acre

Coastal Plain Analysis

Both genetics and vegetation control significantly affected basal area per acre in the Coastal Plain (Table 10). Competition control significantly increased basal area an average of 30.6 ft^2/ac across all levels of genetic stock. Genetic stock also significantly increased basal area per acre. While there was no significant difference between single family and bulk lot, or between bulk lot and unimproved, single family increased basal area by 5.8 ft^2/ac over unimproved stock. The interaction between competition control and genetic stock was not significant indicating the effects are additive in nature (Figure 5). Table 11 summarizes the least square means for basal area per acre (ft^2).

Table 10. Test of fixed effects (reproduced from SAS® output) for basal area (ft²/ac) in the Coastal Plain.

Source	Numerator Degrees of Freedom	Denominator Degrees of Freedom	Type III F	Pr > F
Genetics	2	79.9	3.18	0.0470
Competition Control	1	13.1	80.06	0.0001
Genetics* Competition Control	2	79.2	0.75	0.4777

Table 11. Summary of least squares means for basal area (ft²/ac) in the Coastal Plain.

	No Control	Complete Control	Average
Unimproved	101.7	130.8	116.2
Bulk Lot	104.0	132.9	118.5
Single Family	105.1	138.9	122.0
Average	103.6	134.2	118.9

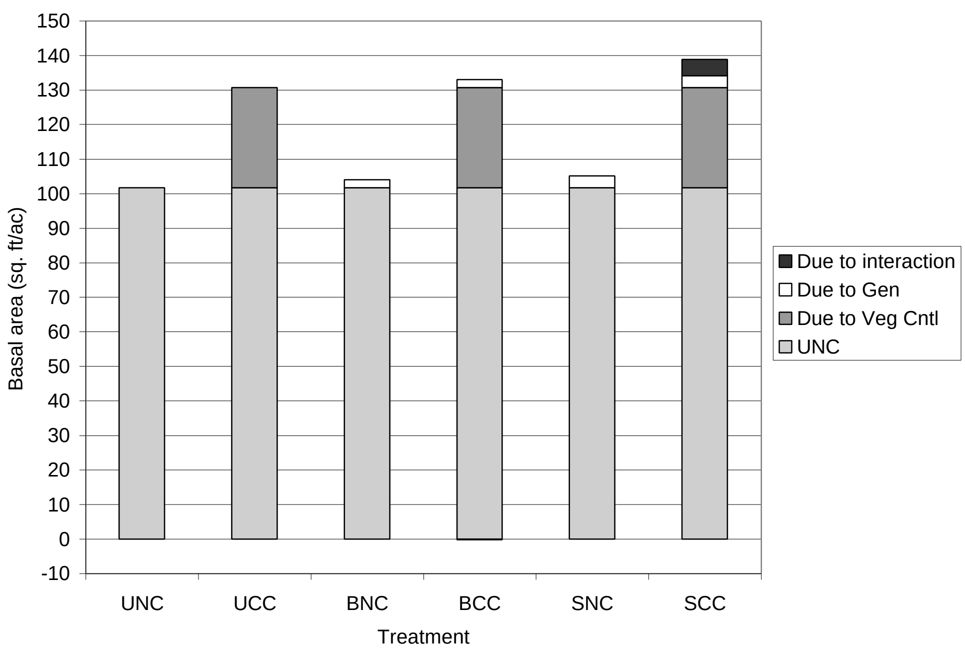

Figure 5. Basal area per acre by treatment for 12-yr-old loblolly pine in the Coastal Plain.

Piedmont Analysis

The interaction between vegetation control and genetic stock had a significant effect on basal area per acre in the Piedmont (Table 12).

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

Source	Numerator Degrees of Freedom	Denominator Degrees of Freedom	Type III F	Pr > F
Genetics	2	72	3.71	0.0292
Competition Control	1	11.3	55.59	0.0001
Genetics* Competition Control	2	71.4	3.87	0.0253

Figure 6 graphically shows that mean basal area with complete vegetation control does not receive significant additional gain due to genetics. This interaction can be explained in part by examining the results for the survival analysis. There was a significant interaction between vegetation control and genetic stock with regards to trees per ac in the Piedmont region. These results suggest that managers using less intensive competition control in the Piedmont may benefit more with respect to basal area per ac and survival from improved seedlings than mangers using vegetation control. In the case of no vegetation control there was no significant difference between bulk lot and single family, but bulk lot and single family increased basal area 16.2 and 11.4 ft^2/ac respectively, over unimproved stock. With unimproved genetic stock, complete vegetation control increased basal area 41.2 ft^2/ac. Competition control increased basal area 27.0 and 25.7 ft^2/ac for single family and bulk lot genetic stock, respectively. Table 13 and Figure 7 summarize the least square means for basal area (ft^2/ac) by treatment.

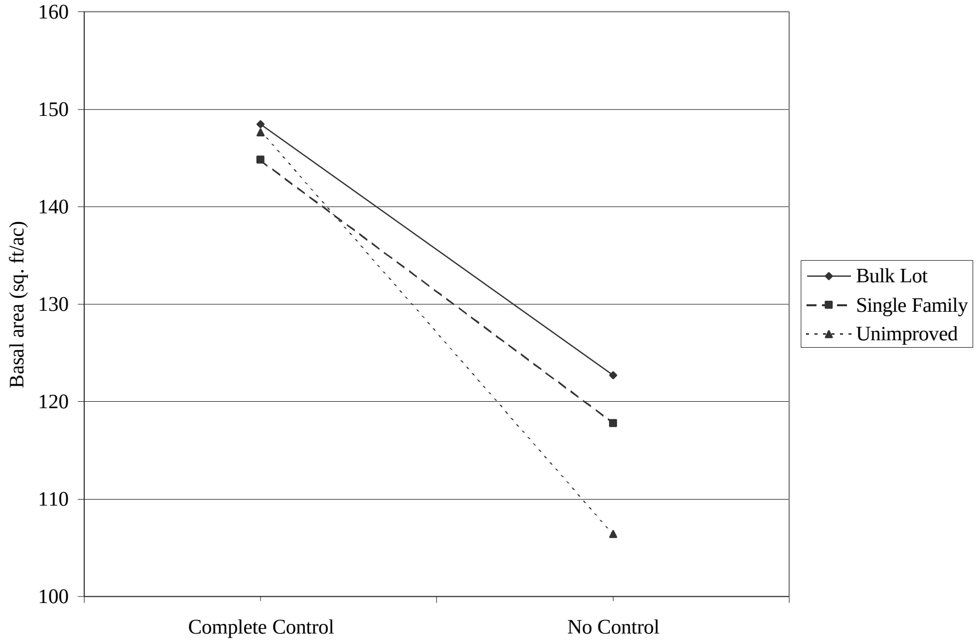

Figure 6. **The interaction between competition control and genetic stock on basal area per acre in the Piedmont.**

Table 13. **Summary of least squares means for basal area (ft^2/ac) in the Piedmont.**

	No Control	Complete Control	Average
Unimproved	106.4	147.6	127.0
Bulk Lot	122.7	148.5	135.6
Single Family	117.8	144.8	131.3
Average	115.6	147.0	131.3

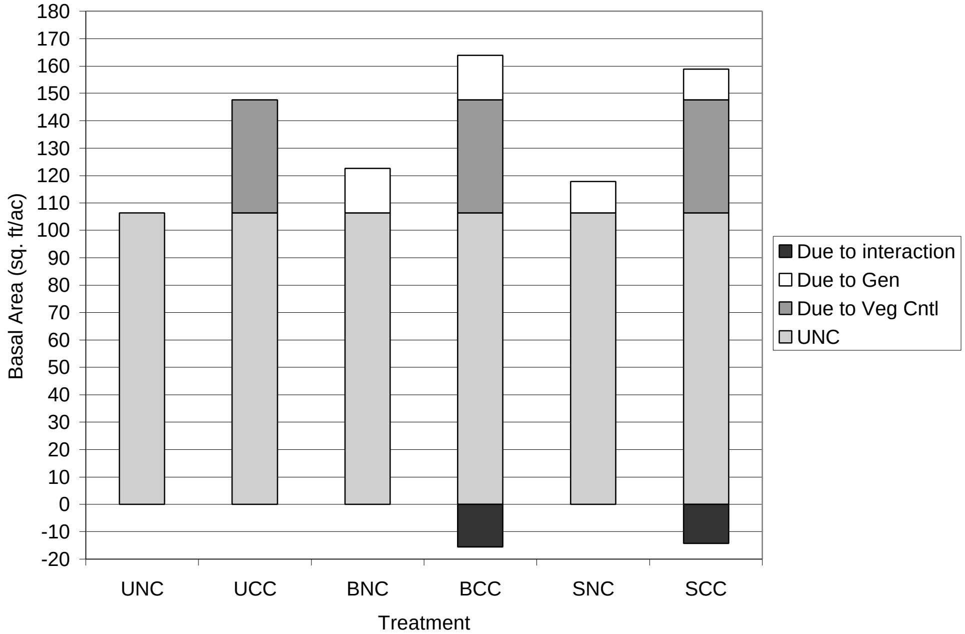

Figure 7. Basal area per acre by treatment for 12-yr-old loblolly pine in the Piedmont.

Total Volume per Acre

Coastal Plain Analysis

Table 14 gives the results of the tests of fixed effects for total outside bark volume per acre in the Coastal Plain. Competition control significantly increased yield in the Coastal Plain an average of 882 ft^3/ac across all levels of genetic stock. Genetic stock also significantly increased total volume per acre. While there was no significant difference between single family and bulk lot, they increased yield by 364 ft^3/ac and 246 ft^3/ac, respectively over unimproved stock. The interaction between competition control and genetic stock was not significant. Table 15 and Figure 8 summarize the least square means for total volume per acre by treatment.

Table 14. Test of fixed effects (reproduced from SAS® output) for total volume (ft³/ac) in the Coastal Plain.

Source	Numerator Degrees of Freedom	Denominator Degrees of Freedom	Type III F	Pr > F
Genetics	2	80.1	13.71	0.0001
Competition Control	1	13.3	82.92	0.0001
Genetics* Competition Control	2	79.3	0.97	0.3822

Table 15. Summary of least squares means for total volume (ft³/ac) in the Coastal Plain.

	No Control	Complete Control	Average
Unimproved	1811.3	2615.7	2213.5
Bulk Lot	2033.8	2885.6	2459.7
Single Family	2082.3	3073.1	2577.7
Average	1975.8	2858.1	2417.0

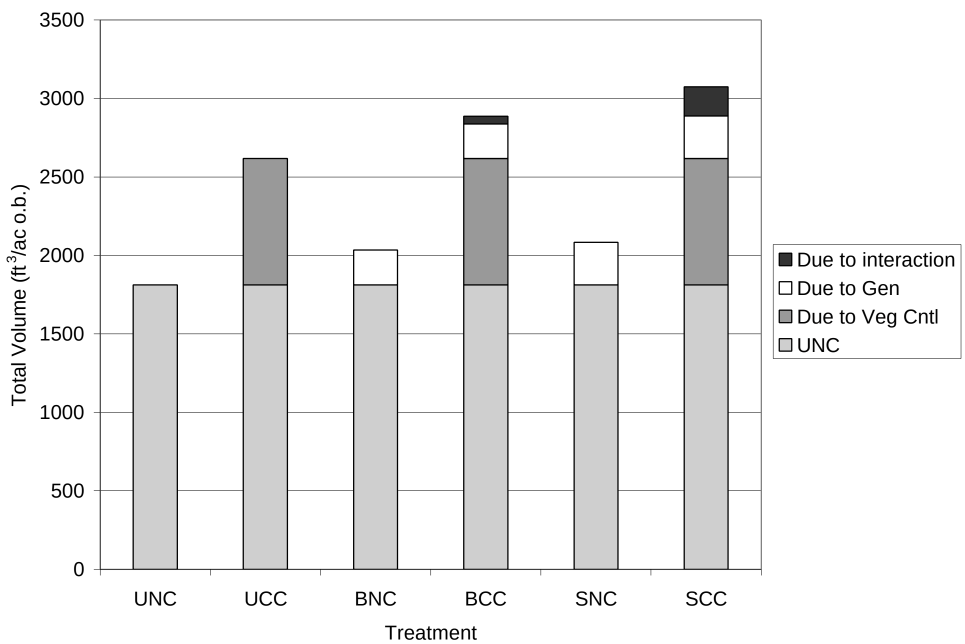

Figure 8. Total Volume per acre by treatment for 12-yr-old loblolly pine in the Coastal Plain.

Piedmont Analysis

Table 16 gives the results of the tests of fixed effects for total volume in the Piedmont. Both vegetation control and improved genetic stock had significant and additive effects on total volume. Competition control significantly increased yield an average of 863 ft^3/ac across all genetic stock. A t-test on the differences of least square means detected no significant differences between bulk lot and single family, but bulk lot increased yield 445 ft^3/ac and single family 227 ft^3/ac over unimproved stock. The interaction between genetic stock and competition control was not significant. Table 17 and Figure 9 summarize the least square means for total volume by treatment.

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

Source	Numerator Degrees of Freedom	Denominator Degrees of Freedom	Type III F	Pr > F
Genetics	2	23.8	13.21	0.0001
Competition Control	1	11.1	53.43	0.0001
Genetics* Competition Control	2	54	2.14	0.1276

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

	No Control	Complete Control	Average
Unimproved	1849.5	2913.1	2381.3
Bulk Lot	2457.4	3196.7	2827.1
Single Family	2265.6	3052.0	2658.8
Average	2190.8	3053.9	2622.4

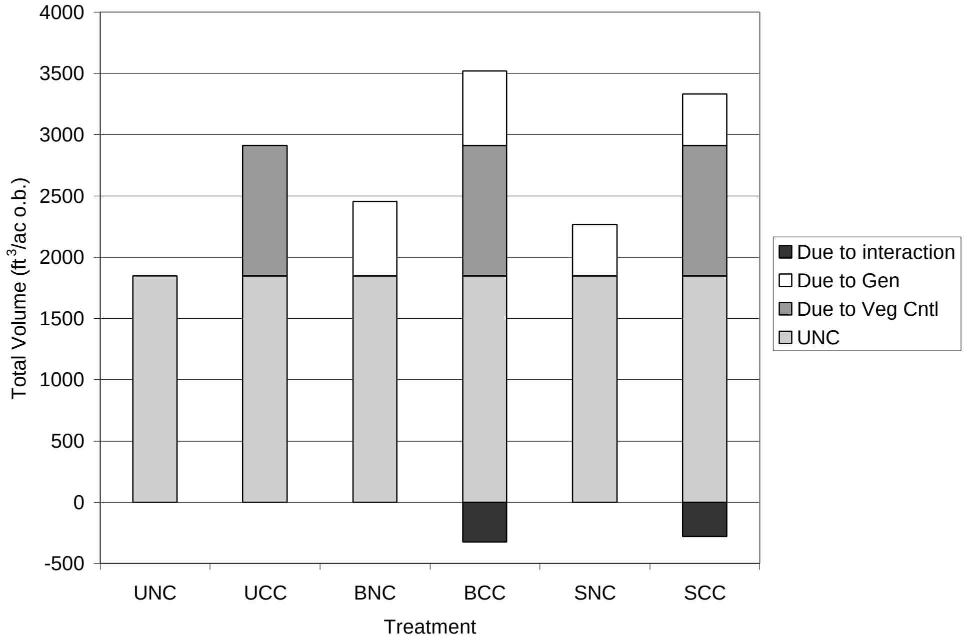

Figure 9. Total Volume per acre by treatment for 12-yr-old loblolly pine in the Piedmont.

Merchantable Volume

Coastal Plain Analysis

Results for merchantable volume were essentially the same as for total volume. In the Coastal Plain, competition control significantly increased merchantable volume (3-in. top) an average of 919 ft^3/ac. across all levels of genetic stock (Table 18). A t-test on the differences of least square means detected no significant differences between bulk lot and single family, but bulk lot increased merchantable yield 232 ft^3/ac and single family 355 ft^3/ac over unimproved stock. The interaction between genetic stock and competition control was not significant. Table 19 and Figure 10 summarize the least square means for merchantable volume by treatment.

Table 18. Test of fixed effects (reproduced from SAS® output) for merchantable volume o.b. to a 3-in. top o.b. (ft³/ac) in the Coastal Plain.

Source	Numerator Degrees of Freedom	Denominator Degrees of Freedom	Type III F	Pr > F
Genetics	2	80.1	12.7	0.0001
Competition Control	1	13.3	86.51	0.0001
Genetics* Competition Control	2	79.3	0.87	0.4240

Table 19. Summary of least squares means for merchantable volume o.b. to a 3-in. top o.b. (ft³/ac) in the Coastal Plain.

	No Control	Complete Control	Average
Unimproved	1572.6	2419.3	1996.0
Bulk Lot	1784.6	2671.4	2228.0
Single Family	1839.8	2862.5	2351.1
Average	1732.4	2651.0	2191.7

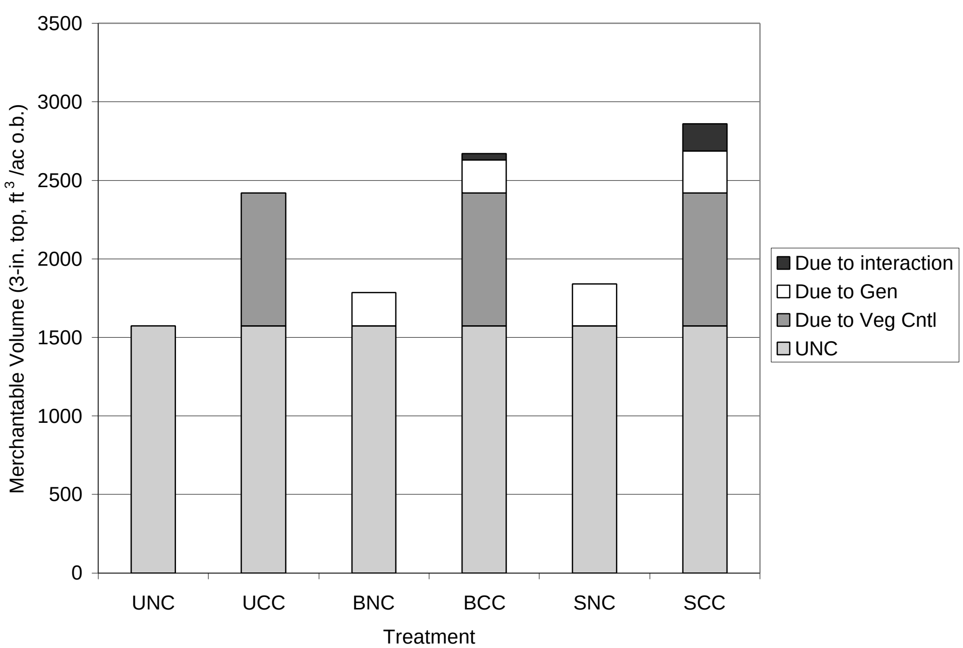

Figure 10. Merchantable volume (3-in. top) per acre by treatment for 12-yr-old loblolly pine in the Coastal Plain.

Piedmont Analysis

Table 20 gives the results of the tests of fixed effects for merchantable volume in the Piedmont. Both vegetation control and genetics had significant and additive effects on merchantable volume. Competition control significantly increased merchantable outside bark yield to a 3-in. top an average of 896 ft^3/ac across all genetic stock. No significant difference was detected between bulk lot and single family, but bulk lot increased merchantable yield 441 ft^3/ac and single family 272 ft^3/ac over unimproved stock. The interaction between genetic stock and competition control was not significant. Table 5 and Figure 11 summarize the least square means for merchantable volume.

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

Source	Numerator Degrees of Freedom	Denominator Degrees of Freedom	Type III F	Pr > F
Genetics	2	24.4	13.14	0.0001
Competition Control	1	11.1	60.97	0.0001
Genetics* Competition Control	2	54.6	1.86	0.1648

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

	No Control	Complete Control	Average
Unimproved	1646.7	2731.3	2189.0
Bulk Lot	2244.9	3016.8	2630.9
Single Family	2045.4	2877.5	2461.5
Average	1979.0	2875.2	2427.1

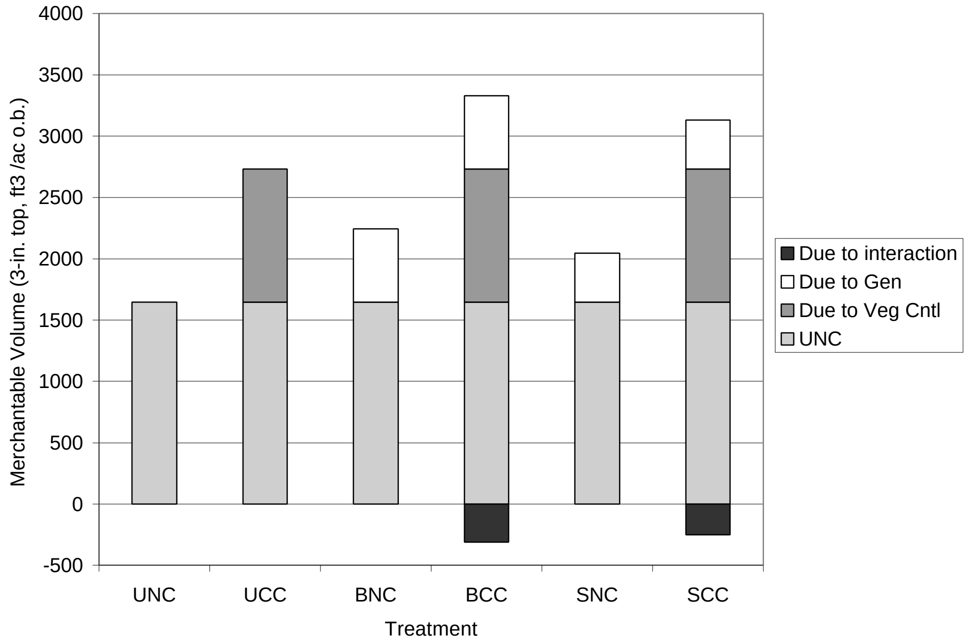

Figure 11. **Merchantable volume (3-in. top) per acre by treatment for 12-yr-old loblolly pine in the Piedmont.**

Trees per Acre

Coastal Plain Analysis

There were no significant differences in trees per acre due to genetics or competition control in the Coastal Plain (Table 22). There was an average of 667 surviving trees per acre after 12 years in the Coastal Plain region (Figure 12).

Table 22. Test of fixed effects (reproduced from SAS® output) for trees per acre in the Coastal Plain.

Source	Numerator Degrees of Freedom	Denominator Degrees of Freedom	Type III F	Pr > F
Genetics	2	12.3	0.09	0.9186
Competition Control	1	7.88	0.01	0.9414
Genetics* Competition Control	2	46.8	1.42	0.2520

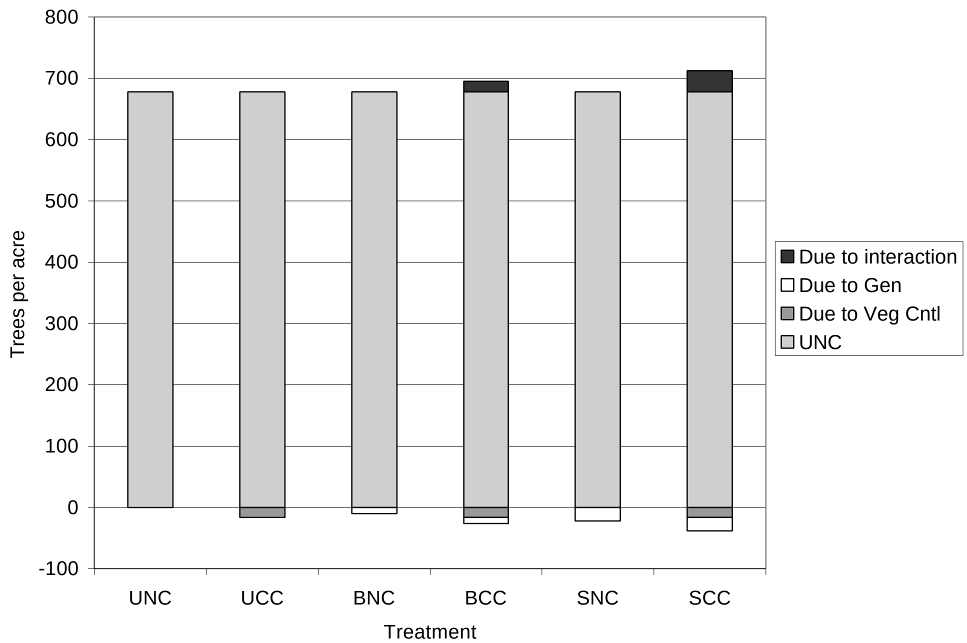

Figure 12. Trees per acre by treatment for 12-yr-old loblolly pine in the Coastal Plain.

Piedmont Analysis

The interaction between vegetation control and genetic stock had a significant effect on trees per acre in the Piedmont (Table 23). The interaction is depicted in Figure 13. Unimproved survival in the Piedmont region is affected by competition control. Competition control significantly increased survival an average of 53 trees per acre for unimproved stock. Although bulk lot and single family cross, the differences are practically insignificant. This dramatic difference in survival for the unimproved genetic stock helps explain the significant interaction in the basal area per acre analysis. Table 24 and Figure 14 give the least square treatment means.

Table 23. Test of fixed effects (reproduced from SAS® output) for trees per acre in the Piedmont.

Source	Numerator Degrees of Freedom	Denominator Degrees of Freedom	Type III F	Pr > F
Genetics	2	20.1	0.09	0.9132
Competition Control	1	11	0.95	0.3513
Genetics* Competition Control	2	50.4	3.84	0.0280

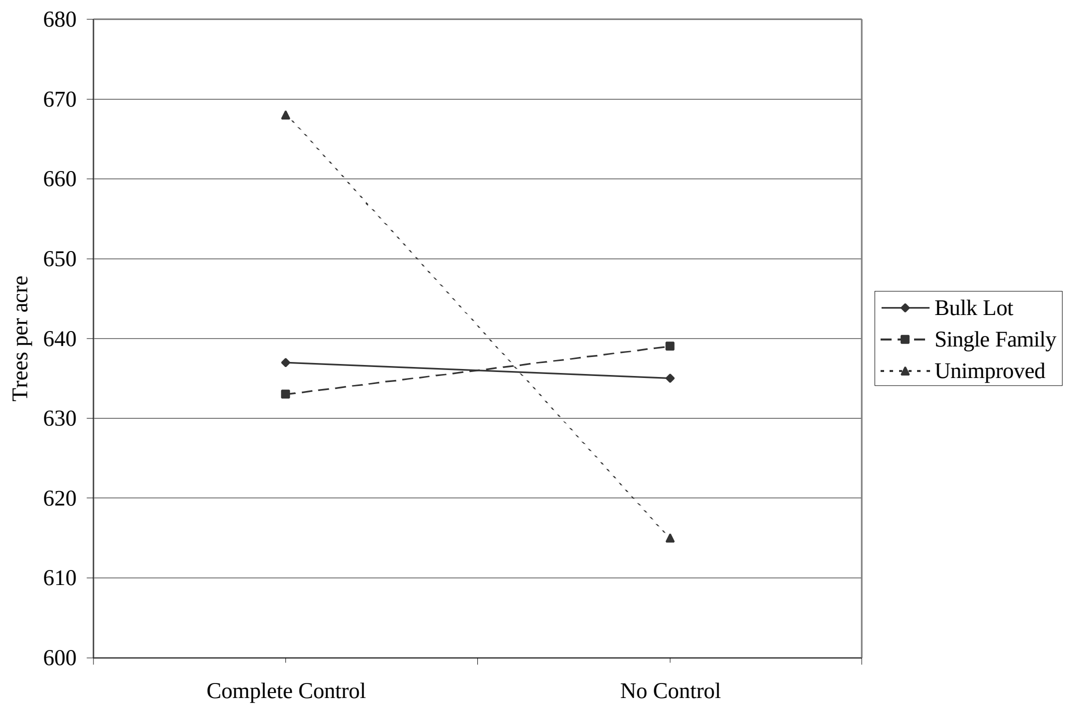

Figure 13. The interaction between competition control and genetic stock on trees per acre in the Piedmont.

Table 24. Summary of least squares means for trees per acre in the Piedmont.

	No Control	Complete Control	Average
Unimproved	615	668	641
Bulk Lot	635	637	636
Single Family	639	633	636
Average	630	646	638

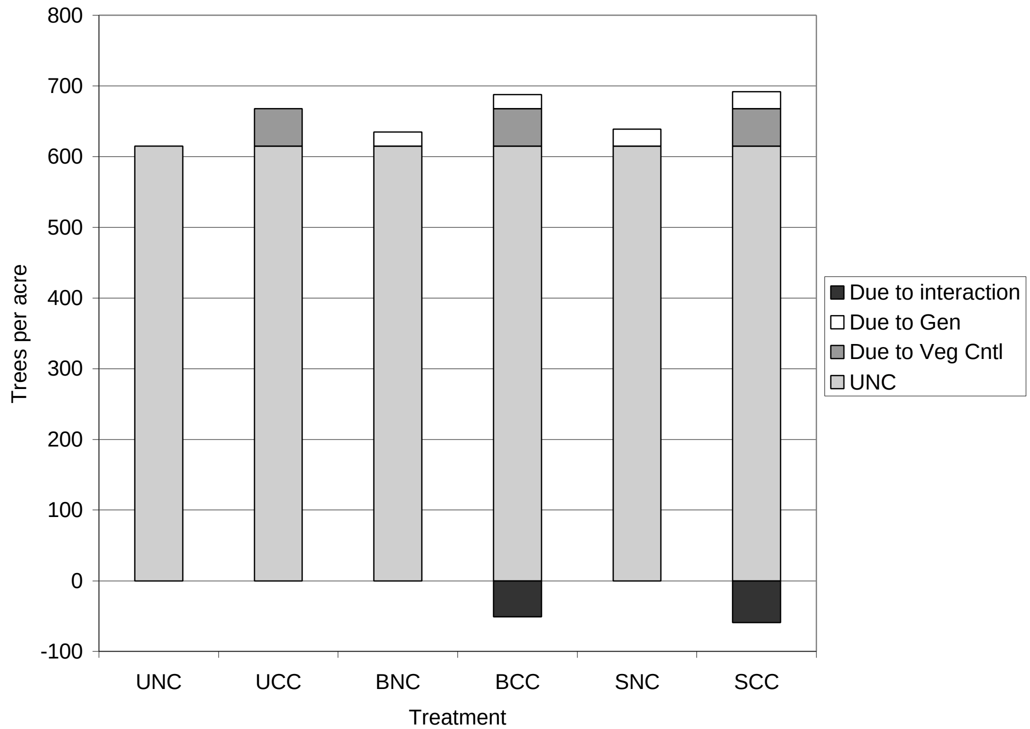

Figure 14. Trees per acre by treatment for 12-yr-old loblolly pine in the Piedmont.

Percent Fusiform Infection

Coastal Plain Analysis

Genetic improvement significantly contributed to reduced percent fusiform infections in the Coastal Plain (Table 25). There were no significant differences between bulk lot and single family but both reduced percent fusiform infections from 17.1% to 7.4% and 7.6%, respectively over unimproved stock. Vegetation control did not significantly affect the rust infection level (Figure 15).

Table 25. Test of fixed effects (reproduced from SAS® output) for percent fusiform infection in the Coastal Plain.

Source	Numerator Degrees of Freedom	Denominator Degrees of Freedom	Type III F	Pr > F
Genetics	2	24.1	35.36	0.0001
Competition Control	1	12.8	0.68	0.4254
Genetics* Competition Control	2	25.2	1.00	0.3816

Table 26. Summary of least squares means for percent fusiform infection in the Coastal Plain.

	No Control	Complete Control	Average
Unimproved	15.8%	18.3%	17.1%
Bulk Lot	7.1%	7.7%	7.4%
Single Family	7.6%	7.7%	7.6%
Average	10.2%	11.2%	10.7%

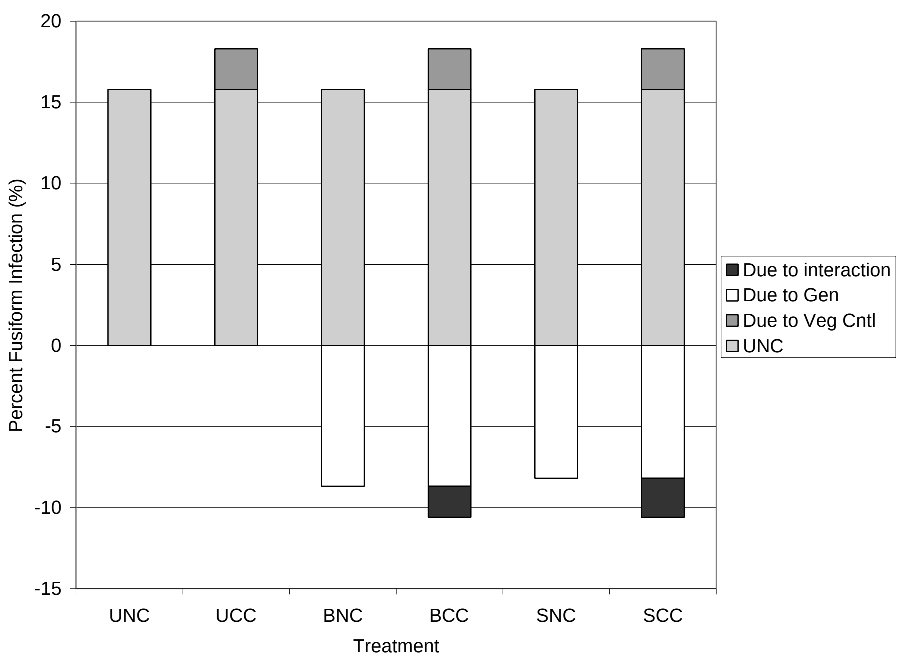

Figure 15. Percent fusiform rust infection by treatment for 12-yr-old loblolly pine in the Coastal Plain.

Piedmont Analysis

Results for the Piedmont analysis are very similar to those for the Coastal Plain. Genetic improvement significantly contributed to reduced percent fusiform (Table 27). There were no significant differences between bulk lot and single family but both decreased percent fusiform infections from 16.7% to 9.7% and 9.9%, respectively over unimproved stock. Vegetation control did not significantly affect the rust infection level (Figure 16).

Table 27. Test of fixed effects (reproduced from SAS® output) for percent fusiform infection in the Piedmont.

Source	Numerator Degrees of Freedom	Denominator Degrees of Freedom	Type III F	Pr > F
Genetics	2	24.4	12.88	0.0002
Competition Control	1	12.1	0.02	0.9037
Genetics* Competition Control	2	51.6	0.55	0.5826

Table 28. Summary of least squares means for percent fusiform infection in the Piedmont.

	No Control	Complete Control	Average
Unimproved	17.2%	16.2%	16.7%
Bulk Lot	9.8%	9.7%	9.7%
Single Family	9.6%	10.2%	9.9%
Average	12.2%	12.0%	12.1%

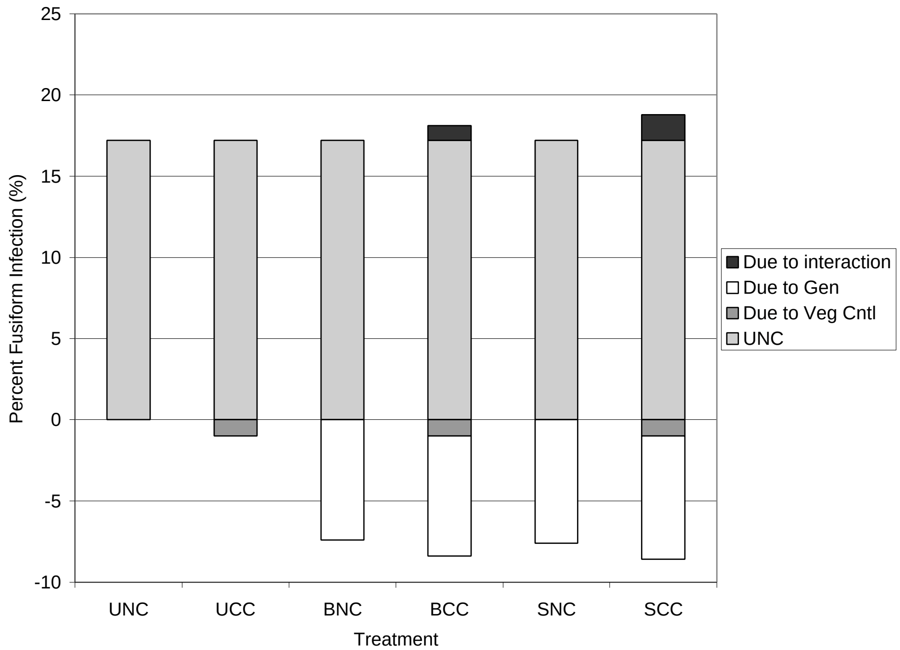

Figure 16. Percent fusiform rust infection by treatment for 12-yr-old loblolly pine in the Piedmont.

THREE YEAR PERIODIC GROWTH

An analysis was conducted to examine the 3-yr periodic growth, between ages 6 and 9, and 9 and 12, of the dependent variables. The objective was to determine whether genetics and competition control are continuing to contribute to increased growth rates or whether the treatment combination means are converging over time.

Table 29. Average difference (in.) in mean dbh growth for the two 3-yr periods. Different letters indicate a significant difference between complete vegetation control and no control.

3-yr period	Coastal Plain		Piedmont	
	CC	NC	CC	NC
6 to 9 yr	1.07 (a)	1.26 (b)	1.37 (a)	1.58 (b)
9 to 12 yr	0.74 (a)	0.95 (b)	0.80 (a)	1.02 (b)

The 3-yr periodic growth in mean dbh between ages 6 and 9, and 9 and 12 are significantly larger for no competition control than complete control in both the Piedmont and Coastal Plain regions (Table 29). These results indicate that the mean dbh for the two different competition control treatments are converging over time (Figures 17 and 18). This convergence may indicate that the two competition control treatments are at different stages of stand development. The complete control treatment exhibited significantly greater dbh growth rates early in stand development and now, as the stand matures, the complete control is starting to exhibit slightly lower growth rates as it approaches the onset of intraspecific competition. This stage of development is characterized by a reduction in individual tree growth rates relative to their potential in the absence of competitive interaction (Long and Smith, 1984). It is important to note that while the 3-yr periodic growth rates are significantly higher for the no competition control plots, the absolute difference in dbh between the treatments at age 12 average 0.7 to 0.8 in. and are considerably larger than the differences in the periodic growth. There are no significant differences between mean dbh growth during these two periods with respect to genetics in either region.

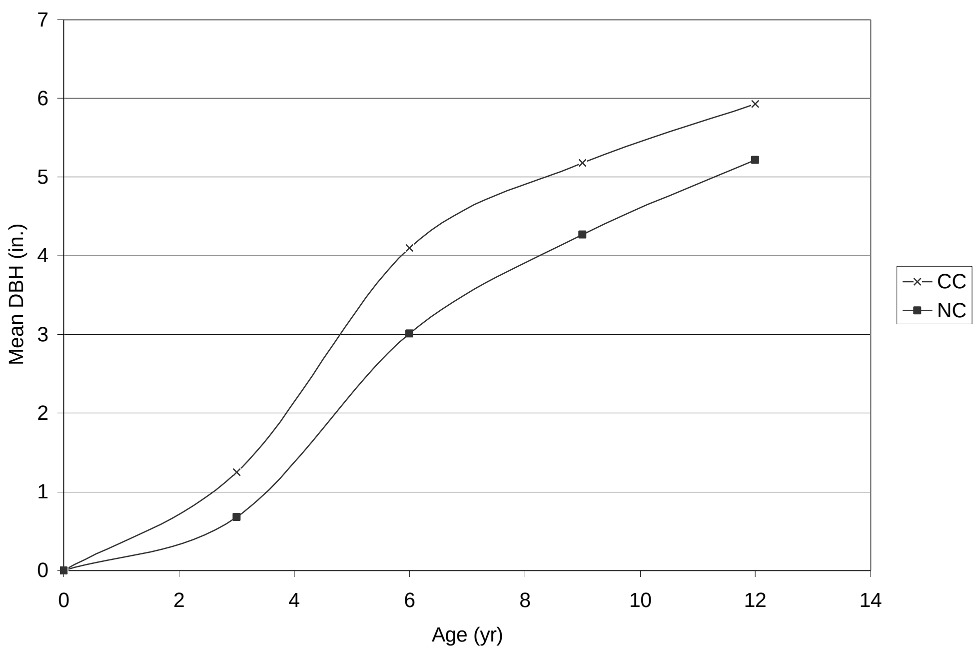

Figure 17. **Mean dbh for the two competition control treatments in the Coastal Plain.**

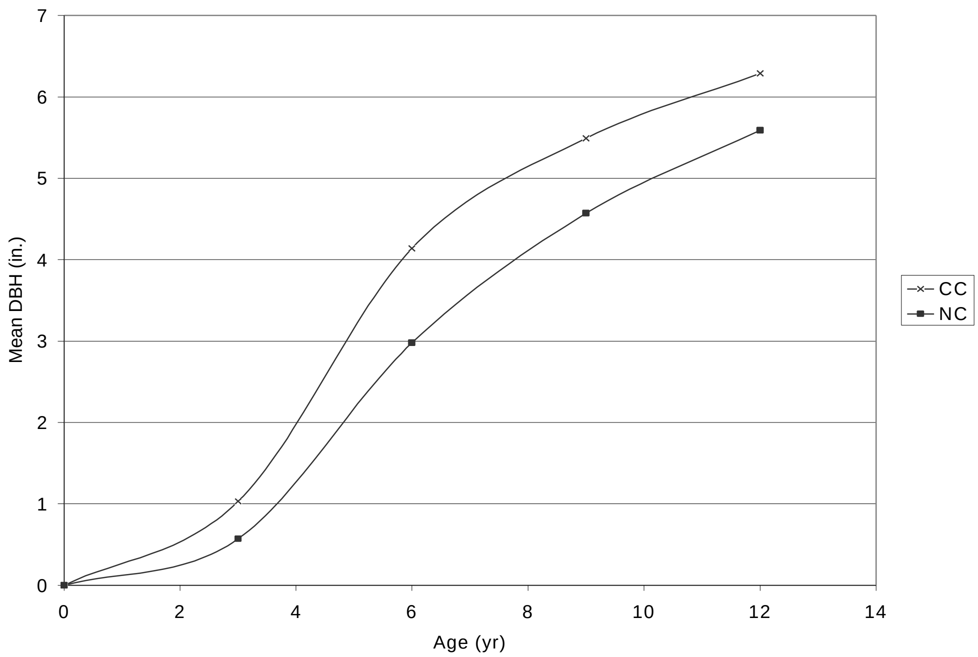

Figure 18. Mean dbh for the two competition control treatments in the Piedmont.

In terms of mean dominant height, improved genetic stock continues to outgrow the unimproved stock in both physiographic regions (Table 30). Figures 19 and 20 show that mean dominant height for the improved versus unimproved genetic stock continues to diverge. There were no significant differences in dominant height growth during the two 3-yr periods attributed to competition control, indicating that the mean periodic dominant height growth for the two competition control treatments are no longer diverging.

Table 30. Average difference (ft) in mean dominant height growth for the two 3-yr periods. Different letters indicate a significant difference between genetic treatments.

3-yr period	Coastal Plain			Piedmont		
	UI	BL	SF	UI	BL	SF
6 to 9 yr	9.41 (a)	10.67 (b)	10.61 (b)	9.52 (a)	10.74 (b)	10.43 (b)
9 to 12 yr	10.44 (a)	11.03 (a,b)	11.41 (b,c)	10.05 (a)	11.37 (b)	10.86 (b)

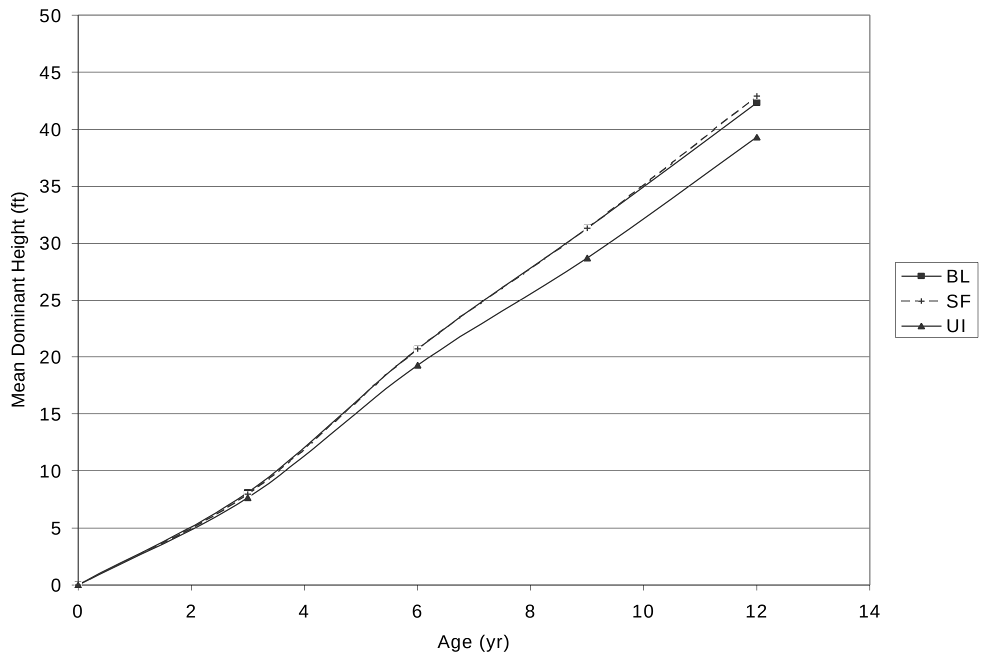

Figure 19. Mean dominant height for the three genetic treatments in the Coastal Plain.

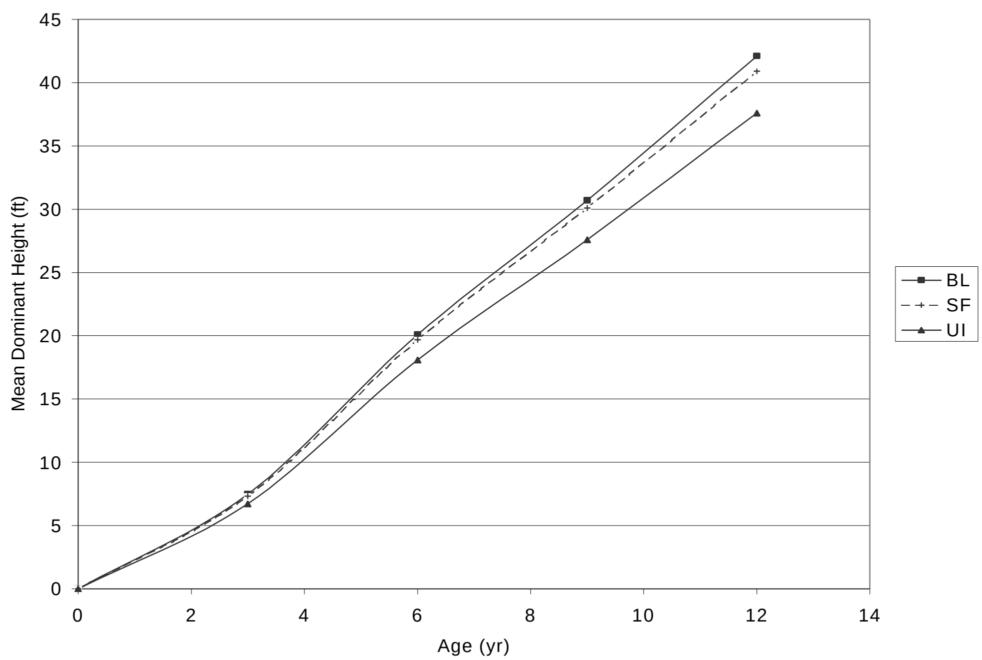

Figure 20. Mean dominant height for the three genetic treatments in the Piedmont.

There were significant differences between mean growth of basal area per acre for competition control in both regions during the period between 6 and 9 yrs. Complete control was still exceeding no control in growth. These results differ from the dbh analysis and can be explained by the dynamics of dbh growth. A 1-in. increase in dbh on a 3-inch tree is going to result in less basal area growth than a 1-in. increase on a 6-in. tree. Increasing the diameter of a larger cylinder will result in a larger cross sectional area, and therefore adding a smaller growth increment on a large dbh can result in more basal area growth than a larger diameter growth increment on a smaller dbh. During the period between 9 and 12 years there was no significant difference between competition control in the Coastal Plain, while in the Piedmont region, no control had significantly greater growth than the complete control. These results indicate that in both regions, basal area per acre is no longer diverging and in fact, in the Coastal Plain, basal area growth between the competition control treatments has begun to converge (Figure 21 and 22). Even with this convergence, the absolute gain in basal area per ac at age 12 ranges from 25 to 31 ft^2, indicating the large gains due to complete vegetation control. It is interesting to note that the mean basal area per acre growth for complete control reached its maximum mean annual increment (MAI) somewhere before age 12, while for no vegetation control MAI is still increasing at age 12. There were no significant differences due to genetics in periodic growth of basal area per acre.

Table 31. Average difference (ft^2) in mean basal area growth for the two 3-yr periods. Different letters indicate a significant difference between complete vegetation control and no control.

3-yr period	Coastal Plain		Piedmont	
	CC	NC	CC	NC
6 to 9 yr	40.06 (a)	36.66 (b)	51.31 (a)	46.29 (b)
9 to 12 yr	29.18 (a)	30.96 (a)	32.76 (a)	36.00 (b)

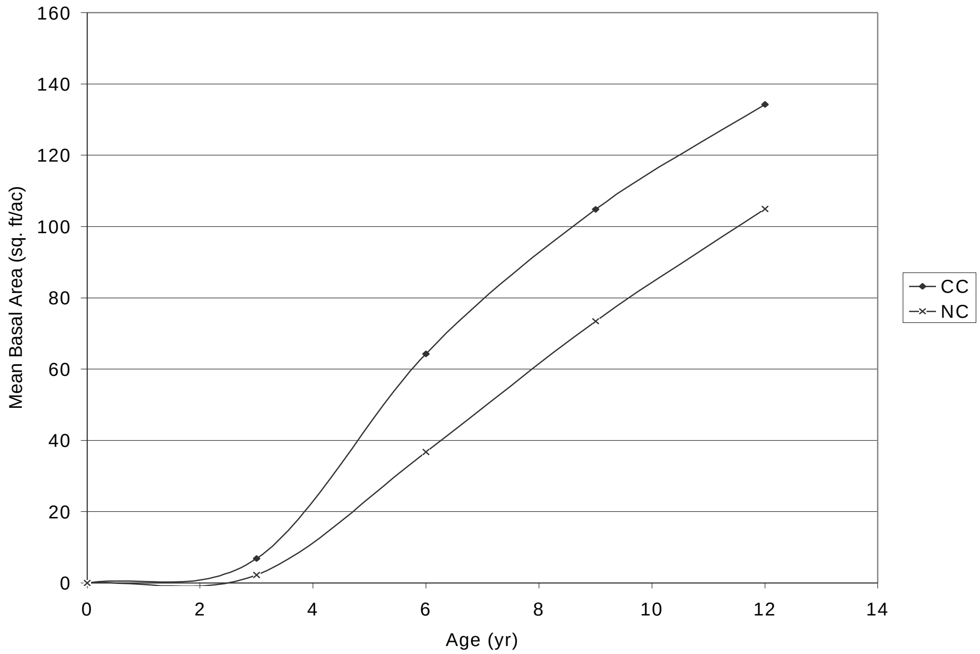

Figure 21. **Mean basal area per acre for the two competition control treatments in the Coastal Plain.**

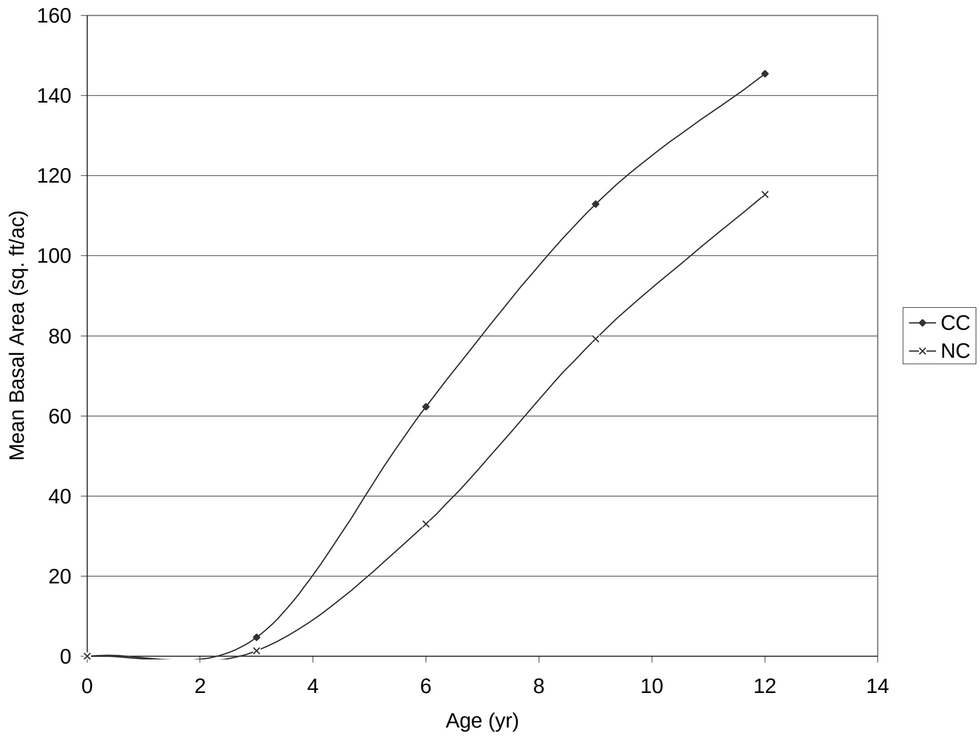

Figure 22. **Mean basal area per acre for the two competition control treatments in the Piedmont.**

In the Coastal Plain region, genetics and competition control continued to significantly increase volume growth during both periods (Figure 23). During the period from 6 to 9 yrs, both competition control and genetics additively increased volume growth in the Piedmont region, while during the period from 9 to 12, the interaction between genetics and competition control was significant (Figure 24). It is obvious from these results that volume growth curves have not yet reached their inflection points for any of the treatment combinations. This is expected due in part to the fact that MAI for basal area growth is expected to peak several years prior to volume growth MAI.

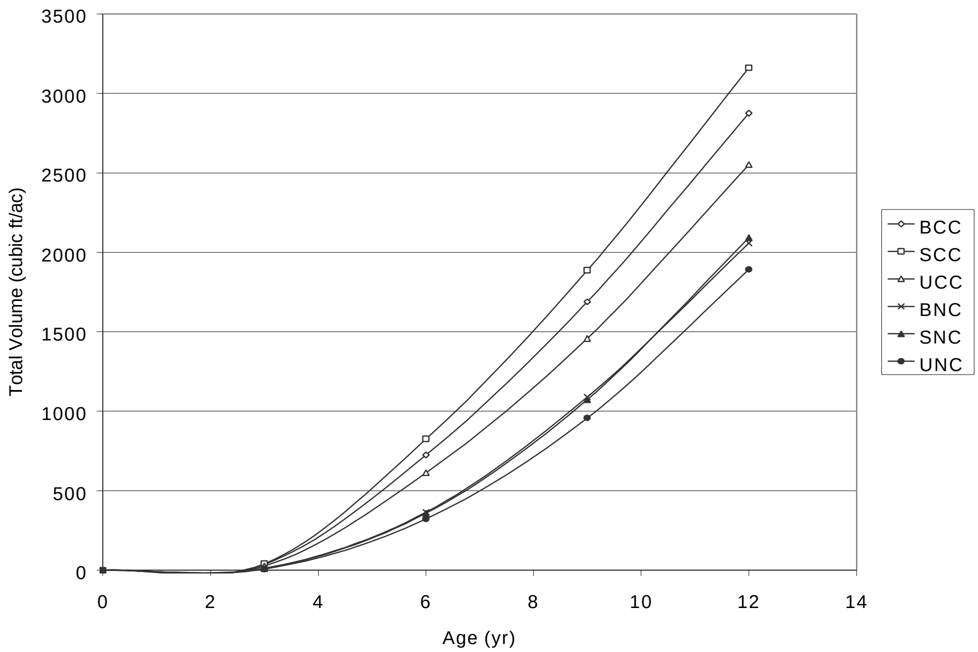

Figure 23. Total volume (ft^3/ac) for the six different treatment combinations in the Coastal Plain.

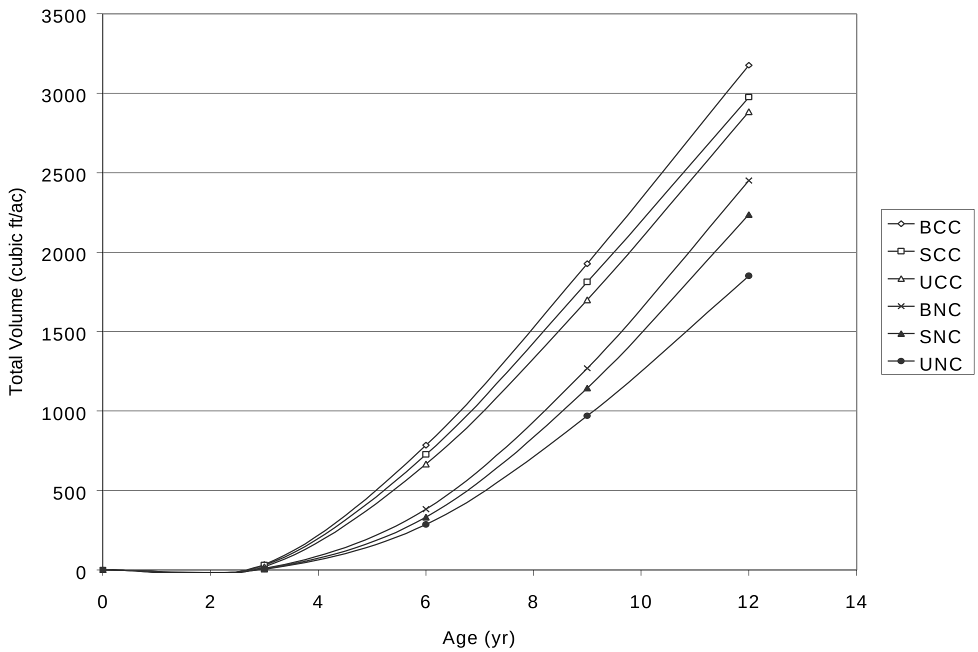

Figure 24. **Total volume (ft^3/ac) for the six different treatment combinations in the Piedmont.**

In the Coastal Plain region, improved genetics continued to significantly reduce mean fusiform infections during the period from 6 to 9 yrs, and while not significantly different, the improved genetic stock also had a smaller increase in infection percentage during the period from 9 to 12 yrs. In the Piedmont region, the interaction between competition control and genetics was significant during the period from 6 to 9 yrs. During the period between 9 and 12 yrs there were no significant differences in mean fusiform infection percentage in the Piedmont region.

CONCLUSIONS

Competition control significantly increased average tree characteristics and basal area per acre in both the Piedmont and Coastal Plain regions. In the Piedmont region, improved genetics significantly increased average dbh. Average dominant height was significantly increased in both physiographic regions by improved genetics. For Coastal Plain loblolly pine, improved genetics significantly increased basal area per acre. In the Piedmont region, there was a significant interaction between competition control and genetics with respect to basal area per acre and trees per acre. Total and merchantable volume were significantly increased by both improved genetics and competition control, and the effects are additive in nature. In the Coastal Plain region, neither competition control nor genetics significantly affected trees per acre. In both regions, improved genetics significantly reduced the percent fusiform infection.

The results of the 3-yr period growth analysis showed that the no competition control plots had significantly larger 3-yr growth in mean dbh in both the Piedmont and Coastal Plain regions. In terms of mean dominant height, improved genetic stock continued to outgrow unimproved stock in both physiographic regions. During the 3-yr period between 9 and 12 yrs there were no significant differences in dominant height growth between competition control and no competition control in the Coastal Plain, while in the Piedmont region no control had significantly greater growth than the complete control. In the Coastal Plain region, genetics and competition control continued to significantly increase volume growth during both periods. During the period from 6 to 9 yrs, both competition control and genetics additively increased volume growth in the Piedmont region, while during the period from 9 to 12, the interaction between genetics and competition control was significant.

The results of this study show that there is a clear benefit from using intensive competition control and improved genetics. In terms of total volume, increases up to 45% and 39% can be obtained from using complete vegetation control in the Coastal Plain and Piedmont regions, respectively. Improved genetic stock can increase total volume an average of 11% to 16% in the Coastal Plain and 10% to 19% in the Piedmont. These volume percentage gains fall in the range estimated by progeny test conducted by Talbert et al. (1985). For the age 12 analyses, the gains in total and merchantable volume due to genetics and competition control were determined to be additive in nature which indicates managers can expect to receive the full benefit of both improved genetics and competition control if they use both treatments.

A separate analysis on this study will be completed to attempt to correlate growth with quantity and type of vegetation present on the plots. In addition, models will be developed with the intent of helping managers better estimate future gains from competition control, genetics and their interaction. This study is scheduled to be remeasured at age 15.

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