SLASH PINE SITE PREPARATION STUDY:

AGE 23 RESULTS

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EXECUTIVE SUMMARY

One of the first designed studies established by the PMRC was a study to evaluate growth, yield and stand structure of slash pine (*Pinus elliottii* Engelm.) plantations following different site preparation treatments alone and in combination with fertilization and herbicide. The study was established in 1979 at 20 locations distributed geographically from north of Savannah, GA, south along the Atlantic coast to Daytona Beach, FL and across north Florida to Appalachicola on the Gulf Coast. All installations were located in the flatwoods region of the lower coastal plain province. Twenty-three years after installation, 15 of the original 20 installations remain for analysis. Of these, six are nonspodosols and nine are spodosols.

Analysis of variance for a split plot design was used to test for significant sources of variation with the 23-year data. Soil groups represent the whole plots and treatments represent the splits. The split plot analysis was carried out using a mixed model. The location (installation) and its interactions were regarded as random factors and the treatment and soil effects were considered fixed. This approach allows for inferences across all sites represented by the sample of sites included in this study. Analyses were conducted on average individual tree characteristics (height, dominant height, dbh, crown length, crown ratio) and per acre stand characteristics (basal area, total volume, merchantable volume, percent fusiform infection) at age 23. Analyses were also conducted on remeasurement data between the ages of 5 and 23 to determine the response of growth curves to silvicultural treatments.

Chopping and burning had no significant effect on any of the average, individual tree characteristics. Bedding significantly increased average and dominant height but was not a significant factor for dbh or crown length. Bedding resulted in a significant decrease in crown ratio for nonspodosols. Herbicide and fertilization significantly increased average and dominant tree height, dbh and crown length. Herbicide significantly decreased crown ratio on spodosol soils, but was not significant on nonspodosols. Unlike younger ages, some of the least intensively managed plots had crown lengths at age 23 comparable to the most intensively managed plots. In general, treatments that promoted rapid height growth tended to result in higher levels of cronartium infection. Herbicide had the only significant effect on cronartium, increasing the infection rate.

There was no significant interaction between treatment and soil type at age 23, unlike age 20 when per acre basal area and merchantable volume both had a significant soil by treatment interaction. Fertilization significantly increased all measured stand level characteristics except trees per acre, while herbicide significantly impacted all measured stand level characteristics. Both bedding and burning significantly impacted basal area, merchantable volume and total volume. Chopping had no significant impact on any measured characteristics.

Growth was examined between the ages 5 and 23. A multivariate approach was used in the growth analysis. Age was considered a within subject effect. Both between subject and between*within subject effects were examined. Soil significantly affected average dbh growth, average mean height growth and average dominant height growth. There was a significant soil*age interaction present for dbh, basal area per acre and total volume per acre. Fertilization, fertilization*age, vegetation control and vegetation control*age were significant for all analyzed tree and stand level characteristics on spodosol soils. For nonspodosol soils vegetation control was significant for all but mean and dominant height. Fertilization significantly affected total volume*age, and was borderline significant on basal area per acre. This indicates the importance of fertilization and vegetation control for all aspects of stand growth. The fact that fertilization not only increases growth, but slows the rate at which growth decreases over time, indicates how valuable added nutrition is in maintaining rapid growth in intensively managed slash pine plantations.

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1 INTRODUCTION

One of the first designed studies established by the PMRC was a study to evaluate growth, yield and stand structure of slash pine (*Pinus elliottii* Engelm.) plantations following different site preparation treatments alone and in combination with fertilization and herbicide. The study was established in 1979 at 20 locations distributed geographically from north of Savannah, GA, south along the Atlantic coast to Daytona Beach, FL and across north Florida to Appalachicola on the Gulf Coast. All installations were located in the flatwoods region of the lower coastal plain province.

The 20 locations were originally stratified equally over four soil groups defined by the following characteristics:

- Poorly drained, nonspodosol
- Somewhat poorly to moderately well drained, nonspodosol,
- Poorly to moderately well drained spodosol with an underlying argillic horizon,
- Poorly to moderately well drained spodosol without an underlying argillic horizon.

Twenty-three years after installation, 15 of the original 20 installations remain for analysis. Of these, six are nonspodosols and nine are spodosols.

For each installation, ½ -acre treatment plots were surveyed into existing plantations that were at least 20 years old and were available for clearcutting. Within each plot, dominant and codominant trees were measured for total height and site index was calculated using an equation developed by Newberry and Pienaar (1978). In order to ensure site homogeneity within an installation, the maximum allowable range in site index among the plots was five feet. Soil profiles were also checked for homogeneity. Site indexes across installations ranged from 54 to 80 feet.

Existing plantations were harvested in 1978 and plots were site prepared in 1978-79. First generation genetically improved slash pine seedlings grown in a single nursery were hand planted during the winter of 1979-80 at an 8 ft. x 10 ft. spacing. To ensure adequate survival, two seedlings were planted at each planting location. After two growing seasons, one tree was removed from all planting spots where two trees had survived. The result was reasonably uniform spacing with a density of approximately 545 trees per acre on most plots.

The following treatments were applied at each location:

1. Control (harvest and plant, no site preparation) **CNTL**
2. Chop (single pass with a rolling drum chopper) **UCHP**
3. Chop, fertilize **FCHP**
4. Chop, burn (chop followed by a broadcast burn) **UCHB**
5. Chop, burn, fertilize **FCHB**
6. Chop, burn, bed (treatment 4 followed by a double-pass bed) **UCBB**
7. Chop, burn, bed, fertilize **FCBB**
8. Chop, burn, herbicide (treatment 4 followed by complete herbicide) **UCBH**
9. Chop, burn, herbicide, fertilize **FCBH**
10. Chop, burn, bed, herbicide (treatment 6 followed by complete herbicide) **UBHB**
11. Chop, burn, bed, herbicide, fertilize **FBHB**.

The fertilizer treatment consisted of 250 pounds of diammonium phosphate applied after the first growing season. After the 12th growing season, 200 pounds of nitrogen in the form of urea and 100 pounds of potassium in the form of KCL were applied. After the 17th growing season, 625 pounds per acre of a 16-4-8 turf fertilizer were applied. This converts to 100, 25 and 50 pounds per acre of N, P and K, respectively.

A 1/5-acre measurement plot was established within each ½ - acre treatment plot. Measurements were made after two, five, eight, eleven, fourteen, seventeen, twenty and twenty-three growing seasons. At each measurement, all trees that were at least 4.5 feet tall were measured for dbh to the nearest 0.1 inch and checked for fusiform rust stem cankers. Every other tree was tagged and measured for total height to the nearest foot. At the 14, 17, 20 and 23-year measurements, height to the base of the live crown was measured on each tagged tree.

The tagged trees were used to develop a height / diameter regression equation for each plot to estimate the height of the untagged trees. Total and merchantable (trees with dbh > 4 inches to a 3-inch top o.b.) volumes were calculated using individual tree volume equations developed by Pienaar *et.al.* (1996). Analysis of variance for a split plot design was used to test for significant sources of variation with the 23-year data. Soil groups represent the whole plots and treatments represent the splits. The split plot analysis was carried out using a mixed model. The location (installation) and its interactions were regarded as random factors and the treatment and soil effects were considered fixed. This approach allows for inferences across all sites represented by the sample of sites included in this study. Analyses were conducted on average individual tree characteristics (height, dominant height, dbh, crown length, crown ratio) and per acre stand characteristics (basal area, total volume, merchantable volume, percent fusiform infection) at age

23. Analyses were also conducted on remeasurement data between the ages of 5 and 23 to determine the response of growth curves to silvicultural treatments. An alpha level of 0.05 was used to determine statistical significance. Least square means were used to account for the unbalanced nature of this data.

2 TWENTY-THREE YEAR RESULTS

2.1 Individual Tree Characteristics

Analysis of variance and one-degree-of-freedom contrast analyses to evaluate the additive effects of chopping, burning, bedding, fertilization and herbicide were conducted on average tree height, average dominant height, average dbh, average crown length and average crown ratio. Treatment significantly affected all of these individual tree measures. Soil group was not significant and there were no soil group x treatment interactions for all variables except crown ratio. Least square mean values by treatment across all soil groups and for spodosols (SP) and nonspodosols (NS) for crown ratio are shown in Table 1.

Table 1. Least square mean height (ft.), dominant height (ft.), dbh (in.), crown length (ft.) and crown ratio by treatment at age 23.

Treatment Number	Treatment Code	Average Height (ft.)	Dominant Height (ft.)	Dbh (in.)	Crown Length (ft.)	Crown Ratio	
						NS	SP
1	CNTL	50.8	53.6	6.34	17.0	0.36	0.32
2	UCHP	52.5	55.9	6.52	16.9	0.33	0.31
3	FCHP	59.8	62.3	7.52	19.8	0.36	0.32
4	UCHB	53.9	56.7	6.73	17.4	0.33	0.32
5	FCHB	61.5	63.9	7.54	19.0	0.32	0.31
6	UCBB	55.5	58.4	6.84	16.9	0.31	0.30
7	FCBB	63.1	65.7	7.69	19.2	0.31	0.30
8	UCBH	61.2	63.5	8.03	19.1	0.34	0.29
9	FCBH	65.8	68.4	8.46	20.0	0.33	0.29
10	UBHB	63.0	65.0	7.98	18.2	0.29	0.29
11	FBHB	66.9	69.7	8.37	19.7	0.31	0.28

Treatment gains due to chopping, burning, bedding, fertilization and herbicide were computed by the difference of least squares means method. Table 2 shows the treatment gains on average height, dominant height, dbh, crown length and crown ratio. Gains marked with an asterisk (*) were found to be significant in the contrast analysis.

2.1.1 Average tree height

Average heights of all tagged trees ranged from a high of 66.9 feet on the most intensive treatment to a low of 50.8 feet for the control. The average height values were well correlated with treatment intensity (Table 1). Fertilization provided a positive response on all treatments with slightly higher gains on treatments without herbicide. The chop, burn and fertilize treatment (FCHB) had about the same average height as the chop, burn and herbicide treatment (UCBH). This was also the case with the chop, burn, bed and fertilize treatment (FCBB) and the chop, burn, bed and herbicide treatment (UBHB). At age 23, the average height gain from fertilization has surpassed the gain from herbicide by 0.5 feet. This is in contrast to the results at age 20 when herbicide resulted in average height gains 0.24 feet greater than fertilization. In the contrast analysis, fertilization, bedding and herbicide provided significant gains of 6.28, 1.54, and 6.28 feet, respectively (Table 2).

Table 2. Gains due to chopping, burning, bedding, fertilization and herbicide on average height (ft.), dominant height, dbh (in.), crown length (ft.) and crown ratio at age 23.

Treatment	Height (ft.)	Dominant Height (ft.)	Dbh (in.)	Crown Length (ft.)	Crown Ratio	
					NS	SP
Chop	2.25	2.49	0.33	0.41	-0.02	0.00
Burn	1.53	1.25	0.16	-0.05	-0.01	0.00
Bed	1.54*	1.57*	0.04	-0.40	-0.02*	-0.01
Herbicide	5.79*	5.48*	1.02*	1.16*	0.00	-0.02*
Fertilization	6.28*	6.16*	0.71*	1.87*	0.01	0.00

2.1.2 Average dominant height

Average dominant height closely resembles the same trends as found in average height. Average dominant heights of all tagged trees ranged from a high of 69.7 feet on the most intensive treatment to a low of 53.6 feet for the control (Table 1). Bedding, herbicide and fertilization significantly increased average dominant height. Fertilization increased average dominant height by 6.16 feet, closely followed by herbicide at 5.48 with bedding adding 1.57 feet (Table 2). The difference between fertilization and herbicide continues to increase at age 23. At age 20, fertilization averaged 0.38 feet greater than herbicide, and at age 23 the difference has increased to 0.68 feet.

2.1.3 Average tree dbh

There is a 2-inch difference between the control treatment's dbh and the most intensive treatment's dbh, at 6.34 inches and 8.37 inches, respectively (Table 1). Only herbicide and fertilization increased average dbh significantly. Herbicide increased average dbh the most with gains of 1.02 inches (Table 2). This indicates that interspecific competition, even when mainly composed of understory species, has a significant negative impact on dbh growth. Fertilization increased average dbh by 0.71 inches. Unlike average height and dominant height, the average dbh of the FCBB treatment plots was still less than the average dbh of the herbicide treatments with or without fertilization. Gains from fertilization on treatments without herbicide were approximately double the gains from fertilization on treatments with herbicide. This indicates that the fertilization and herbicide effects are less than additive. Chopping, burning and bedding had no significant effect on average dbh.

2.1.4 Average crown length

Crown height was measured on all tagged trees after 14, 17, 20 and 23 growing seasons. Crown height was defined as the height to the base of the live crown. The average crown length for a plot was obtained by subtracting the crown height from the total height of each tree and averaging these values for all trees on the plot (Table 1). Unlike age 20, there was a significant difference in crown length by treatment at age 23. Both fertilization and herbicide significantly increased crown length, with gains of 1.87 and 1.16 feet, respectively (Table 2). The combination of fertilization and herbicide were less than additive, indicating that the full effect of both treatments will not be expressed when used together. Average crown length varied from 16.9 feet for the control plots to 20.0 feet for the FCBH treatment. The long crown lengths on the intensively managed plots that have been maintained through age 23 are important factors in stimulating early growth rates and maintaining these rapid growth rates over time.

2.1.5 Average crown ratio

Soil type significantly affected average crown ratio. At age 23, all treatments still had crown ratios greater than the minimum value of approximately 22% suggested as critical for dbh growth in a slash pine pruning study (Bennett, 1955). In fact, even though these stands have not been thinned, crown ratios ranged from 29% to 36% on non-spodosol soils and from 28% to 32% on spodosol soils (Table 1). Bedding significantly decreased average crown ratio by about 2% on non-spodosol soils, although it was not significant on spodosol soils (Table 2). On spodosol soils, herbicide significantly decreased crown ratio by about 2.0%, but was not significant on non-spodosol soils. All other treatments were non-significant.

Although crown lengths were greater for fertilization and herbicide treatments than other treatments, the crown ratio for fertilization and herbicide treatments was lower than on other treatments. This is due to the positive effects of fertilization and herbicide on average height.

2.1.6 Average percent cronartium infection

Each tree in the study was examined for the presence of fusiform stem cankers. The percentage of infected trees on each plot was calculated. The only significant source of variation was treatment. Least square mean percent infection values are presented in Table 3. There was a general increase in rust infection rate as treatment intensity increased. The average infection percentages by treatment ranged from 9.2% for the control to 23.7% for the FCBH treatment. The four treatments that included herbicide had the highest infection percentages. Herbicide significantly increased infection rate by 9.2% over plots with no herbicide (Table 4). In each case, treatment combinations with fertilization had equal or higher infection rates than the same treatment combination with no fertilization. While not significant, plots with fertilization had a 1.4% higher infection rate than plots with no fertilization. This is consistent with results reported by Zutter *et.al.* (1987) who noted that increased growth rates resulted in higher cronartium infection rates. The seed used to establish this study came from orchards of the late 1970’s that had not been rogued of disease-susceptible clones. The improved planting stock/herbicide study results at age 12 indicate that increased growth without increased fusiform infection is possible with genetically improved stock (Harrison et. al., 2001).

Table 3. Least square mean percent cronartium infection by treatment at age 23.

Treatment	Treatment Code	Percent Cronartium
1	CNTL	9.2
2	UCHP	11.7
3	FCHP	11.7
4	UCHB	11.6
5	FCHB	13.6
6	UCBB	12.4
7	FCBB	12.3
8	UCBH	21.7
9	FCBH	23.7
10	UBHB	18.9
11	FBHB	22.6

Table 4. Gain from chopping, burning, bedding, fertilization and herbicide on average percent cronartium infection after 23 growing seasons.

Treatment	Cronartium Percent Gain
Chopping	1.7
Burning	1.4
Bedding	-1.0
Herbicide	9.2*
Fertilization	1.4

2.2 Per Acre Stand Characteristics

Unlike the individual tree characteristics, basal area per acre and per acre volumes directly involve the number of trees per acre and the distribution of diameters. The same split plot analysis of variance was used for these characteristics as for the individual tree variables. Treatment significantly affected each of these whole-stand characteristics. Unlike age 20, when significant interactions between treatment and soil group were found for all whole stand characteristics except total per acre volume, no soil-treatment interactions were significant for whole-stand characteristics at age 23.

Table 5. Average per acre basal area (ft^2), trees per acre, merchantable volume per acre (ft^3) and total volume per acre (ft^3) by treatment at age 23.

Treatment	Treatment Code	Basal Area (ft^2)	Trees per Acre	Merchantable Volume (ft^3/acre)	Total Volume (ft^3/acre)
1	CNTL	96.05	426	2217	2402
2	UCHP	101.93	432	2442	2615
3	FCHP	124.8	407	3387	3522
4	UCHB	106.6	420	2631	2787
5	FCHB	136.58	431	3778	3925
6	UCBB	119.1	450	3029	3188
7	FCBB	139.96	428	3966	4100
8	UCBH	137.74	401	3806	3920
9	FCBH	145.6	372	4293	4388
10	UBHB	138.7	396	3912	4018
11	FBHB	160.23	415	4808	4917

Table 6. Gains in per acre basal area (ft^2), trees per acre, merchantable volume per acre (ft^3) and total volume per acre (ft^3) from chopping, burning, bedding, fertilization and herbicide by treatment at age 23.

Treatment	Basal Area (ft^2)	Trees per Acre	Merchantable Volume (ft^3/acre)	Total Volume (ft^3/acre)
Chopping	6.9	-1.6	253	231
Burning	8.1*	4.8	282*	278*
Bedding	8.0*	16.0	302*	301*
Herbicide	20.1*	-36.4*	857*	813*
Fertilization	20.9*	-9.5	891*	873*

2.2.1 Average basal area per acre

The mean basal areas per acre by treatment are shown in Table 5. The most intensive treatment, FBHB, produced almost 65 ft^2 /ac. more than the control plots at age 23. This is approximately the same difference that was present at age 20. Fertilization significantly increased average basal area per acre by 20.9 ft^2, followed closely by herbicide at 20.1 ft^2 /ac. (Table 6). Burning caused an 8.1 ft^2 /ac. increase in basal area and bedding increased basal area per acre by 8.0 ft^2. Only chopping did not significantly increase average basal area, although it did increase basal area per acre by 6.9 ft^2 on average. This was due to the extreme variation in basal area response from site to site, with approximately half of the sites having a positive basal area response to chopping and half having a negative response to chopping.

The fertilized, chop, burn and bed treatment (FCBB) had more per acre basal area than the unfertilized herbicide plots at age 23. This was the case only on spodosol soils at age 20. This indicates that repeated fertilizations can produce more basal area than complete herbicide without the addition of supplemental nutrients.

2.2.2 Average trees per acre

Average trees per acre (TPA) ranged from a low of 401 for the UCBH treatment to a high of 450 for the UCBB treatment. There was little correlation between treatment intensity and TPA at age 23. Only herbicide significantly impacted TPA, decreasing survival by 36 (Table 6). Herbicide has significantly decreased TPA since age 17. Age 23 is the first measurement year that bedding has not significantly increased TPA, although it did increase average TPA by 16.

2.2.3 Average merchantable volume per acre

Merchantable volume outside bark to a 3-inch top (o.b.) was calculated for all trees with a dbh greater than 4 inches. These values were summed by plot and expanded to a per acre basis. Average values for merchantable volume are presented in Table 5. The most intensive treatment had over twice the merchantable volume of the control plots. Fertilization, herbicide, bedding, and burning treatments significantly increased merchantable volume with gains of 891ft^3, 857 ft^3, 302 ft^3 and 282 ft^3 respectively (Table 6). This is the first time that fertilization has caused a greater overall increase in merchantable volume than herbicide. At age 20, herbicide increased merchantable volume per ace 83 ft^3 more than the fertilization treatment. Only chopping had no significant effect on merchantable volume due to the high variability on the chop only treatment. Again, the treatments with fertilization have caught, or almost caught, the counterpart treatment with herbicide.

2.2.4 Average total volume per acre

Total outside bark stem volume ranged from a low of 2402 ft^3 per acre on the control plots to a high of 4917 ft^3 per acre on the most intensive treatment (Table 5). There was no soil significance at age 23 as there was at age 20. All treatments except chopping caused a significant increase in total volume per acre (Table 6). Fertilization and herbicide caused the largest increases at 873 ft^3 and 813 ft^3 per acre, respectively. Bedding and burning caused similar increases in total volume per acre of 301 ft^3 and 278 ft^3, respectively. Fertilization has surpassed herbicide in regards to the treatment that causes the greatest total volume increase. In all cases, the fertilization treatments have a higher total volume per acre than the counterpart treatments with herbicide. When fertilization and herbicide are used in combination, the treatment gains are less than additive, although land managers can expect total volume gains of 400 – 900 ft^3 / acre over the use of either fertilization or herbicide (Table 5).

3 GROWTH CURVE RESPONSE ANALYSIS

Remeasurement data between the ages of 5 and 23 were used to analyze growth curve response to silvicultural treatments. Average dbh, average height, dominant height, per acre basal area and per acre total volume were examined. Multivariate analysis was used to test for a significant soil and soil*age interaction, indicating the need for separate analyses of spodosol and nonspodosol soils. Treatments and treatment interactions were tested to determine if they caused a change in the mean value for a tree or stand level characteristic. Treatment*age and treatment interactions*age were tested to determine if a treatment caused a change in the growth curve over the length of the study period. Least square means by age and treatment were used to account for the unbalanced nature of the study.

3.1 Average Dbh Growth

A test of fixed effects of the age and age*soil interaction indicated a significant difference between spodosol and nonspodosol soils. Figure 1 and 2 show the average dbh by treatment for spodosol and nonspodosol soils, respectively.

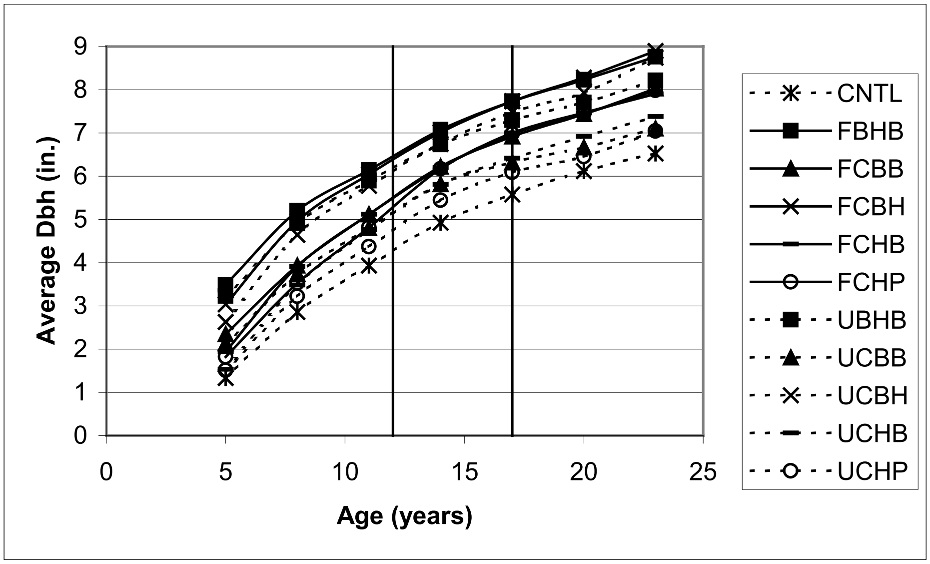

Figure 1. Average Dbh by treatment for nonspodosol soils between the ages of 5 and 23. Vertical lines at age 12 and 17 represent mid-rotation fertilizations.

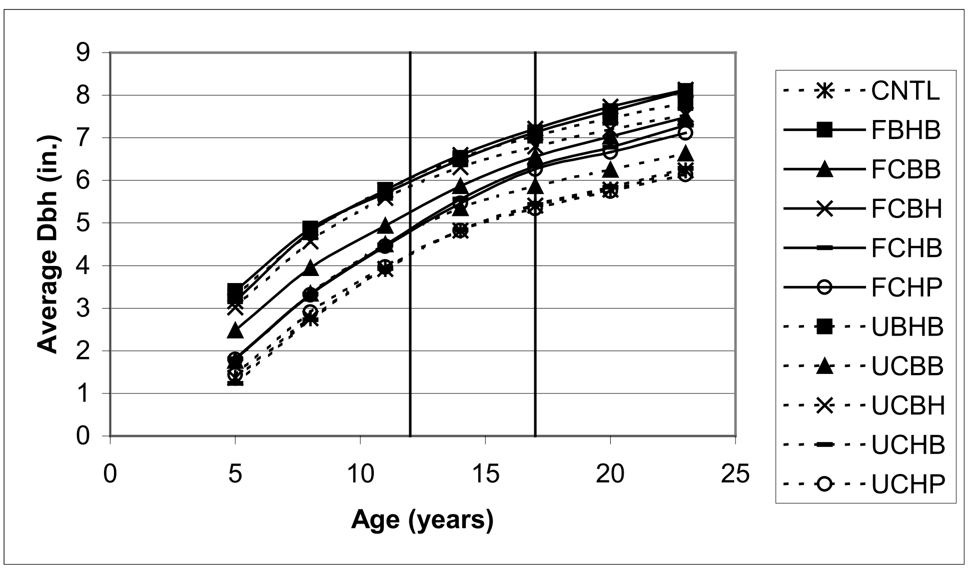

Figure 2. Average Dbh by treatment for spodosol soils between the ages of 5 and 23. Vertical lines at age 12 and 17 represent mid-rotation fertilizations.

The most intensive treatment, FBHB, had the largest dbh on both soils at young ages. This was the case until age 20 on nonspodosol soils, when the FCBH treatment had the largest average dbh. On spodosol soils the UBHB treatment had the largest dbh at age 11, but from age 14 until present the FCBH treatment maintained the largest dbh. Nonspodosol soils have had a larger average dbh than spodosol soils from age 11 until present on each treatment.

On nonspodosol soils, herbicide significantly increased overall mean dbh, and affected dbh growth over the range of measured ages. Chopping had a significant effect on average dbh growth throughout the study, although it did not increase the mean dbh compared to other treatments on nonspodosol soils (Figure 3). Both fertilization and herbicide increased the dbh growth rate on spodosol soils, while fertilization, herbicide, and bedding increased overall mean dbh (Figure 4).

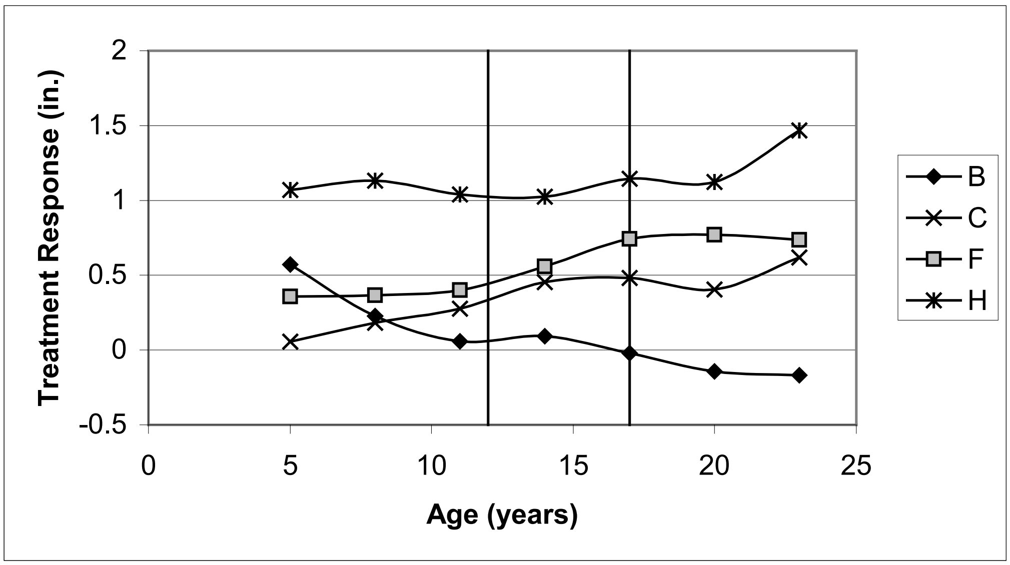

Figure 3. Average dbh response to treatment between ages 5 and 23 on nonspodosol soils. Vertical lines at age 12 and 17 represent mid-rotation fertilizations. B=bedding, C=chopping, F=fertilization, H=herbicide.

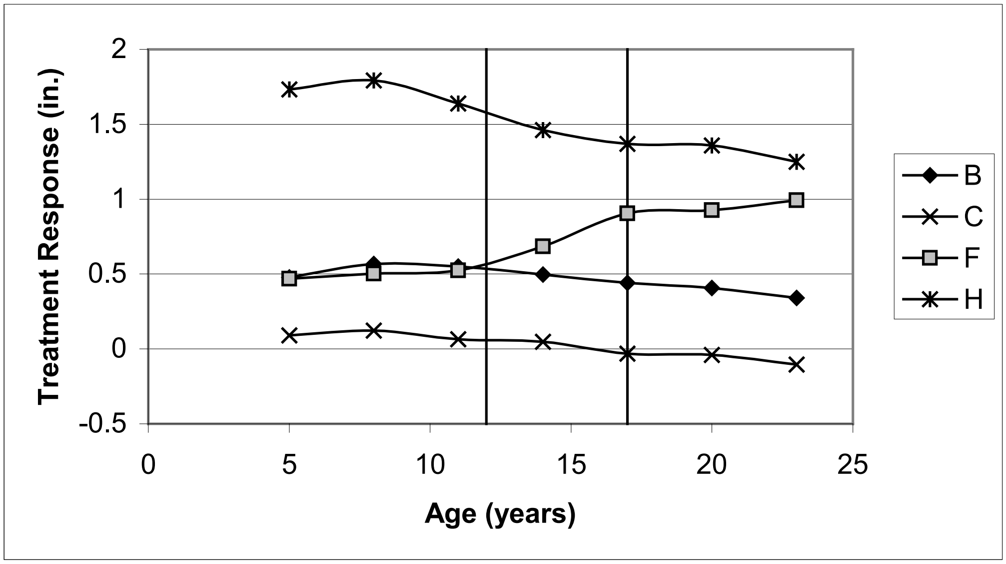

Figure 4. Average dbh response to treatment between ages 5 and 23 on spodosol soils. Vertical lines at age 12 and 17 represent mid-rotation fertilizations. B=bedding, C=chopping, F=fertilization, H=herbicide.

Maximum dbh mean annual increment (MAI) for the two most intensive treatments, UBHB and FBHB, has occurred by age 5 for both soil types (Figures 5 and 6). This is approximately 6 years earlier than maximum dbh MAI on the control treatment. In general, maximum dbh MAI occurs at the same age or earlier on spododol soils than nonspodosol soils.

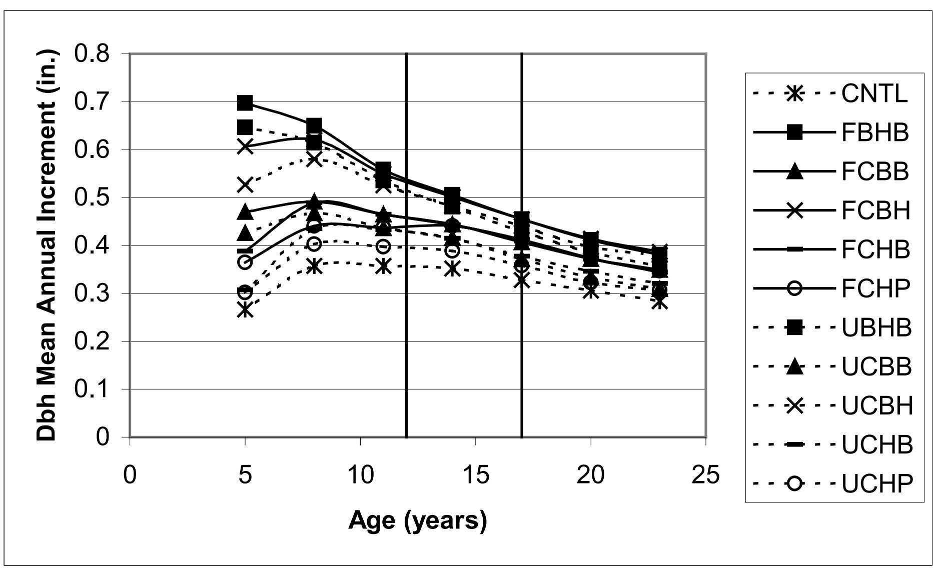

Figure 5. Dbh mean annual increment in inches from ages 5 to 23 for nonspodosol soils. Vertical lines at age 12 and 17 represent mid-rotation fertilizations.

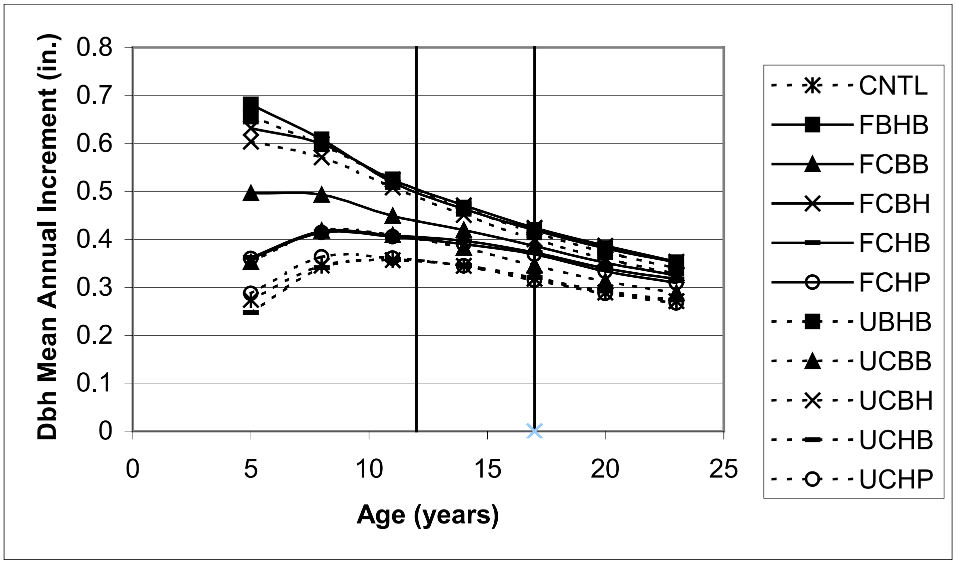

Figure 6. Dbh mean annual increment in inches from ages 5 to 23 for spodosol soils. Vertical lines at age 12 and 17 represent mid-rotation fertilizations.

3.2 Mean Height Growth

Soil significantly affected the average mean height value at the alpha = 0.05 level, but was not significant for the soil*age interaction. This indicates that the mean height difference across all treatments was significantly different between soil types at all measurement ages, and did not significantly converge or diverge over the study period. Figure 7 and 8 show average height by treatment for nonspodosol and spodosol soils, respectively.

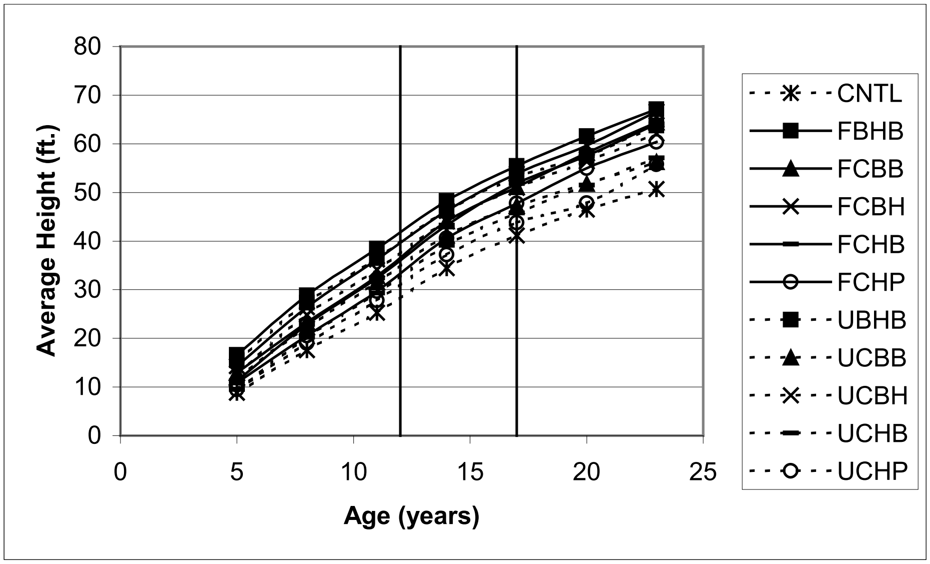

Figure 7. Average height by treatment between ages 5 and 23 for nonspodosol soils. Vertical lines at age 12 and 17 represent mid-rotation fertilizations.

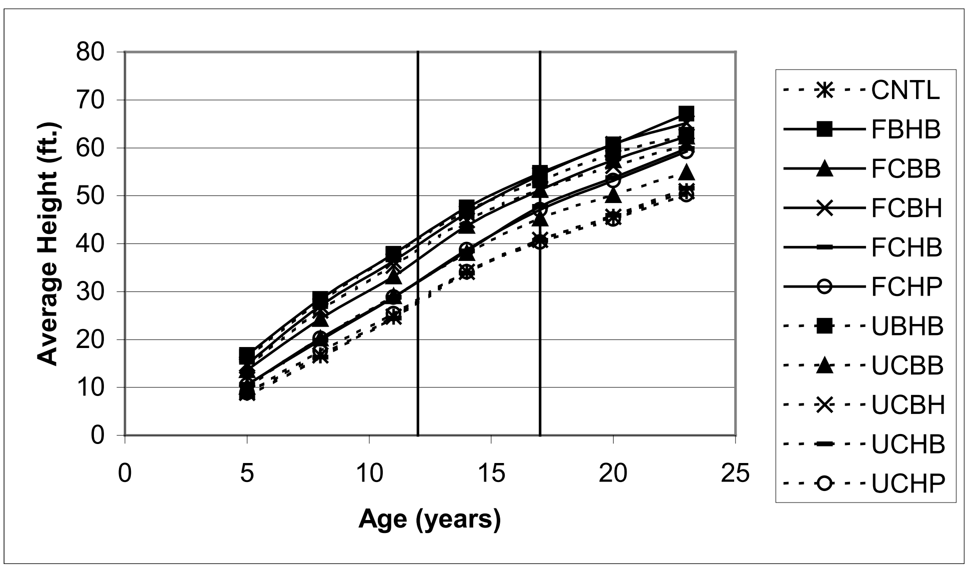

Figure 8. Average height by treatment between ages 5 and 23 for spodosol soils. Vertical lines at age 12 and 17 represent mid-rotation fertilizations.

The most intensive treatment, FBHB, had the largest height at each measured age on both soils, with the exception of age 20 on spodosols, when the FCBH treatment was slightly larger than the most intensive treatment. No treatment significantly affected mean height on nonspodosols soils at the alpha=0.05 level, although herbicide was close to being significant with a p-value of 0.595 (Figure 9). On spodosol soils, fertilization, bedding, and herbicide significantly increased average mean height, while fertilization and herbicide significantly interacted with age (Figure 10).

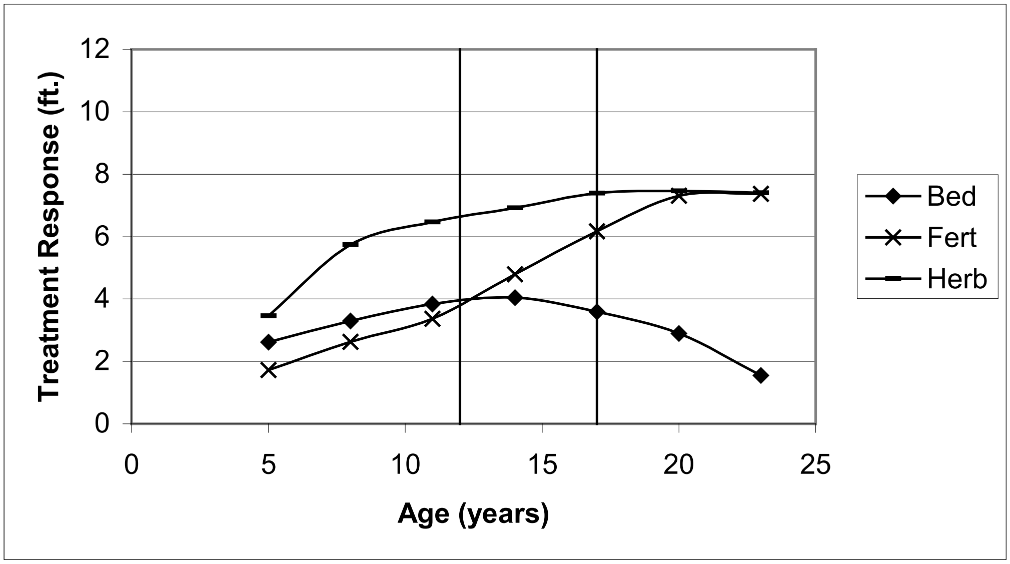

Figure 9. Average mean height response to treatment between ages 5 and 23 on nonspodosol soils. Vertical lines at age 12 and 17 represent mid-rotation fertilizations.

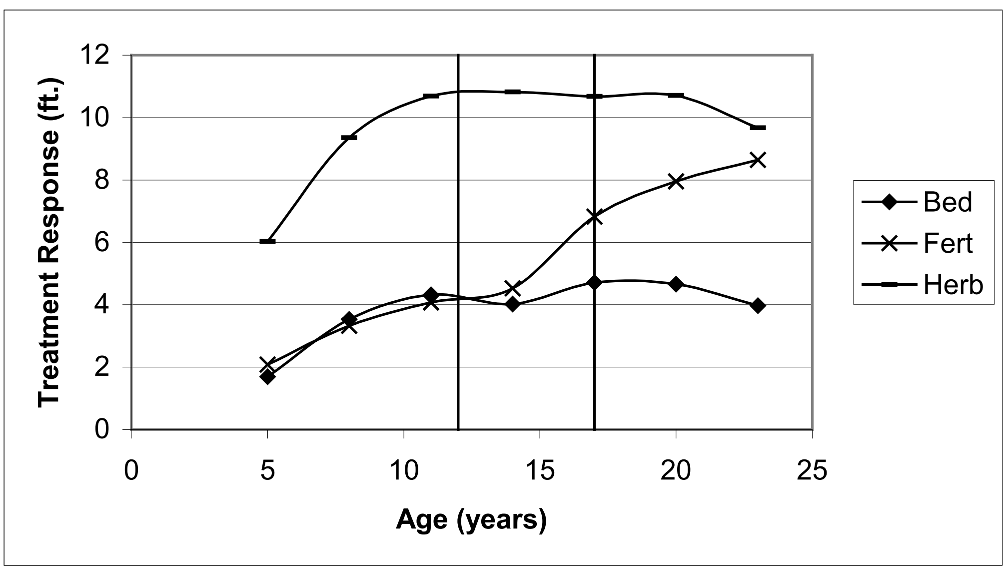

Figure 10. Average mean height response to treatment between ages 5 and 23 on spodosol soils. Vertical lines at age 12 and 17 represent mid-rotation fertilizations.

Age of peak MAI for mean height followed a general trend of decreasing as cultural treatment intensity increased. Maximum mean height MAI on nonspodosol soils had occurred by approximately age 8 for the three most intensive treatments, FBHB, UBHB and FCBH. The remaining treatments did not peak until around age 14 on nonspodosol soils (Figure 11). On spodosol soils, the FBHB, FCBH, UBHB and UCBH treatments had reached maximum mean height MAI by approximately age 8. This is in contrast to the lower intensity treatments that reached maximum mean height MAI between 14 and 17 years of age (Figure 12).

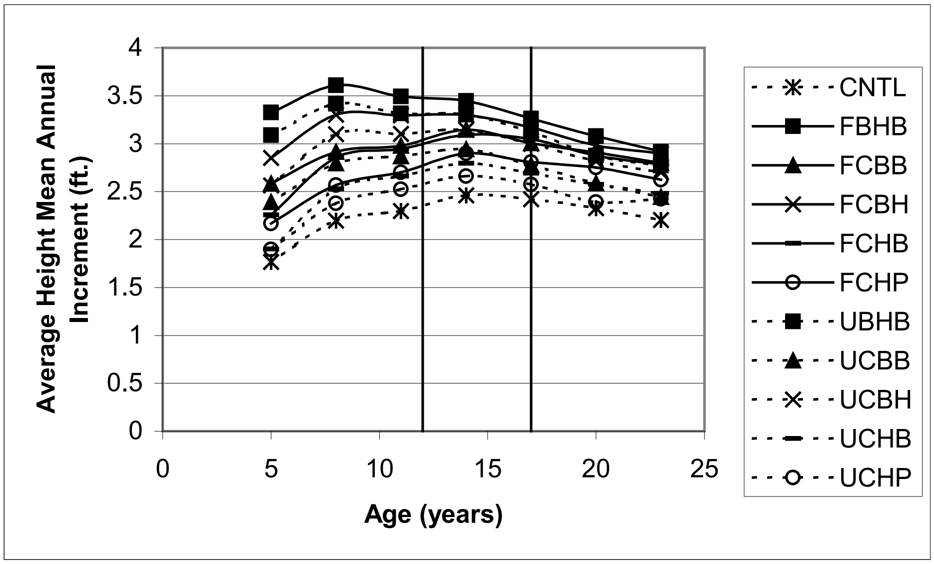

Figure 11. Average height MAI by treatment between ages 5 and 23 for nonspodosol soils. Vertical lines at age 12 and 17 represent mid-rotation fertilizations.

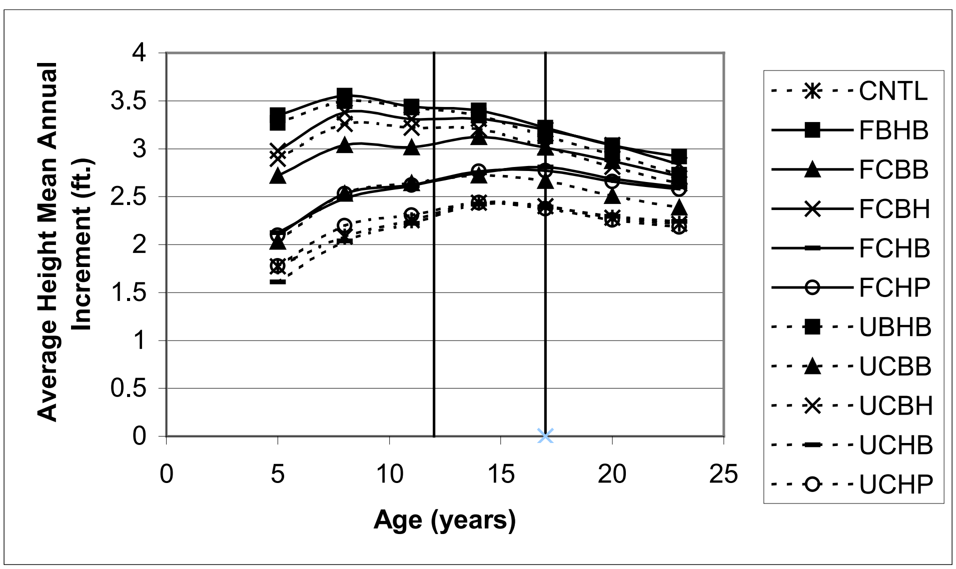

Figure 12. Average height MAI by treatment between ages 5 and 23 for spodosol soils. Vertical lines at age 12 and 17 represent mid-rotation fertilizations.

3.3 Average Dominant Height Growth

Soil significantly affected average dominant height, but no soil*age interaction was present. On nonspodosol soils, the FBHB treatment had the greatest dominant height on all but the age 23 measurements, when the FCBH treatment was slightly larger (Figure 13). On spodosol soils, the FBHB treatment was the largest until age 20, when the FCBH treatment was the largest. By the age 23 measurements, the FBHB treatment again had the greatest dominant height (Figure 14).

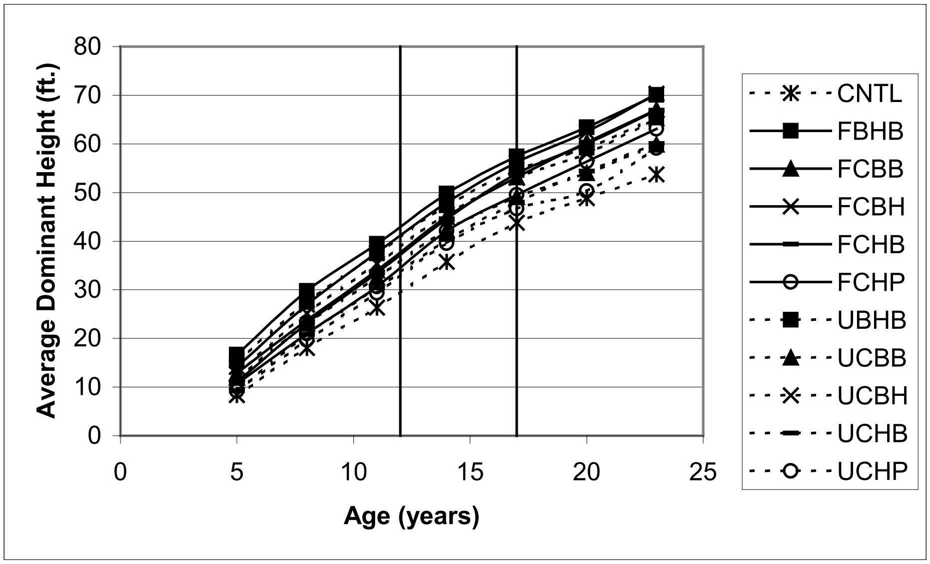

Figure 13. Average dominant height by treatment between ages 5 and 23 for nonspodosol soils. Vertical lines at age 12 and 17 represent mid-rotation fertilizations.

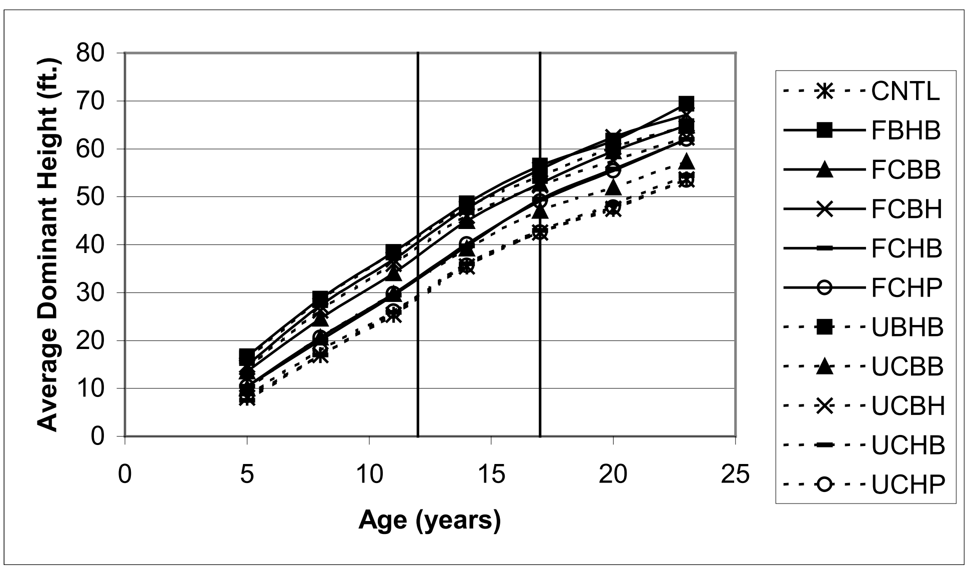

Figure 14. Average dominant height by treatment between ages 5 and 23 for spodosol soils. Vertical lines at age 12 and 17 represent mid-rotation fertilizations.

No treatments significantly affected dominant height or the dominant height * age interaction on nonspodosol soils, although herbicide was close to being significant at the alpha = 0.05 level with a p-value of 0.0651 (Figure 15). On spodosol soils, fertilization, bedding and herbicide significantly increased the mean dominant height, and fertilization and herbicide significantly affected the dominant height*age interaction (Figure 16).

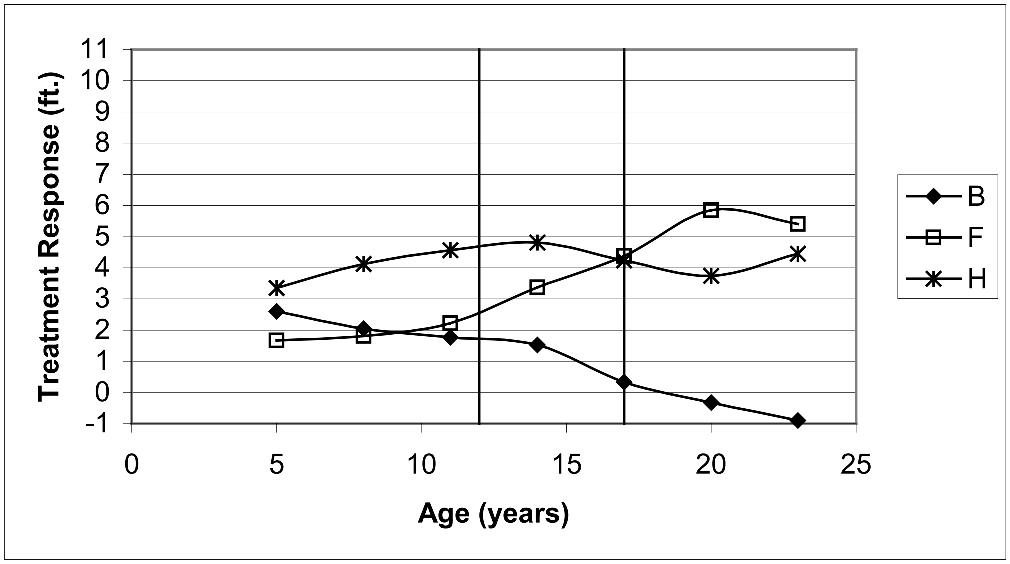

Figure 15. Average dominant height response to treatment between ages 5 and 23 on nonspodosol soils. Vertical lines at age 12 and 17 represent mid-rotation fertilizations. B=bedding, F=fertilization, H=herbicide.

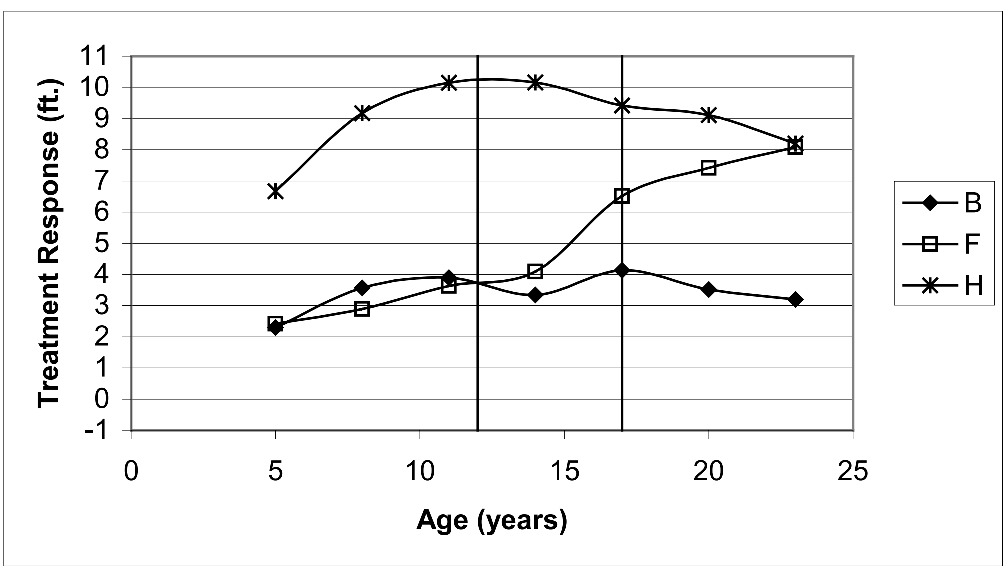

Figure 16. Average dominant height response to treatment between ages 5 and 23 on spodosol soils. Vertical lines at age 12 and 17 represent mid-rotation fertilizations. B=bedding, F=fertilization, H=herbicide.

On nonspodosol soils, only the two most intensive treatments reached peak MAI for dominant height growth by approximately age 8. Most treatments did not reach maximum MAI until age 14. The control treatment was approximately age 17 before reaching peak dominant height MAI (Figure 17). Spodosol soil followed a similar trend, although three treatments, FBHB, UBHB and FCBH reached peak dominant height MAI by approximately age 8 (Figure 18).

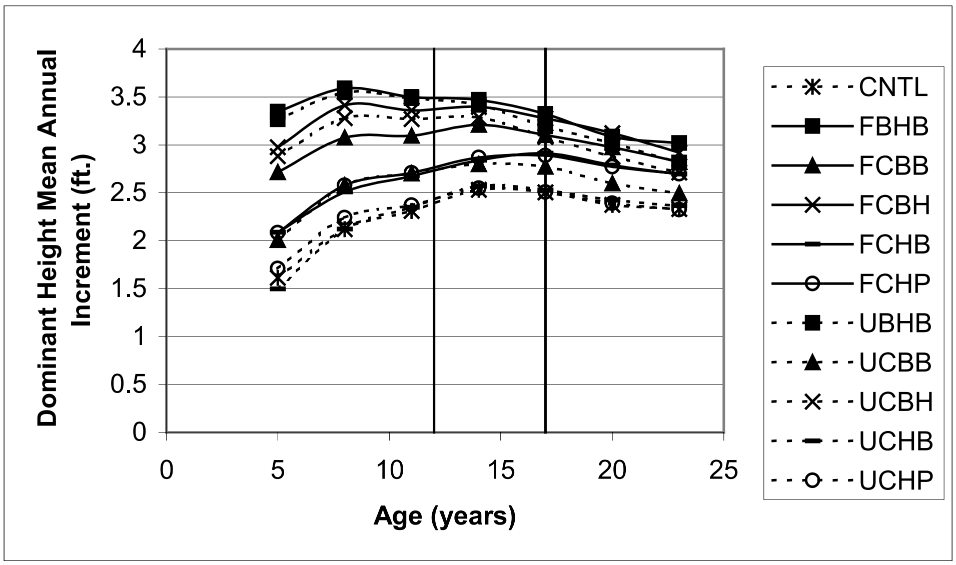

Figure 17. Average dominant height MAI by treatment between ages 5 and 23 for nonspodosol soils. Vertical lines at age 12 and 17 represent mid-rotation fertilizations.

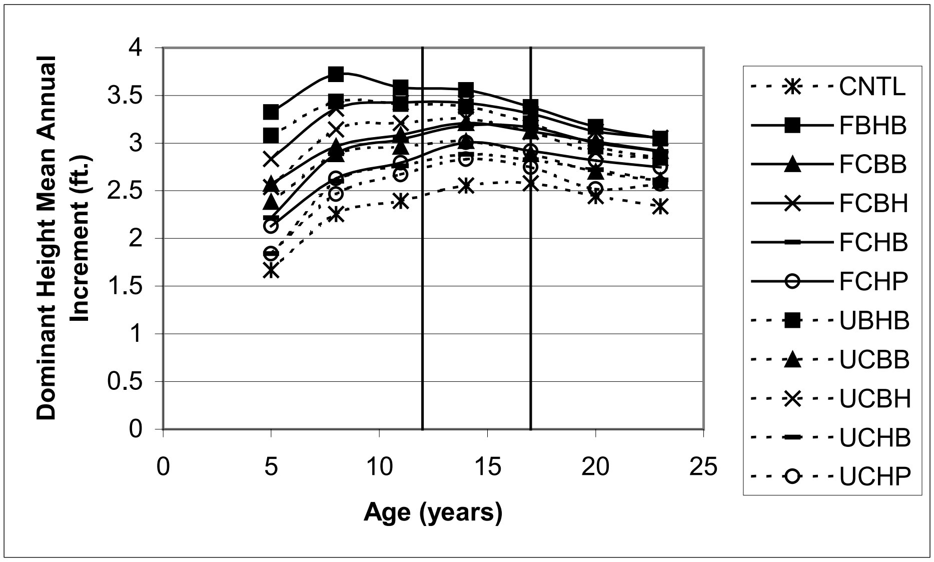

Figure 18. Average dominant height MAI by treatment between ages 5 and 23 for spodosol soils. Vertical lines at age 12 and 17 represent mid-rotation fertilizations.

3.4 Average per acre Basal Area Growth

There was a significant soil * age interaction present for basal area per acre growth over the study period. The FBHB treatment had the largest per acre basal area at each measured age for both spodosols and nonspodosols. Nonspodosol soils had a larger basal area per acre than spodosol soils until age 14 on the most intensive treatment. Since then, spodosol soils have had the largest basal area per acre on the most intensive treatment (Figures 19 and 20).

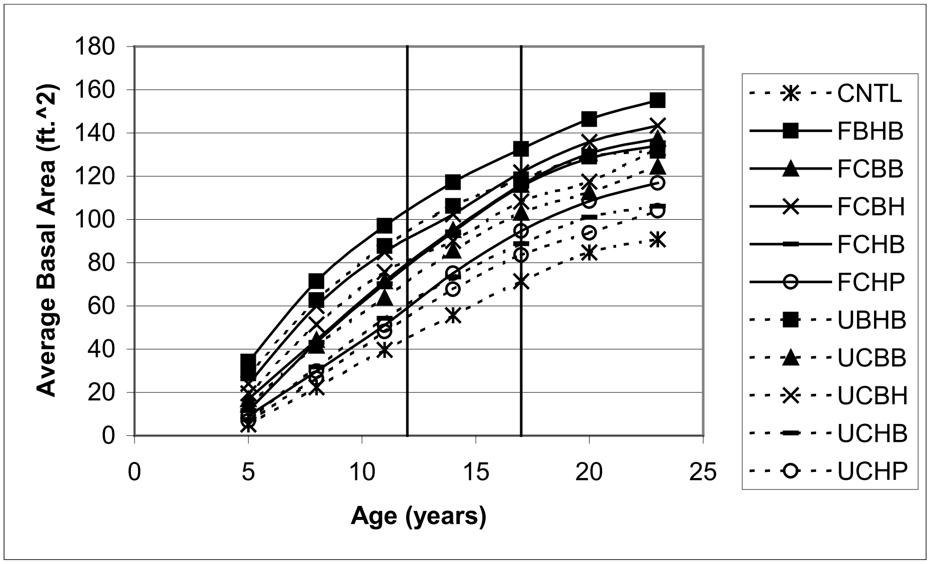

Figure 19. Average basal area per acre by treatment between ages 5 and 23 for nonspodosol soils. Vertical lines at age 12 and 17 represent mid-rotation fertilizations.

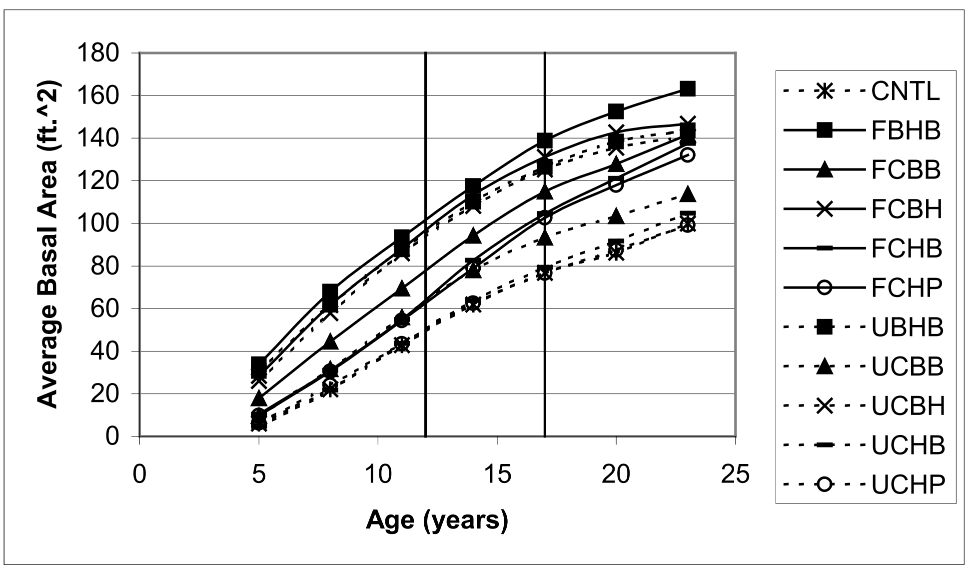

Figure 20. Average basal area per acre by treatment between ages 5 and 23 for spodosol soils. Vertical lines at age 12 and 17 represent mid-rotation fertilizations.

Herbicide significantly increased basal area per acre on nonspodosol soils over the study period, and fertilization was close to being significant with a p-value of 0.0886. There was also a significant herbicide * bedding interaction with age on nonspodosol soils (Figure 21). On spodosol soils, fertilization, bedding, herbicide and the fertilization * herbicide interaction significantly increased mean basal area per acre, while fertilization, herbicide and the fertilization * herbicide interaction significantly affected basal area growth rate (Figure 22).

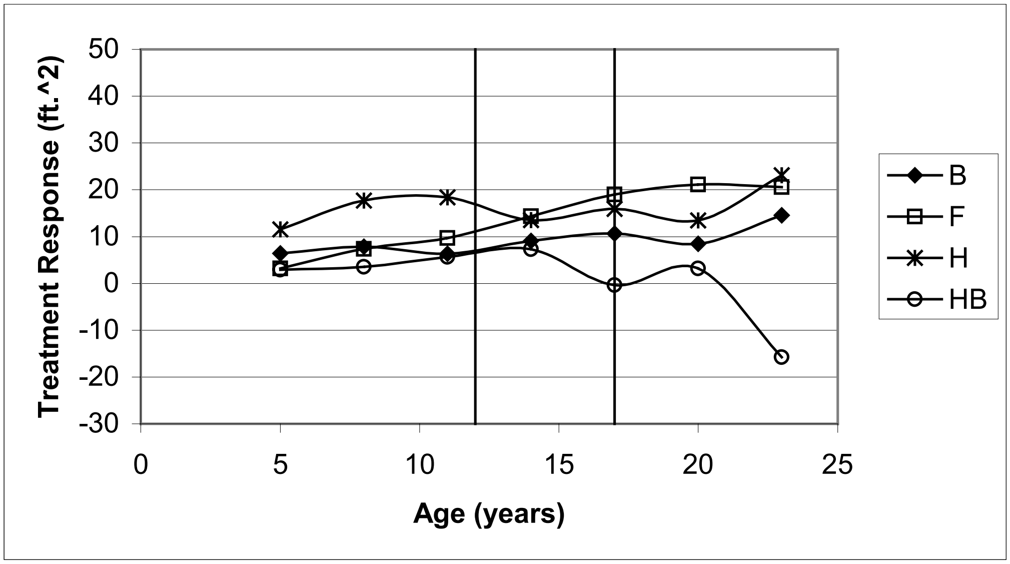

Figure 21. Average basal area per acre response to treatment between ages 5 and 23 on nonspodosol soils. Vertical lines at age 12 and 17 represent mid-rotation fertilizations. B=bedding, F=fertilization, H=herbicide.

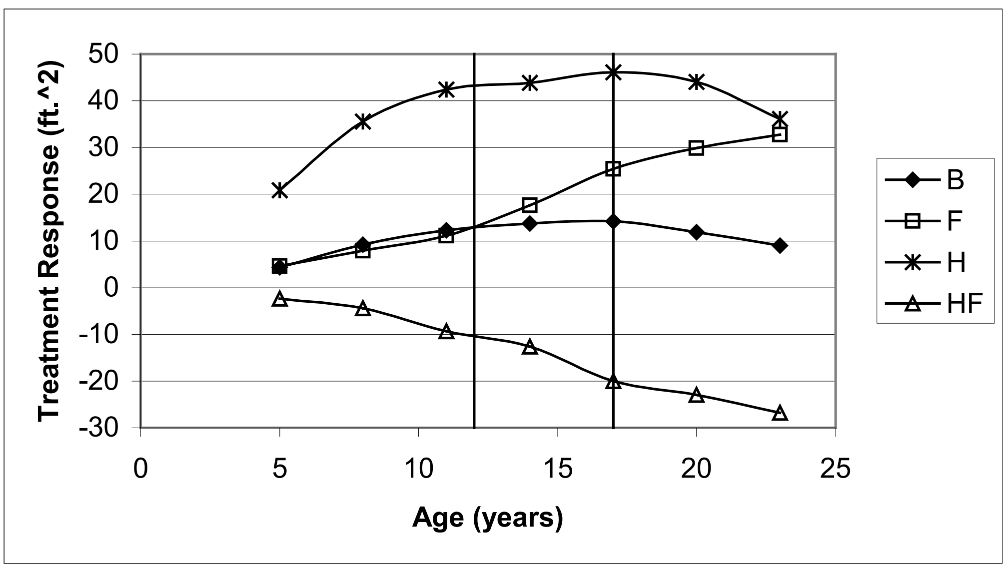

Figure 22. Average basal area per acre response to treatment between ages 5 and 23 on spodosol soils. Vertical lines at age 12 and 17 represent mid-rotation fertilizations. B=bedding, F=fertilization, H=herbicide.

Basal area per acre MAI peaked at approximately age 8 on nonspodosol soils for the FBHB treatment. This is in contrast to a peak basal area per acre MAI on the control treatment at approximately age 20. In addition, peak basal area MAI on the most intensive treatment was over double that of the control treatment (Figure 23). Only herbicide significantly affected basal area per acre MAI on nonspodosol soils.

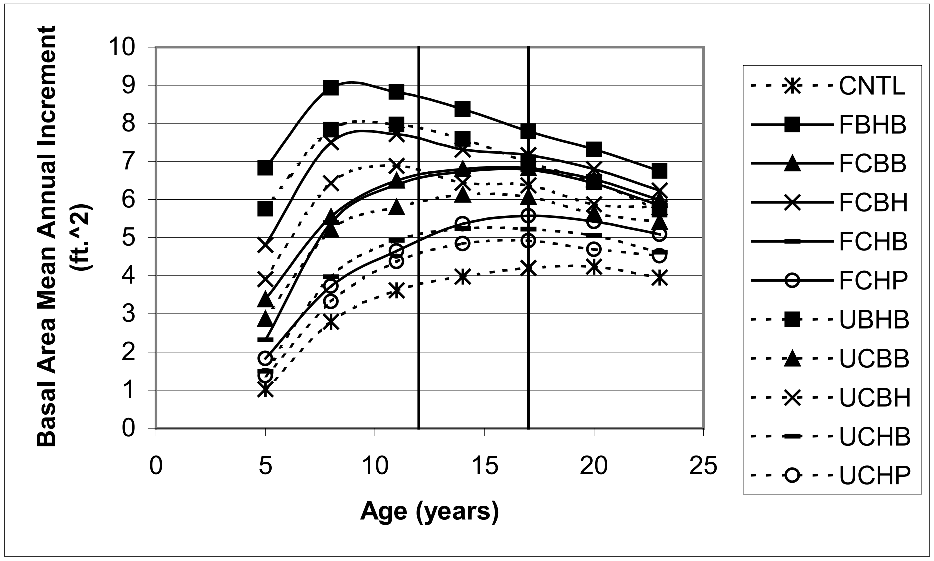

Figure 23. Average basal area per acre MAI by treatment between ages 5 and 23 for nonspodosol soils. Vertical lines at age 12 and 17 represent mid-rotation fertilizations.

On spodosol soils, the most intensive treatment reached peak basal area per acre MAI slightly later than on nonspodosol soils. Again, peak basal was approximately double on the most intensive treatment compared to the control treatment (Figure 24). As with nonspodosols, herbicide had the only significant affect on basal area per acre MAI.

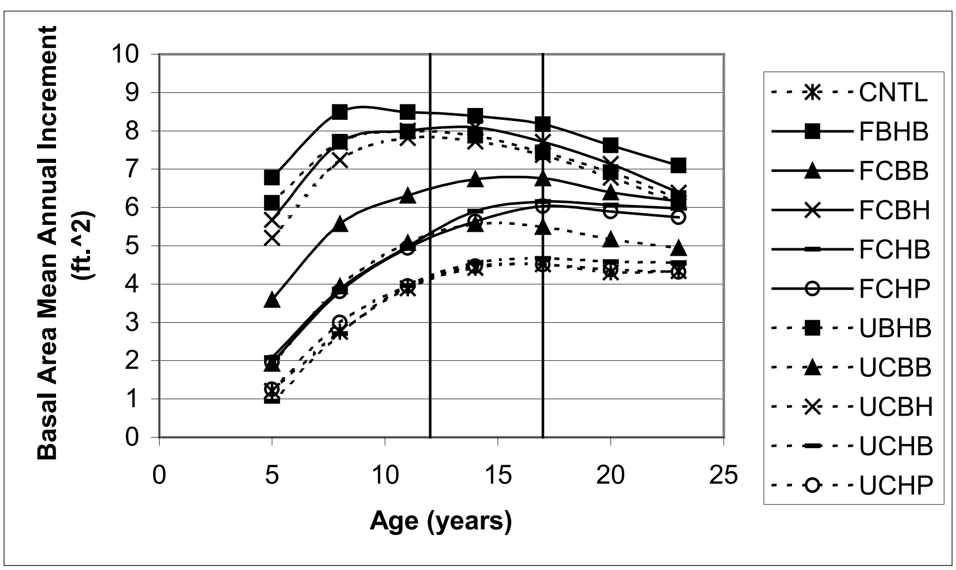

Figure 24. Average basal area per acre MAI by treatment between ages 5 and 23 for spodosol soils. Vertical lines at age 12 and 17 represent mid-rotation fertilizations.

3.5 Average per acre Total Volume Growth

There was a significant soil*age interaction for total volume growth between the ages of 5 and 23. For spodosol and nonspodosol soils, the FBHB treatment had the largest total volume per acre at each measured age (Figures 25 and 26).

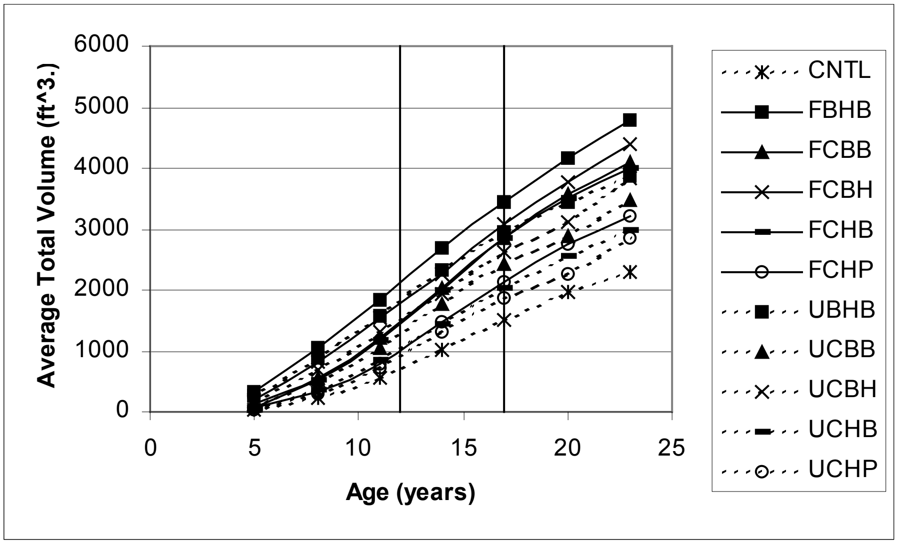

Figure 25. Average total volume outside bark per acre by treatment between ages 5 and 23 for nonspodosol soils. Vertical lines at age 12 and 17 represent mid-rotation fertilizations.

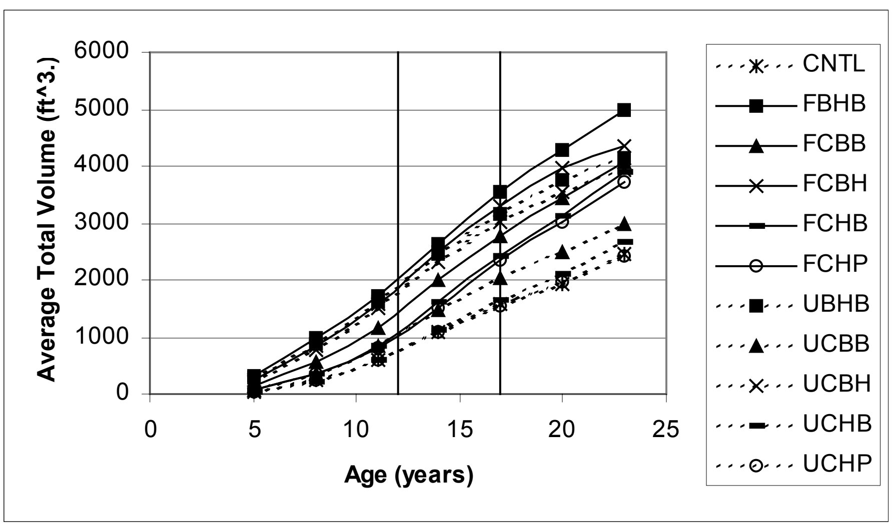

Figure 26. Average total volume outside bark per acre by treatment between ages 5 and 23 for spodosol soils. Vertical lines at age 12 and 17 represent mid-rotation fertilizations.

Total volume outside bark was significantly affected by herbicide on nonspodosol soils. Fertilization was borderline significant for mean total volume with a p-value of 0.0664. There was also a significant fertilization*age and herbicide*age interaction present for total volume on nonspodosol soils during the study period (Figure 27). For spodosol soils fertilization, fertilization*age, herbicide, and herbicide*age significantly affected total volume (Figure 28).

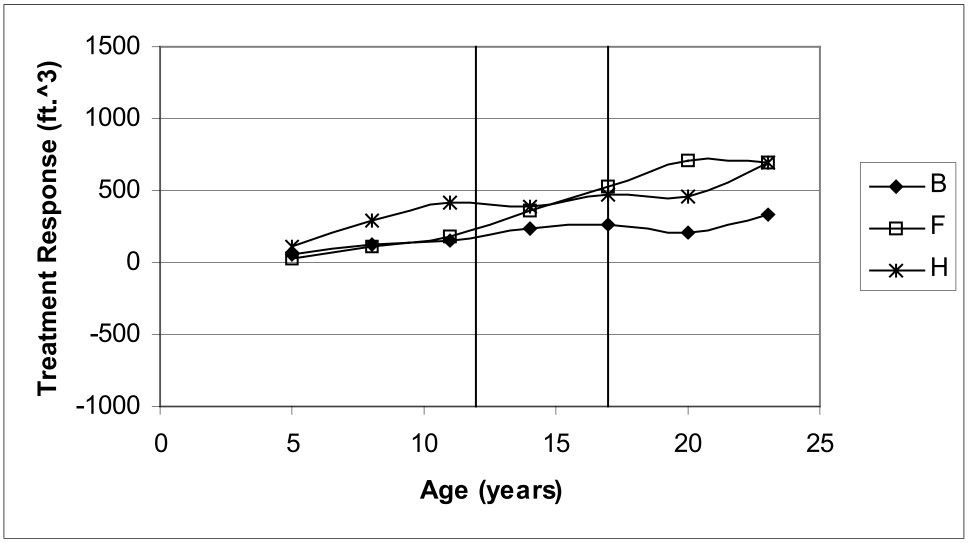

Figure 27. Average total volume per acre response to treatment between ages 5 and 23 on nonspodosol soils. Vertical lines at age 12 and 17 represent mid-rotation fertilizations. B=bedding, F=fertilization, H=herbicide.

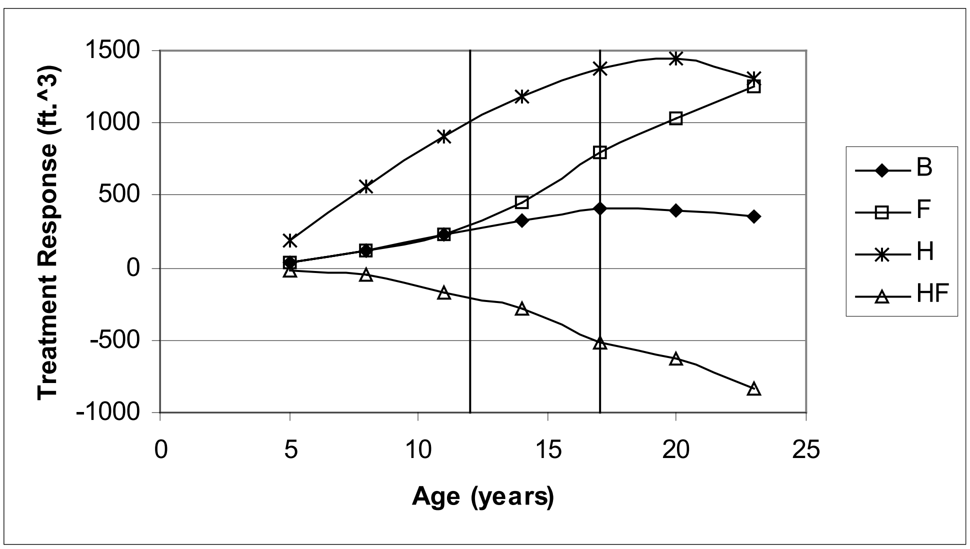

Figure 28. Average total volume per acre response to treatment between ages 5 and 23 on spodosol soils. Vertical lines at age 12 and 17 represent mid-rotation fertilizations. B=bedding, F=fertilization, H=herbicide.

Total volume MAI had only peaked on four treatments by age 23 on nonspodosol soils. The UBHB treatment, the most intensive treatment without fertilization, reached peak total volume MAI at approximately age 17 on nonspodosol soils. The FBHB, FCBB and FCBH treatment reached peak MAI by approximately age 20 (Figure 29). On spodosol soils, only three treatments, FCBH, UBHB and UCBH had reached peak MAI by age 23. The most intensive treatment, FBHB, is averaging 217 ft^3/acre/year at age 23 and still increasing (Figure 30). While the optimum economic rotation for these unthinned plantations may drop due to the size of the investment, these peak MAI ages are not very different from those of extensively managed plantations. However, the volumes produced are much higher.

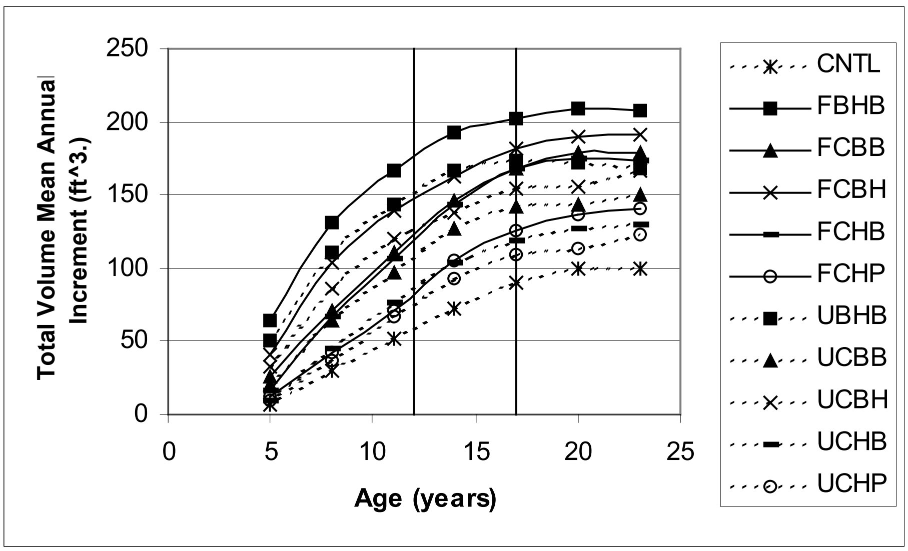

Figure 29. Average total volume outside bark per acre MAI by treatment between ages 5 and 23 for nonspodosol soils. Vertical lines at age 12 and 17 represent mid-rotation fertilizations.

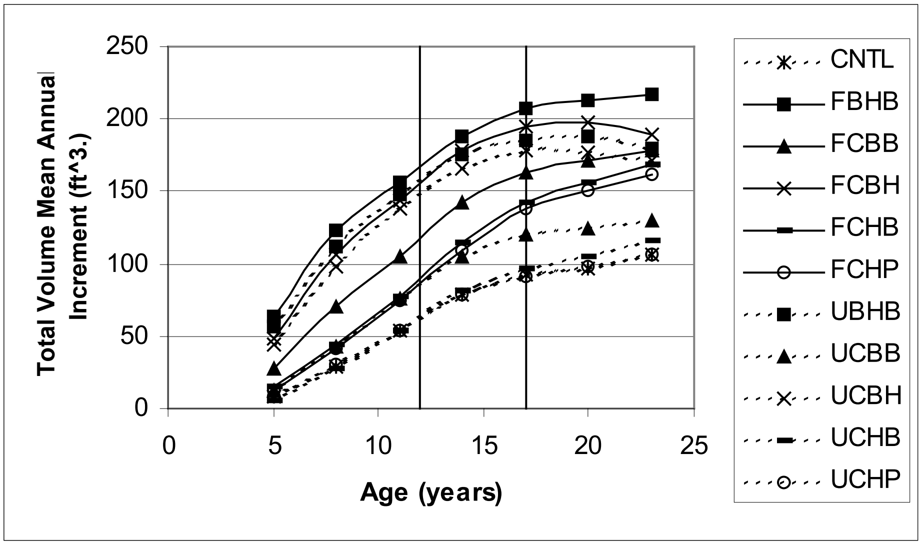

Figure 30. Average total volume outside bark per acre MAI by treatment between ages 5 and 23 for spodosol soils. Vertical lines at age 12 and 17 represent mid-rotation fertilizations.

4 CONCLUSIONS

The slash pine site preparation study was established in 1979 to evaluate the effects of different site preparation treatments on the growth and yield of slash pine. The study was one of the first in the Southeast to demonstrate the potential effects of complete herbicide on the growth of pine plantations. It has, therefore, been followed with great interest throughout its life.

The age 23 data were used to carry out an analysis of variance to evaluate the effects of chopping, burning, bedding, fertilization and herbicide on individual tree and whole stand characteristics. A mixed model approach was used so that the results can be applied with confidence across the range of slash pine sites represented by this study.

Chopping and burning had no significant effect on any of the average, individual tree characteristics. Bedding significantly increased average and dominant height but was not a significant factor for dbh or crown length. Bedding resulted in a significant decrease in crown ratio for nonspodosols. Herbicide and fertilization significantly increased average and dominant tree height, dbh and crown length. Herbicide significantly decreased crown ratio on spodosol soils, but was not significant on nonspodosols. Unlike younger ages, some of the least intensively managed plots had crown lengths at age 23 comparable to the most intensively managed plots. In general, treatments that promoted rapid height growth tended to result in higher levels of cronartium infection. Herbicide had the only significant effect, increasing the infection rate.

In order to indirectly examine the effect of treatment on survival patterns and diameter distributions, analysis of variance was carried out on per acre stand characteristics including basal area, merchantable and total volume. Site preparation treatment significantly affected each of these measures. There was no interaction between treatment and soil type at age 23, unlike age 20 when per acre basal area and merchantable volume both had a significant soil by treatment interaction.

Fertilization significantly increased all measured stand level characteristics except trees per acre, while herbicide significantly impacted all measured stand level characteristics. Both bedding and burning significantly impacted basal area, merchantable volume and total volume. Chopping had no significant impact on any measured characteristics.

At age 20, for the first time, the fertilized chop, burn and bed treatment (FCBB) had similar average tree height and crown length compared to the unfertilized herbicide treatments. The FCBB treatment plots had equal or greater per acre basal area, merchantable and total volumes. These trends continued at age 23, with the FCBB treatment surpassing and diverging from the unfertilized herbicide treatments. The results indicate that there is a limit to the added gains from herbicide on these coastal plain soils without additional nutrients.

Growth was examined between the ages of 5 and 23. A multivariate approach was used in the growth analysis. Age was considered a within subject effect. Both between subject and between*within subject effects were examined. Soil significantly affected average dbh growth, average mean height growth and average dominant height growth. There was a significant soil*age interaction present for dbh, basal area per acre and total volume per acre. Fertilization, fertilization*age, herbicide and herbicide*age were significant for all analyzed tree and stand level characteristics on spodosol soils. For nonspodosol soils herbicide was significant for all but mean and dominant height. Fertilization significantly affected total volume*age, and was borderline significant on basal area per acre. This indicates the importance of fertilization and herbicide for all aspects of stand growth. The fact that fertilization not only increases growth, but slows the rate at which growth decreases over time, indicates how valuable added nutrition is in maintaining rapid growth in intensively managed slash pine plantations.

5 LITERATURE CITED

Bennett, F., 1955. The effect of pruning on the height and diameter growth of planted slash pine. J For 53(9): 636-638.

Harrison, W. M., B. D. Shiver and S.W. Martin, 2001. Slash pine improved planting stock – vegetation control study – age 12 results. PMRC Tech Rep 2001-5. Plant Man Res Coop, University of Georgia. Athens, GA. 22pp.

Newberry, J.D. and L.V. Pienaar, 1978. Dominant height growth models and site index curves for site-prepared slash pine plantations in the lower coastal plain of Georgia and north Florida. PMRC Res Pap 4. Plant Man Res Coop, University of Georgia. Athens, GA. 74pp.

Pienaar, L.V., B.D. Shiver and J.W. Rheney, 1996. Yield prediction for mechanically site-prepared slash pine plantations in the southeastern coastal plain. PMRC Tech Rep 1996-3. Plant Man Res Coop, University of Georgia. Athens, GA. 57pp.

Zutter, B.R., D.H. Gjerstad and G.R. Glover, 1987. Fusiform rust incidence and severity in loblolly pine plantations following herbaceous weed control. For Sci 33(3): 790-800.