SLASH PINE SITE PREPARATION STUDY:

AGE 17 RESULTS

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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 vegetation control. 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.

Seventeen years after installation, 16 of the original 20 installations remain for analysis. Of these, seven are nonspodosols and nine are spodosols.

For each installation, **2**-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 the same purpose. Site indexes across installations ranged from 54 to 80 feet.

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 vegetation control) **UCBH**
9. Chop, burn, herbicide, fertilize **FCBH**
10. Chop, burn, bed, herbicide (treatment 6 followed by complete vegetation control) **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 12^{th} growing season, 200 pounds of nitrogen in the form of urea and 100 pounds of potassium in the form of KCL were applied.

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 x 10 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.

A 1/5-acre measurement plot was established within each **2**-acre treatment plot. Measurements were made after two, five, eight, eleven, fourteen and seventeen 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 and 17-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 17-year data. Soil groups represent the whole plots and treatments represent the splits. Analyses were conducted on average individual tree characteristics (height, dbh, crown length, crown ratio) and per acre stand characteristics (basal area, total volume, merchantable volume, percent fusiform infection). An alpha level of 0.5 was used to determine statistical significance.

In addition to the analysis of variance, the data from ages 5 to 17 were used to develop yield prediction models that account for more intensive silvicultural treatments. Existing model forms to predict average dominant / codominant height, per acre basal area and per acre total volume were adapted to account for site preparation treatment effects on spodic and nonspodic soils. An economic analysis was conducted using these models. Appropriate site preparation costs and stumpage rates were used to determine the optimum economic rotation ages for various treatment combinations and discount rates. Bare land values at the optimum economic rotation ages were calculated.

2 SEVENTEEN 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 vegetation control were conducted on average tree height, average dbh, average crown length and average crown ratio. The analysis of variance results were consistent for all analysis variables with treatment providing the only significant source of variation. Soil group was not significant and there were no soil group x treatment interactions. Average values by treatment across all soil groups are shown in Table 1.

Table 1. Average height (ft.), dbh (in.), crown length (ft.) and crown ratio by treatment.

Treatment Number	Treatment Code	Height (ft.)	Dbh (in.)	Crown Length (ft.)	Crown Ratio
1	CNTL	41.6	5.5	15.8	.37
2	UCHP	43.1	5.7	16.0	.37
3	FCHP	48.2	6.7	18.0	.37
4	UCHB	44.5	5.9	16.7	.37
5	FCHB	50.1	6.6	18.2	.36
6	UCBB	47.4	6.1	17.0	.36
7	FCBB	51.6	6.7	17.6	.34
8	UCBH	51.2	7.0	19.7	.38
9	FCBH	54.3	7.4	19.8	.36
10	UBHB	52.8	7.1	18.3	.34
11	FBHB	55.4	7.4	18.5	.33

Treatment gains due to chopping, burning, bedding, fertilization and vegetation control were computed by averaging values for the appropriate treatments and subtracting the pairs. Table 2 shows the treatment gains on average 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 55.4 feet on the most intensive treatment to 41.6 feet for the control. The average height values were well correlated with treatment intensity (Table 1 and Figure 1). Fertilization provided a positive response on all treatments with slightly higher gains on treatments without vegetation control. In the contrast analysis, fertilization, burning, bedding and vegetation control provided significant gains of 4.12, 1.65, 1.78 and 5.02 feet, respectively. The seventeen year results differ from the fourteen year results where burning had no significant effect on average height.

Table 2. Gains due to chopping, burning, bedding, fertilization and vegetation control on average height (ft.), dbh (in.), crown length (ft.) and crown ratio.

Treatment	Height (ft.)	Dbh (in.)	Crown Length (ft.)	Crown Ratio
Chop	1.50	0.20	0.25	0.00
Burn	1.65*	0.05	0.45	-0.005
Bed	1.78*	0.10	-0.75*	-0.025*
Veg. Control	5.02*	0.90*	1.70*	-0.005
Fertilization	4.12*	0.60*	0.88*	-0.012*

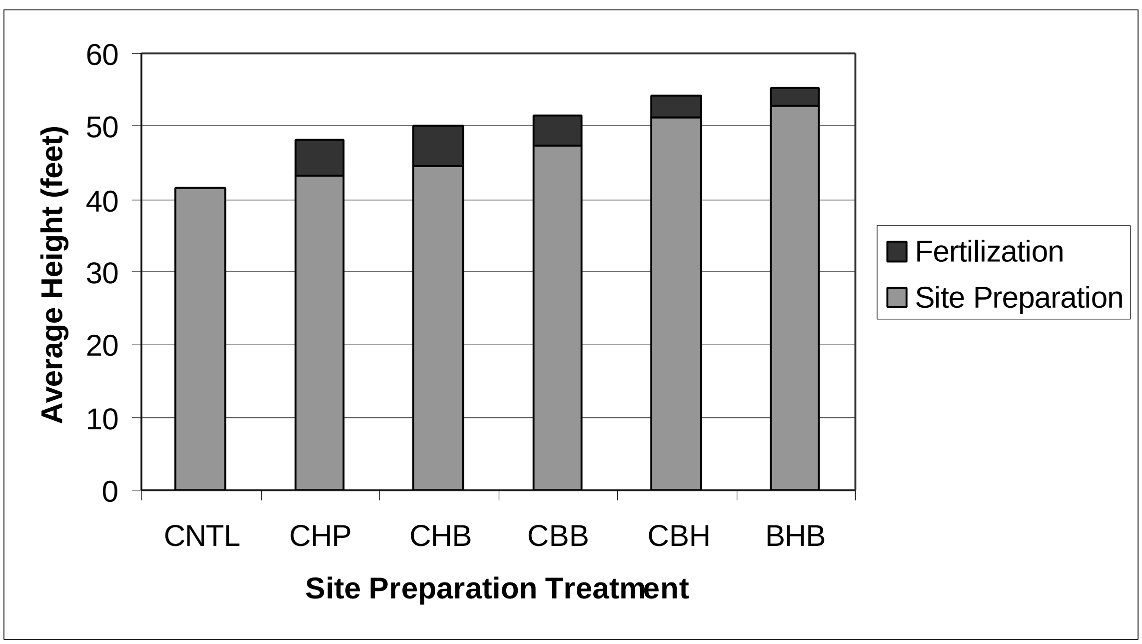

Figure 1. Average height by treatment for all installations at age 17.

2.1.2 Average tree dbh

Tree dbh's on the chop, chop and burn and control treatments ranged from 5.5 to 5.9 inches (Figure 2). The unfertilized chop, burn and bed treatment, an industry standard in the decades of the 1960's and 1970's, had an average dbh of 6.1 inches. With fertilizer added, means ranged from 6.6 to 6.7 inches. Treatments incorporating vegetation control were found to be the best with dbh values ranging from 7.0 to 7.4 inches. These results confirm the importance of interspecific competition to dbh growth, even when that competition is composed of understory plants such as palmetto and gallberry.

The contrast analyses for average dbh at age 17 reinforce the significance of fertilization and vegetation control with gains of 0.60 and 0.90 inches, respectively. Chopping, burning and bedding had no significant effect on average dbh.

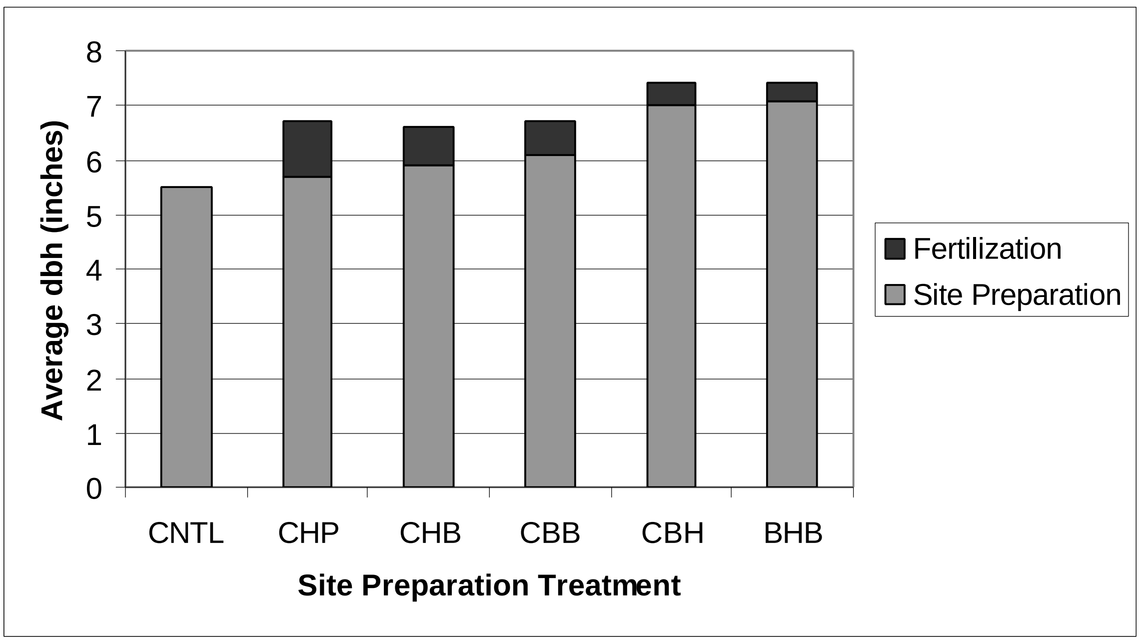

Figure 2. Average dbh by treatment for all installations at age 17.

2.1.3 Average crown length

Crown height was measured on all tagged trees after 14 and 17 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). Figures 2 and 3 show that rankings of crown length and dbh by treatment are closely matched. The treatments including vegetation control had the longest crown lengths. There was relatively little variation in crown length among treatments (15.8 to 19.8 feet) but longer crowns on the more intensive treatments appeared on taller trees and therefore, contributed to maintaining crown ratio.

Contrast analysis results indicated that bedding, fertilization and vegetation control had significant effects on average crown length. The average increase in crown length from fertilization after 17 growing seasons was 0.88 feet and the average increase due to vegetation control was 1.70 feet. The bedding treatment decreased average crown length by 0.75 feet.

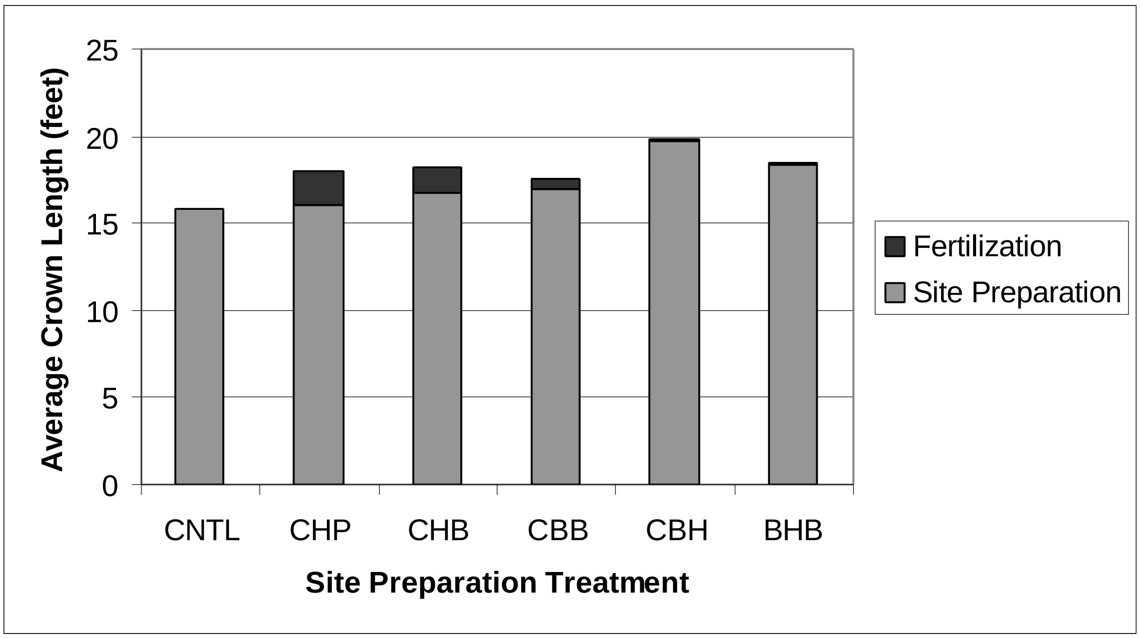

Figure 3. Average crown length by treatment for all installations at age 17.

2.1.4 Average crown ratio

There was a narrow range in average crown ratio by treatment from 0.33 to 0.37. In general, the ranking by treatment was the inverse of the treatment rankings of the other analysis variables (Table1 and Figure 4). The more intensive treatments had lower crown ratios than the less intensive treatments with the control having the highest crown ratio at age 17. All treatments had crown ratios approximately equal to the minimum value suggested as critical for growth in a slash pine pruning study (Bennett, 1955). Since these plots are not scheduled for thinning, growth can be expected to decrease over the next few years.

Contrast analysis indicated that burning, chopping and vegetation control had no significant effect on average crown ratio. The two treatments that were significant at age 17 both reduced average crown ratio. The average decreases due to bedding and fertilization were 0.025 and 0.012, respectively. Though these two treatments increased average crown length, their effect on average height was even greater, resulting in a decreased crown ratio.

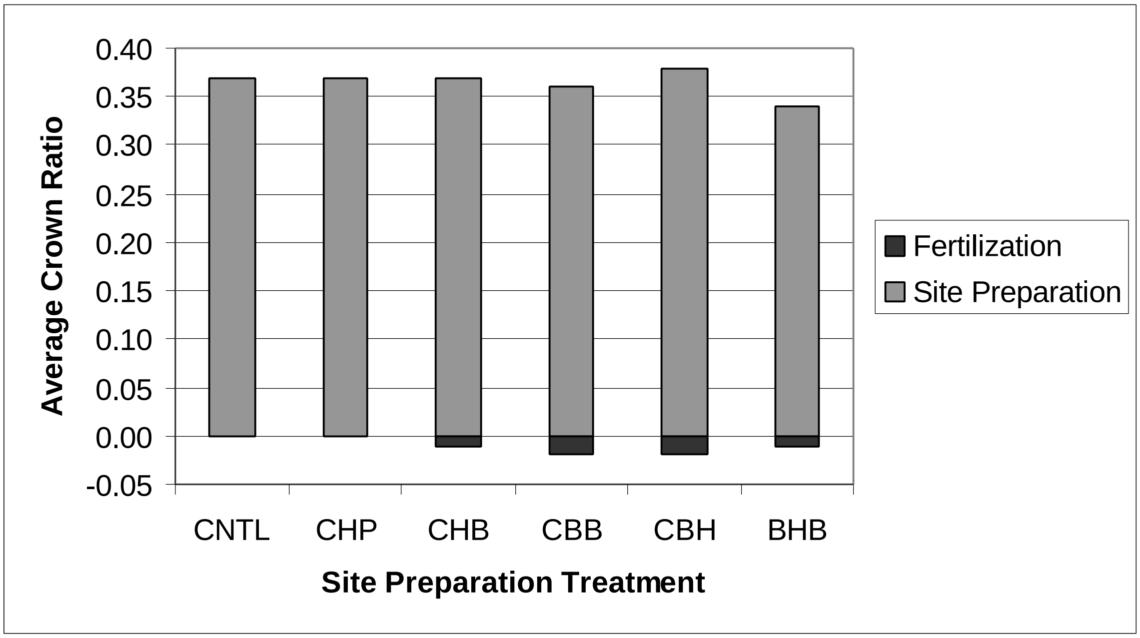

Figure 4. Average crown ratio by treatment for all installations at age 17.

2.1.5 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. Average percent infection values are presented in Table 3. The treatments that consistently promoted rapid height growth also resulted in higher rust infection rates (Figure 5). The average infection percentages by treatment ranged from 8.3% for the control to 23.3% for the most intensive treatment. The four treatments that included vegetation control had the highest infection percentages. This is consistent with results reported by Zutter *et.al.* (1987) who noted that increased growth rates resulted in higher cronartium infection rates.

Contrast analysis identified vegetation control as the only significant treatment, increasing the average infection rate by 6.9% (Table 4). As intensity increased, bedding was the only treatment to reduce the average infection rate although not significantly.

Table 3. Average percent cronartium infection by treatment.

Treatment	Treatment Code	Percent Cronartium
1	CNTL	8.3
2	UCHP	10.6
3	FCHP	11.1
4	UCHB	12.7
5	FCHB	12.8
6	UCBB	12.8
7	FCBB	14.1
8	UCBH	19.7
9	FCBH	23.2
10	UBHB	17.3
11	FBHB	19.9

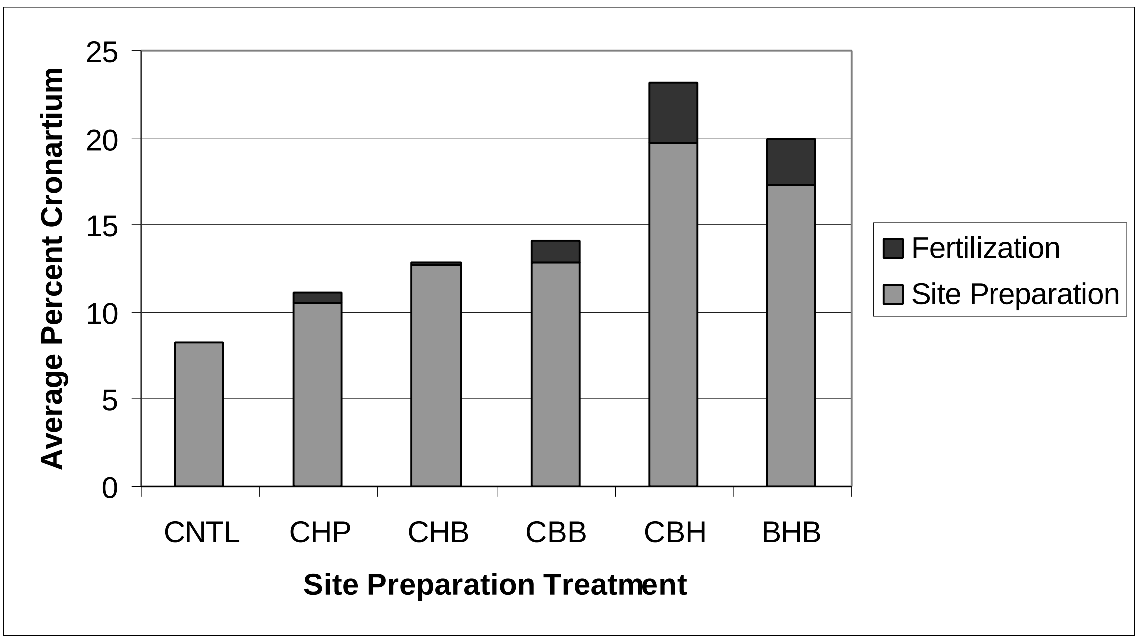

Figure 5. Average percent cronartium infection by treatment for all installations at age 17.

Table 4. Gain from chopping, burning, bedding, fertilization and vegetation control on average percent cronartium infection after 17 growing seasons.

Treatment	Cronartium Percent Gain
Chopping	2.3
Burning	1.9
Bedding	-1.1
Vegetation Control	6.9*
Fertilization	1.6

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. In addition, a significant interaction between treatment and soil group was found. In other words, the treatments had different effects on whole-stand performance on the different soil groups.

2.2.1 Basal area per acre

The mean basal areas by treatment and soil group shown in Table 5 and Figure 6 illustrate the soil group x treatment interaction. An understanding of this interaction should allow forest managers to make more appropriate site-specific treatment prescriptions. In general, without fertilization and vegetation control, nonspodosols are the more productive sites, but with vegetation control, spodic soils are superior. Without vegetation control, spodosols responded better to fertilization than nonspodosols, but with vegetation control, nonspodosols responded better to the fertilization treatment. Spodosols, which make up a large percentage of flatwoods sites and are generally considered inferior, can be made highly productive with intensive treatment. Across all sites, average basal area per acre ranged from 74.5 ft^2 /ac to 136.0 ft^2 /ac at age 17 for the different treatments.

Table 5. Average per acre basal area (ft^2) by soil group and treatment.

Treatment	Treatment Code	Nonspodosols	Spodosols	All Soils
1	CNTL	71.5	76.8	74.5
2	UCHP	84.2	76.7	80.2
3	FCHP	89.8	103.9	97.7
4	UCHB	90.2	79.4	84.2
5	FCHB	115.2	105.9	109.8
6	UCBB	106.2	93.3	98.8
7	FCBB	116.0	114.9	115.4
8	UCBH	108.2	124.2	117.6
9	FCBH	128.2	128.2	125.4
10	UBHB	119.4	126.3	122.9
11	FBHB	131.8	139.3	136.0

Contrast analysis for basal area per acre was carried out by soil group and for the combined soil groups. Of the different treatments, vegetation control, bedding and fertilization significantly increased basal area on both soil groups. In addition, burning was significant on the nonspodosols. Gains from the various treatments are listed in Table 6 and illustrated in Figure 6.

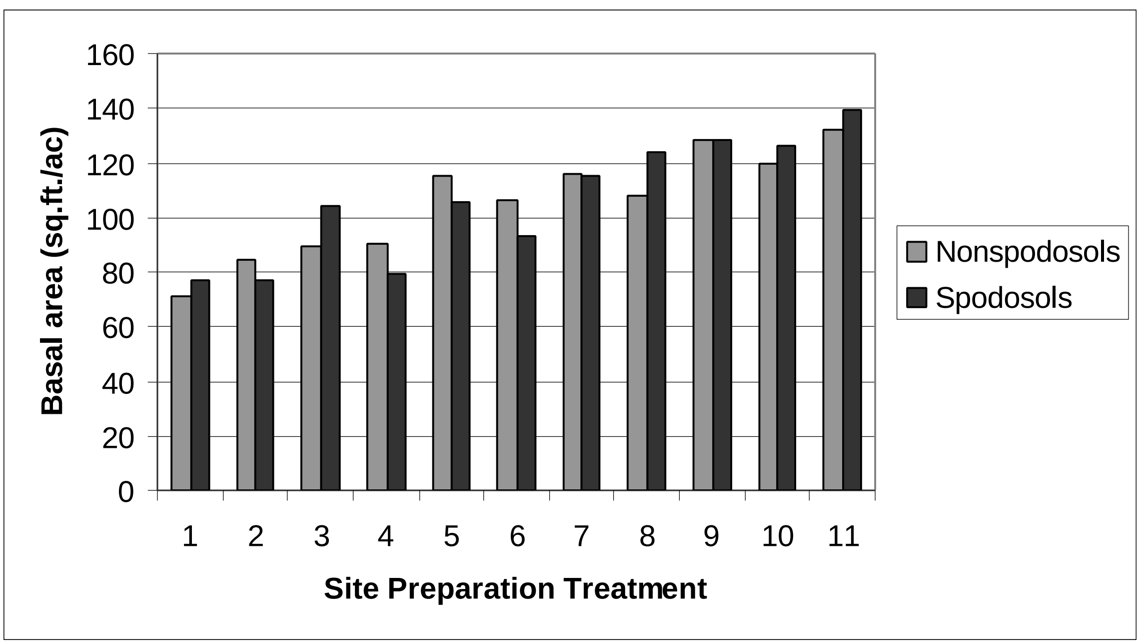

Figure 6. Per acre basal area by treatment and soil group.

Table 6. Gains in average per acre basal area from chopping, burning, bedding, fertilization and vegetation control by soil group.

Treatment	Nonspodosols	Spodosols	All Soils
Chopping	12.7	-0.1	5.7
Burning	15.7*	2.4	8.0*
Bedding	9.5*	9.0*	9.0*
Vegetation Control	13.4*	31.1*	23.4*
Fertilization	13.3*	18.5*	16.1*

2.2.2 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. Total outside bark stem volume was computed for all trees. These values were summed by plot and expanded to a per-acre basis. Average values for merchantable volume are presented in Table 7 and for total volume in Table 8. The analysis of variance and contrast results for per-acre volumes identify the same trends as the basal area analysis. Treatments and the treatment x soil group interaction significantly impact total and merchantable volume per acre.

Table 7. Average merchantable volume (ft^3) by soil group and treatment.

Treatment	Treatment Code	Nonspodosols	Spodosols	All Soils
1	CNTL	1321	1349	1336
2	UCHP	1654	1340	1488
3	FCHP	1960	2238	2115
4	UCHB	1963	1434	1669
5	FCHB	2707	2286	2459
6	UCBB	2354	1883	2082
7	FCBB	2721	2614	2658
8	UCBH	2524	2835	2707
9	FCBH	2996	3098	3053
10	UBHB	2823	3020	2922
11	FBHB	3272	3445	3368

Table 8. Average total volume (ft^3) by soil group and treatment.

Treatment	Treatment Code	Nonspodosols	Spodosols	All Soils
1	CNTL	1523	1574	1551
2	UCHP	1836	1556	1688
3	FCHP	2075	2396	2253
4	UCHB	2085	1638	1837
5	FCHB	2847	2450	2613
6	UCBB	2510	2064	2252
7	FCBB	2863	2780	2814
8	UCBH	2631	2979	2836
9	FCBH	3097	3214	3163
10	UBHB	2943	3143	3043
11	FBHB	3381	3576	3489

For nonspodosols, burning had a significant impact on volume but not for spodosols. For spodosols, the fertilization and bedding treatments appeared to produce major additive responses applied in the absence of vegetation control while they add much less when applied in addition to vegetation control. For nonspodosols, both fertilization and bedding add appreciably even after vegetation control has been imposed. Figures 7 and 8 illustrate the treatment effects and the treatment x soil group interactions for merchantable and total volume per acre.

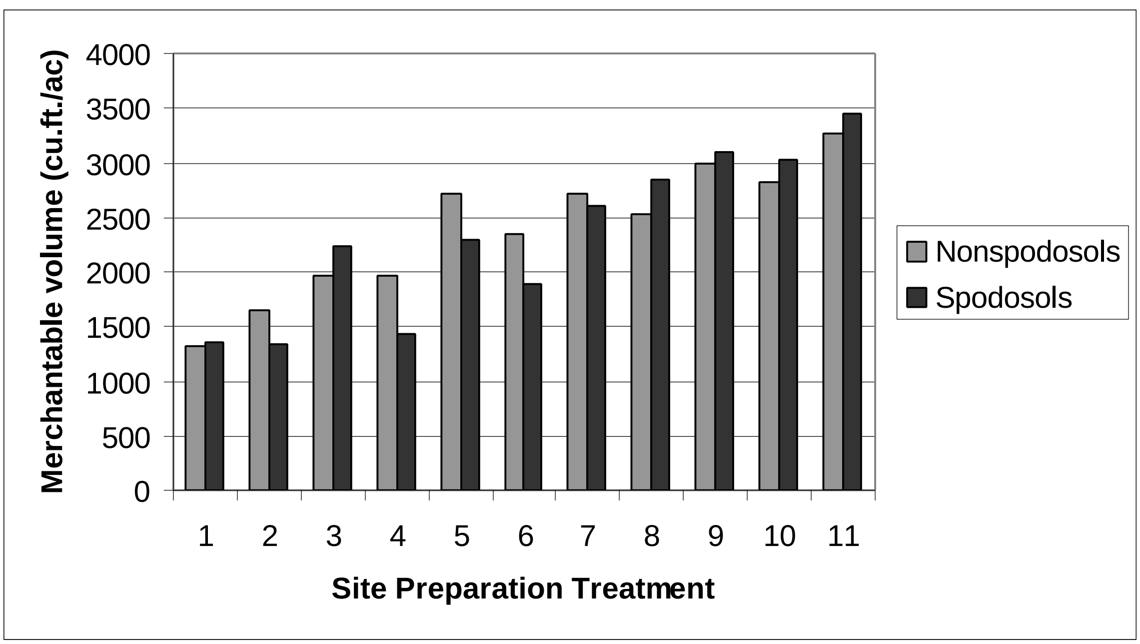

Figure 7. Per acre merchantable volume by treatment and soil group.

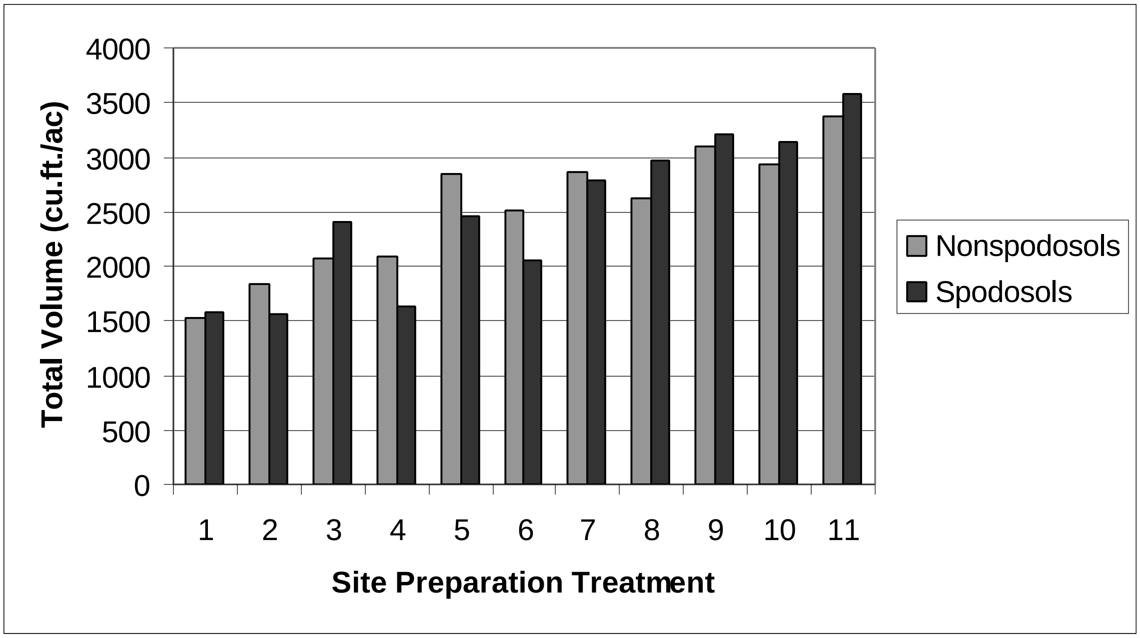

Figure 8. Per acre total volume by treatment and soil group.

The gains in average merchantable and total volumes per acre for the different treatments also follow the same trends as for basal area per acre (Tables 9 and 10). While the amounts differ, vegetation control, bedding and fertilization consistently resulted in significant gains regardless of soil group. Burning was significant only for nonspodosols. Even though chopping was not a significant treatment due to high variability, there were big differences on both soil groups due to this treatment.

Table 9. Gains in per acre merchantable volume from chopping, burning, bedding, fertilization and vegetation control by soil group.

Treatment	Nonspodosols	Spodosols	All Soils
Chopping	333	-8	151
Burning	528*	71	263*
Bedding	245*	327*	285*
Vegetation Control	468*	1050*	796*
Fertilization	468*	634*	557*

Table 10. Gains in per acre total volume from chopping, burning, bedding, fertilization and vegetation control by soil group.

Treatment	Nonspodosols	Spodosols	All Soils
Chopping	314	-18	136
Burning	510*	68	254*
Bedding	259*	320*	287*
Vegetation Control	437*	995*	754*
Fertilization	451*	608*	536*

3 MODELING CONSIDERATIONS

Existing yield prediction models were adapted to account for more intensive silvicultural practices. Results presented here are tentative, based on measurements made through age 17 and should be extrapolated with caution.

3.1 Average Dominant / Codominant Height

Two broad soil groups are represented in this study in anticipation of a need for site-specific silvicultural prescriptions. A basic Chapman-Richards growth model was chosen to describe average upper-canopy height growth with an additional response term to account for the cumulative responses due to more intensive silvicultural treatments (Pienaar and Rheney, 1995).

<u>Nonspodosols</u>

$$
\begin{aligned}
H &= 68.4\left(1-e^{-0.10059\,Age}\right)^{2.09565} \\
&\quad +\left(0.3493Z_c + 0.3829Z_b + 0.4257Z_1 + 0.2631Z_2 + 0.6977Z_3\right)Age\,e^{-0.0621\,Age}
\end{aligned}
$$

Where H = average dominant / codominant height (ft.),

Age = plantation age (years),

Z_C = 1 if chopped, 0 otherwise,

Z_B = 1 if burned, 0 otherwise,

Z_1 = 1 if fertilized, 0 otherwise,

Z_2 = 1 if bedded, 0 otherwise,

Z_3 = 1 if herbicide treated, 0 otherwise.

Spodosols

$$H = 69.3\left(1 - e^{-0.09412\ Age}\right)^{2.02425} + \left(0.8661\ Z_1 + 0.5778\ Z_2 + 1.5968\ Z_3 - 0.6374\ Z_1 Z_3\right) Age\ e^{-0.0653\ Age}$$

On nonspodosols each additional treatment had a significant additive effect on height growth without any significant interactive effects. On spodosols the average effects of the fertilization and bedding treatments were additive, as were the bedding and vegetation control treatment effects. The fertilization and vegetation control treatments, however, are less than additive, while chopping alone or chopping and burning had no significant effects on average dominant / codominant height.

Observed and predicted average dominant / codominant height at age 17 for the two soil groups and different treatments are shown in Table 11. Figures 9 and 10 show observed and predicted average dominant / codominant heights for four treatments on nonspodosols and spodosols, respectively. Figures 11 and 12 show the observed and predicted effect of fertilization on the most intensive site preparation treatment (chop, burn, bed, herbicide) for nonspodosols and spodosols, respectively.

Table 11. Observed and predicted average dominant height (ft.) at age 17 by soil group and treatment.

Treatment	Nonspodosols		Spodosols	
	Observed	Predicted	Observed	Predicted
1	43.8	45.0	42.6	43.9
2	46.7	47.1	42.6	43.9
3	49.5	49.6	49.6	48.7
4	48.7	49.4	43.0	43.9
5	53.9	51.9	49.8	48.7
6	50.4	50.9	47.3	47.1
7	53.1	53.4	52.5	52.0
8	53.0	53.5	51.9	52.8
9	56.3	56.0	54.8	54.1
10	53.7	55.0	54.3	56.1
11	56.7	57.6	56.8	57.4

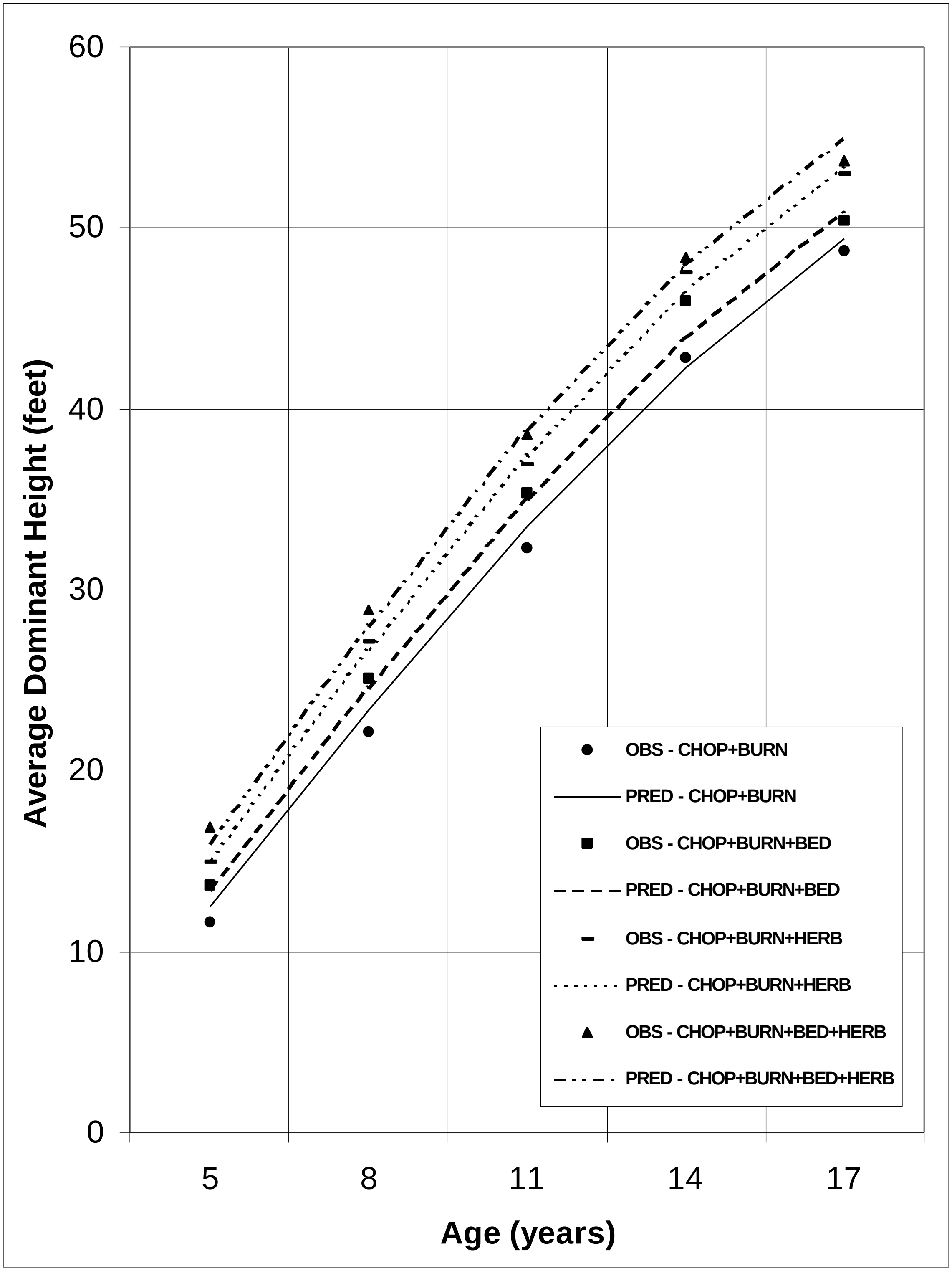

Figure 9. Observed and predicted average dominant / codominant heights for four unfertilized treatments for nonspodosols.

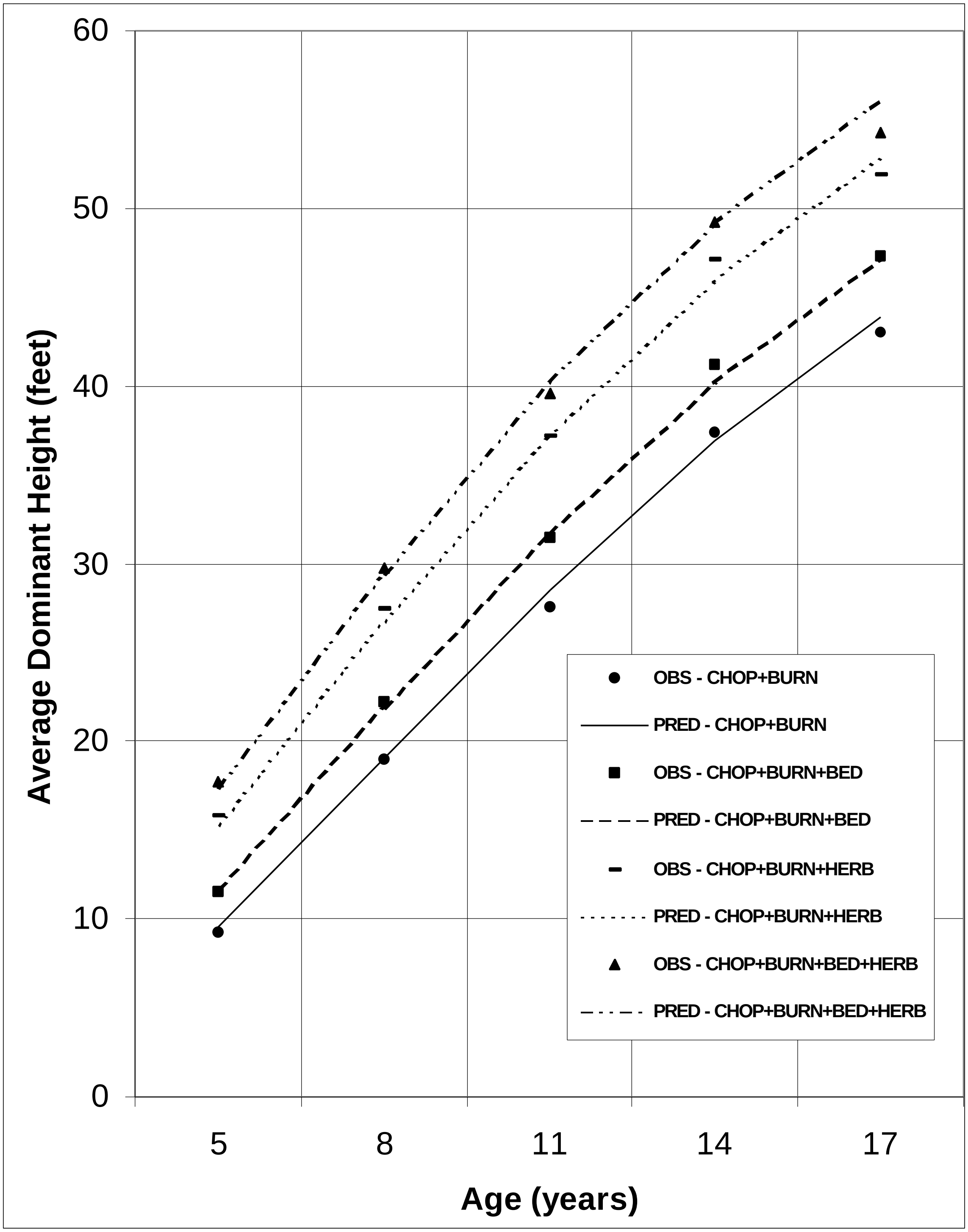

Figure 10. Observed and predicted average dominant / codominant heights for four unfertilized treatments for spodosols.

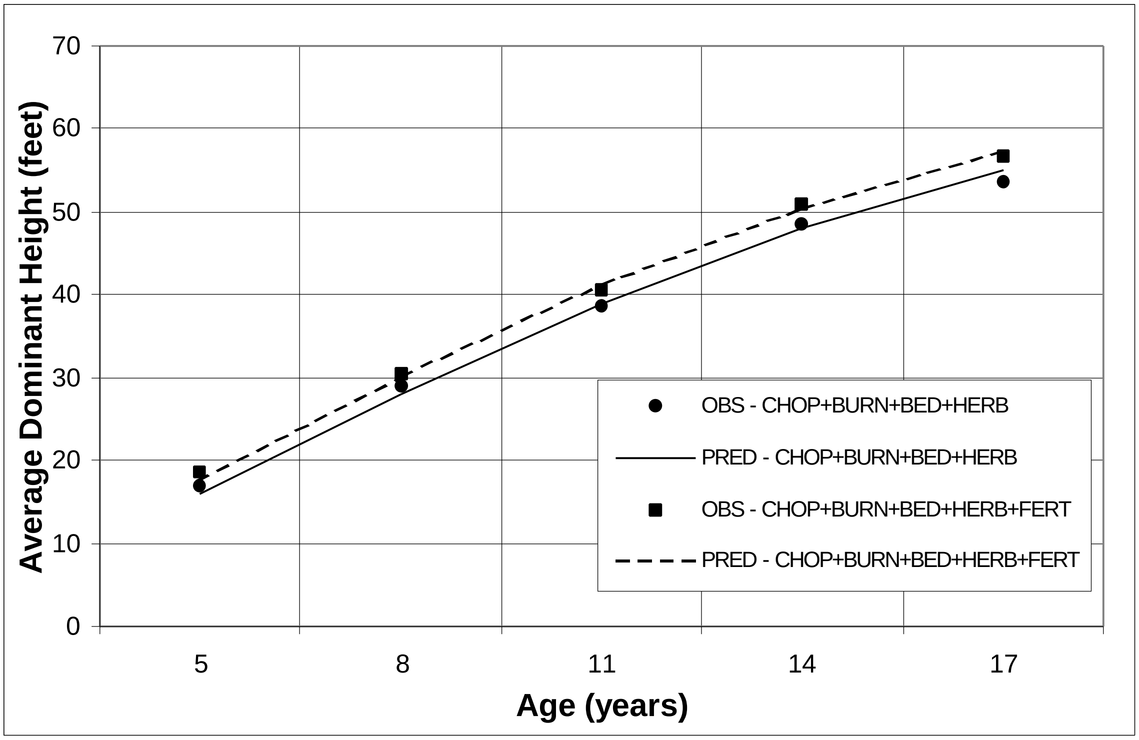

Figure 11. Observed and predicted average dominant / codominant height for fertilized and unfertilized treatments for nonspodosols.

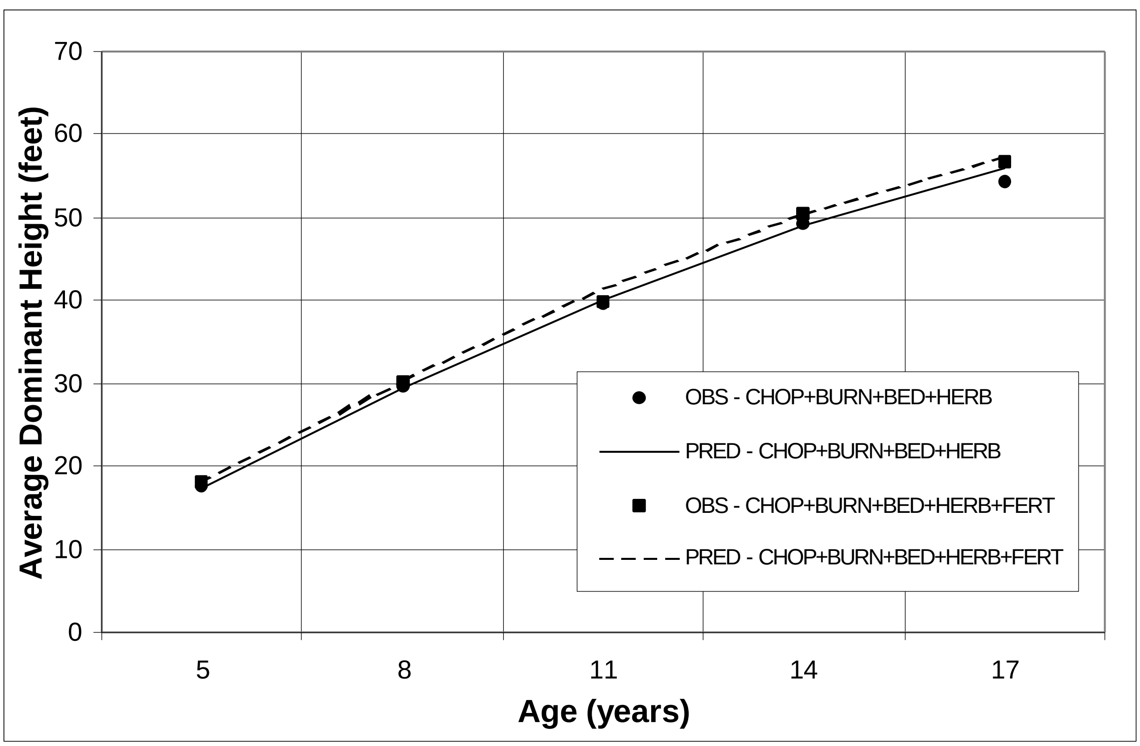

Figure 12. Observed and predicted average dominant / codominant heights for fertilized and unfertilized treatments for spodosols.

3.2 Basal Area Per Acre

A stand-level basal area prediction model that uses average dominant / codominant height as a predictor variable was fitted for each of the two broad soil groups. A term was added to the basic model to account for possible treatment effects in addition to the effects already explained by the predicted dominant / codominant height.

Nonspodosols

$$B = e^{-5.0145 - 24.5791 / Age} H^{1.5907 + 3.7699 / Age} N^{0.5023 + 2.6342 / Age} + 2.5033\, Z_3 Age\ e^{-0.1004\ Age}$$

Spodosols

$$B = e^{-2.8387 - 31.0411 / Age} H^{1.4080 + 2.8217 / Age} N^{0.2891 + 3.7127 / Age} + \left(0.5562\, Z_1 + 2.8541 Z_3\right) Age\ e^{-0.0853\ Age}$$

Where *B* = basal area (ft^2/ac),
Age = plantation age (years),
H = average dominant / codominant height (ft.),
N = surviving trees per acre,
Z_1, Z_3 = as previously defined.

On nonspodic soils, only the vegetation control treatment required an adjustment to the predicted basal area for a plantation with a given average dominant / codominant height, number of surviving trees per acre and age. On spodic soils, both fertilization and vegetation control treatments required additive adjustments to the predicted basal area. Observed and predicted per-acre basal areas at age 17 are shown in Table 12. Figures 13 and 14 show observed and predicted per-acre basal areas for two treatments (with and without vegetation control) for nonspodosols and spodosols, respectively. Figure 15 shows the effect of fertilization in addition to chopping, burning, bedding and vegetation control on spodosols. Predicted basal areas in these figures are computed using the observed average dominant / codominant height.

Table 12. Observed and predicted basal area (ft^2/ac) at age 17 by soil group and treatment.

Treatment	Nonspodosols			Spodosols		
	TPA	Observed	Predicted	TPA	Observed	Predicted
1	403	71.5	75.4	459	76.8	77.6
2	421	84.2	85.8	470	76.7	78.3
3	343	89.8	82.4	456	103.9	100.4
4	375	90.2	87.1	465	79.4	79.6
5	421	115.2	112.1	468	105.9	102.4
6	455	106.2	105.7	474	93.3	93.0
7	432	116.0	112.3	480	115.0	112.0
8	366	108.3	104.2	484	124.2	120.1
9	376	121.8	119.4	445	128.3	127.2
10	420	119.4	119.3	456	126.3	124.6
11	414	131.8	129.0	482	139.3	138.6

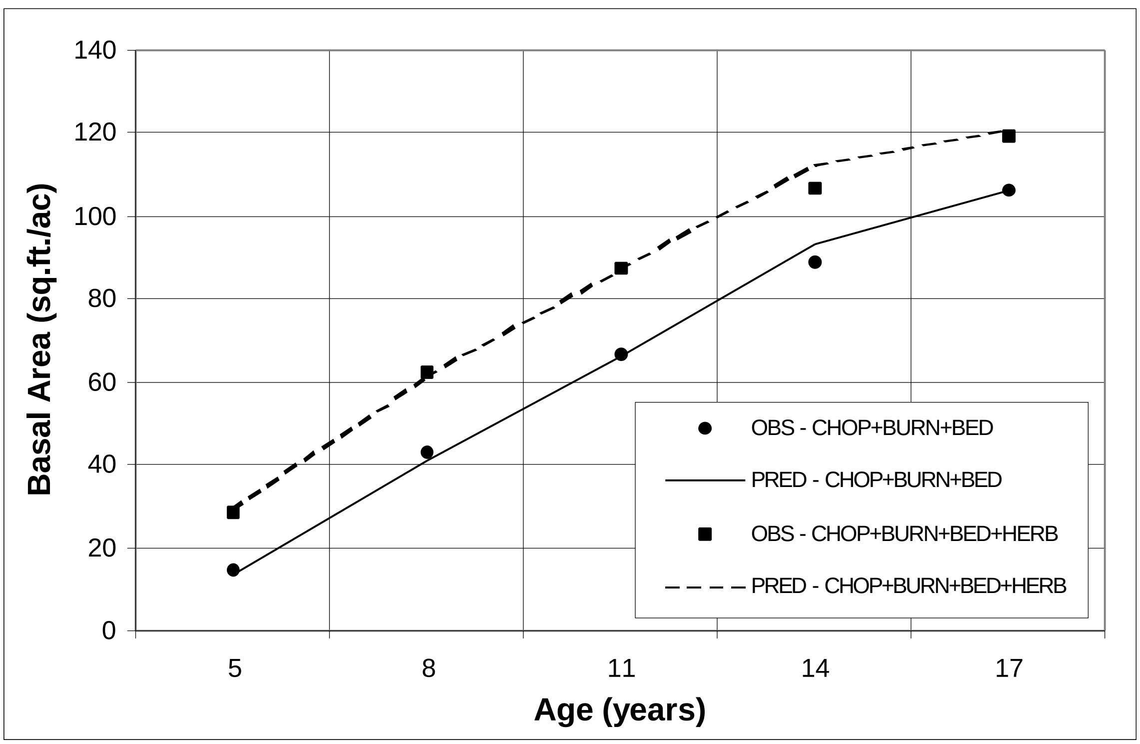

Figure 13. Observed and predicted per-acre basal areas for nonspodosols.

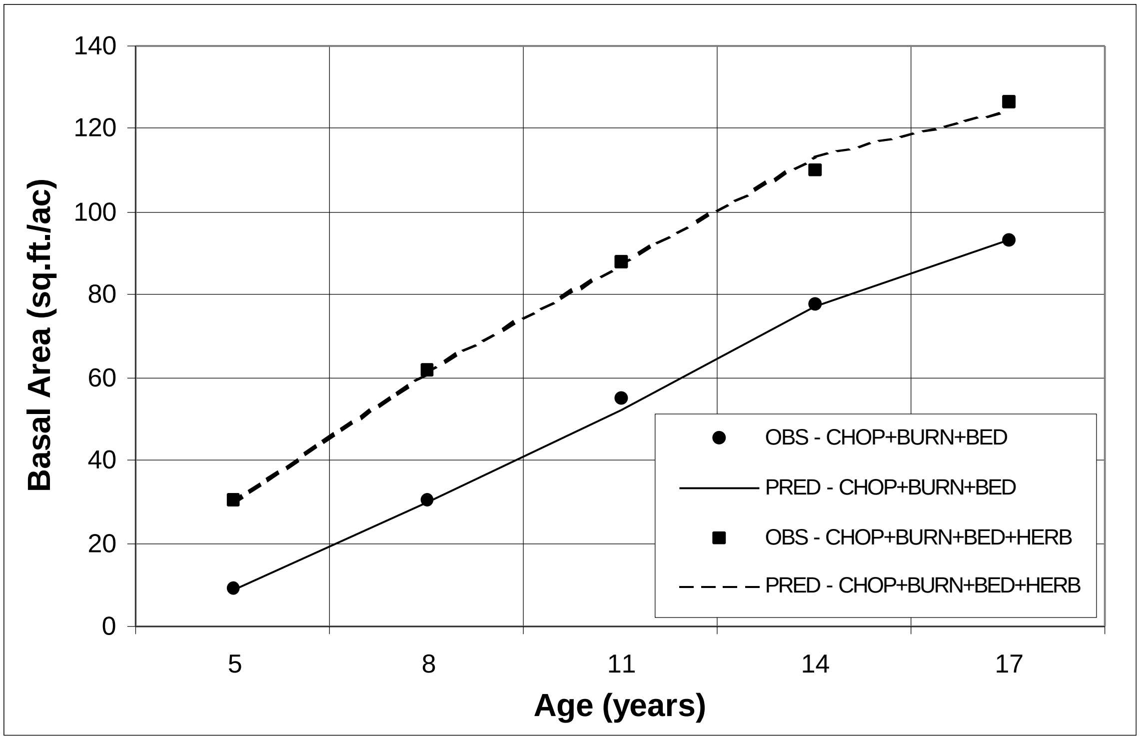

Figure 14. Observed and predicted per-acre basal areas for spodosols.

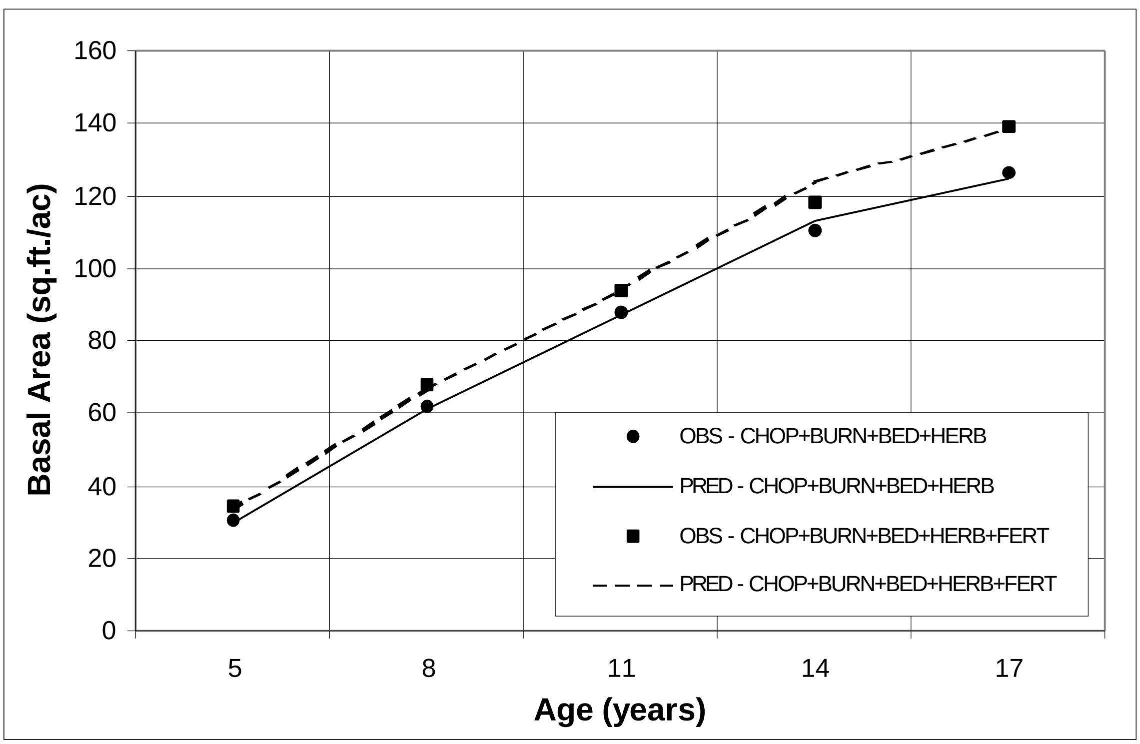

Figure 15. Observed and predicted per-acre basal area for fertilized and unfertilized treatments for spodosols.

3.3 Total Volume Per Acre

A stand-level total volume prediction model with average dominant / codominant height, surviving trees per acre, basal area per acre and age as predictor variables was fitted for each soil group. No adjustment was necessary for either soil group to account for possible additional treatment effects. Observed and predicted volumes per acre at age 17 are shown in Table 13.

<u>Nonspodosols</u>

$$V = e^{4.4596/Age} H^{0.8325-1.1587/Age} N^{-0.0294-0.3101/Age} B^{1.0227+0.2552/Age}$$

<u>Spodosols</u>

$$V = e^{6.5367/Age} H^{0.7653-0.9777/Age} N^{-0.0334-0.5794/Age} B^{1.0853}$$

Where V = total outside bark volume (ft^3/ac),
Age = plantation age (years),
H = average dominant / codominant height (ft.),
N = surviving trees per acre,
B = basal area (ft^2/ac).

Table 13. Observed and predicted total volume (ft^3/ac) at age 17 by soil group and treatment.

Treatment	Nonspodosols			Spodosols		
	Observed	Predicted 1	Predicted 2	Observed	Predicted 1	Predicted 2
1	1523	1473	1605	1574	1536	1584
2	1836	1831	1930	1556	1533	1608
3	2075	2068	1969	2396	2380	2226
4	2085	2042	2012	1638	1604	1621
5	2847	2828	2721	2450	2431	2268
6	2510	2461	2484	2064	2042	2029
7	2863	2813	2753	2780	2752	2624
8	2631	2634	2666	2979	2966	2896
9	3097	3115	3113	3214	3210	3106
10	2943	2930	3029	3143	3133	3159
11	3381	3384	3415	3576	3583	3541

Predicted 1: volume predicted with observed H, N, B.
Predicted 2: volume predicted with predicted H, N, B.

Figures 16 and 17 show observed and predicted per-acre total volumes by treatment for nonspodosols and spodosols, respectively. Total volumes were predicted using the observed average dominant / codominant height and observed per-acre basal area.

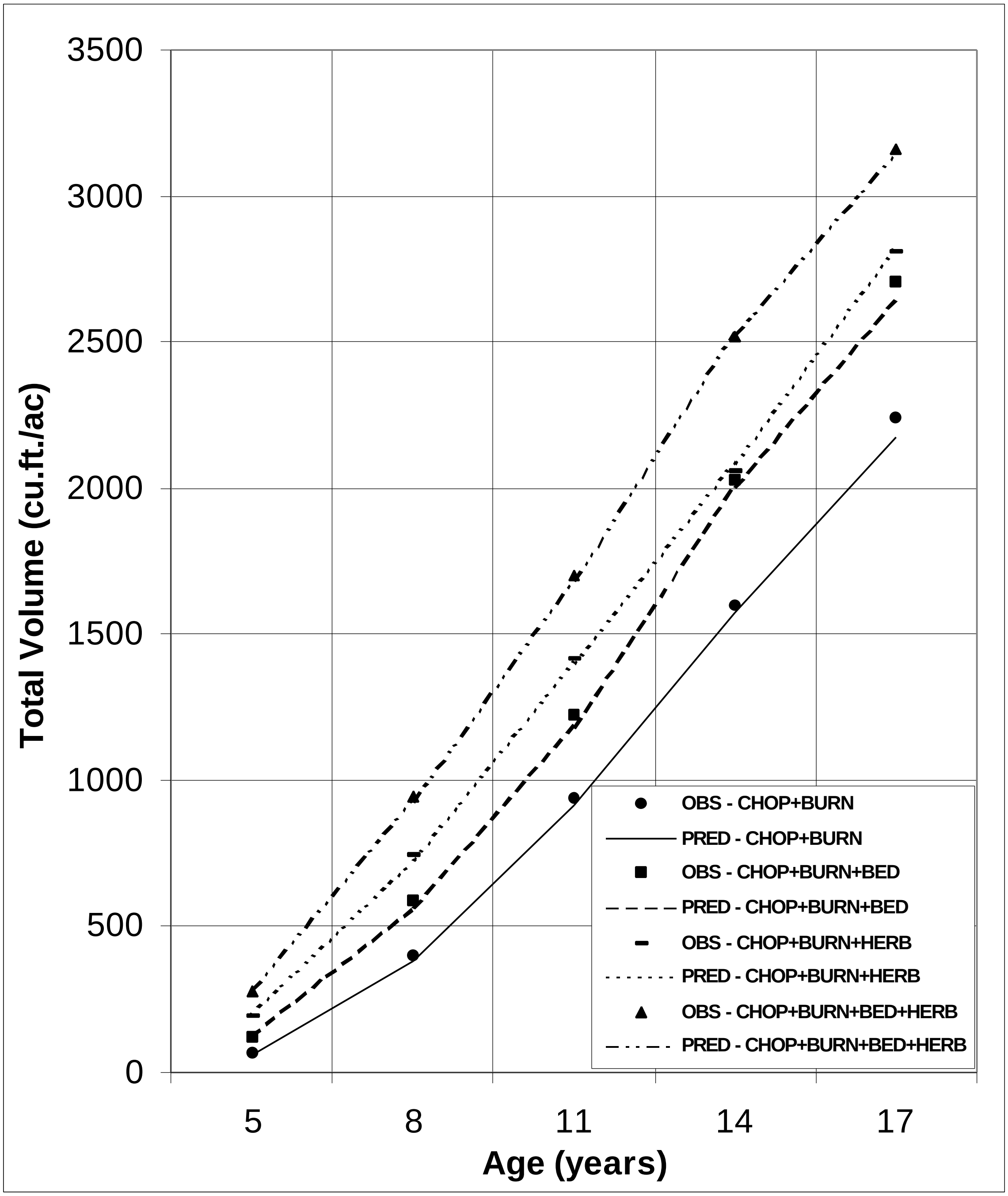

Figure 16. Observed and predicted per-acre total volume for four unfertilized treatments for nonspodosols.

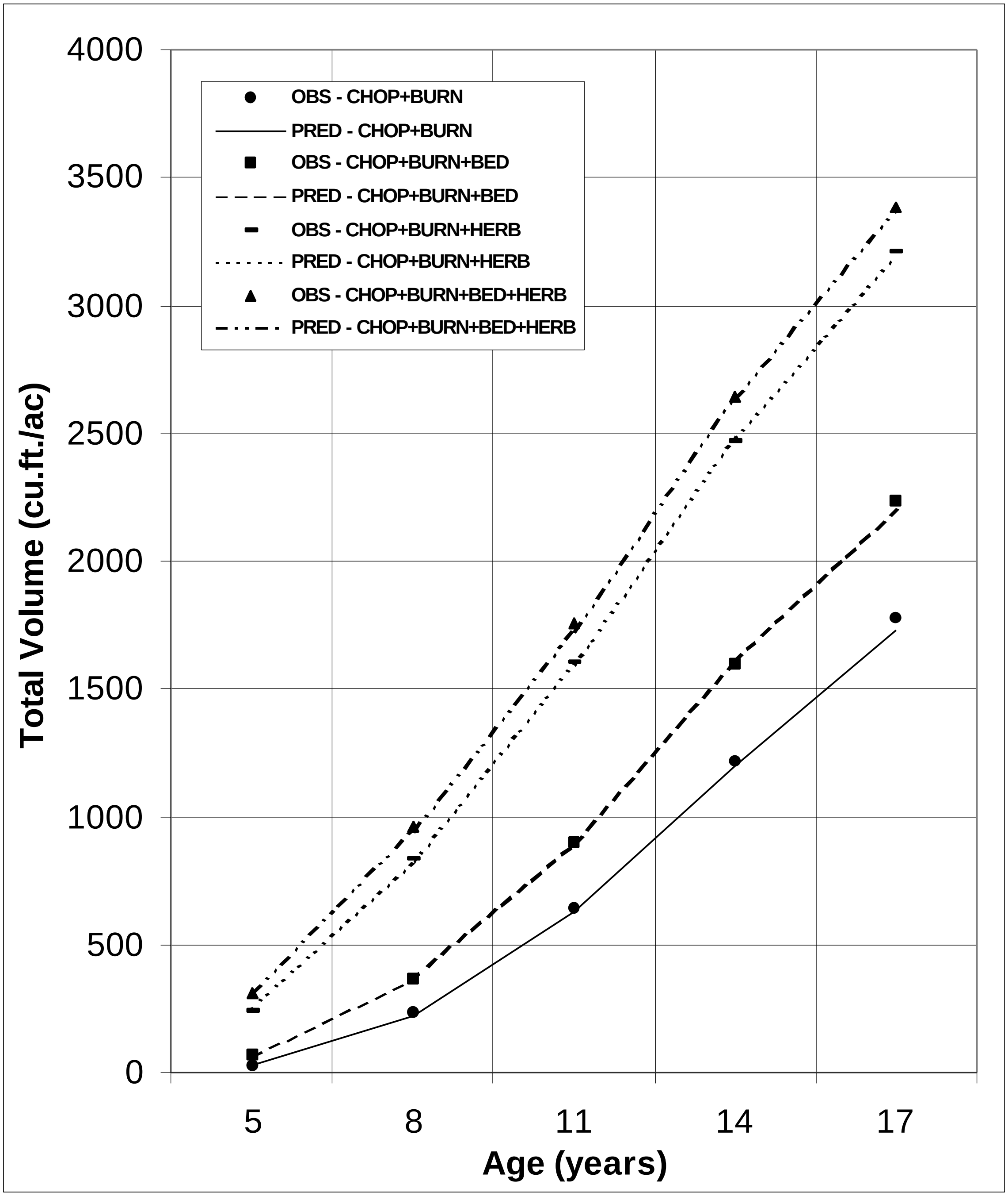

Figure 17. Observed and predicted per-acre total volume for four unfertilized treatments for spodosols.

3.4 Product Volume Breakdown

A product breakdown equation of the form proposed by Amateis *et.al*. (1986) and developed by Pienaar *et.al*. (1996) for site prepared slash pine plantations was used to merchandise per acre volumes into pulpwood and chip-n-saw products. Pulpwood was assumed to have a threshold Dbh of 4.5 inches and a merchantable top diameter of 3 inches. Chip-n-saw was assumed to have a threshold Dbh of 8 inches with a merchantable top diameter of 6 inches. Though many of the plantations sampled to develop the breakdown equation were chopped, burned or bedded, none had been fertilized or had chemical vegetation control treatments. Residual analysis from comparison of predicted product breakdown with actual calculated product breakdown using taper functions revealed a large positive bias (Figure 18) for chip-n-saw. For the same quadratic mean diameter and number of stems per acre, most stands without fertilization and weed control are much older and have larger average heights that these intensively managed plots. Because of that increased height, the percentage of the stand which falls into the chip-n-saw product class is larger. Separate product breakdown equations were, therefore, developed from data on these study plots to predict the percentage of total volume above various threshold Dbh limits to various top diameter limits. The number of stems per acre was not found to be a significant predictor variable, possibly due to the limited range in trees per acre on these plots.

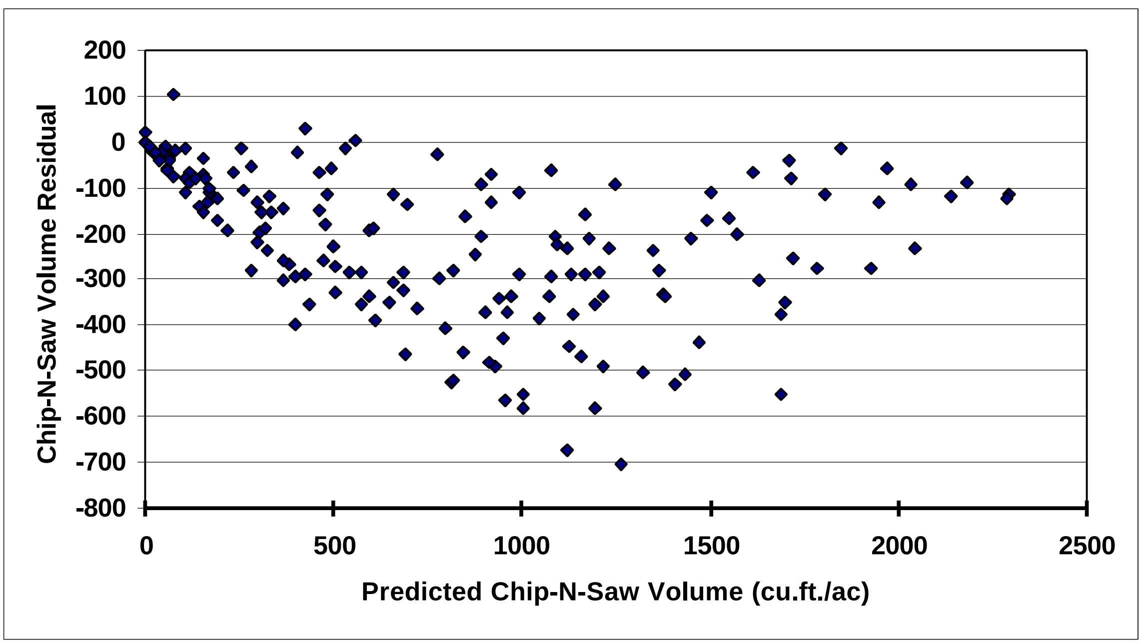

Figure 18. Residual (observed-predicted) chip-n-saw volume using the Pienaar *et.al*. (1996) model on the slash pine site preparation data.

The product breakdown equation is:

$$V_{t,d} = Ve^{-2.0417\left(\frac{t}{D_q}\right)^{6.0049} - 0.2740\left(\frac{d}{D_q}\right)^{6.0331}}$$

where $V_{t,d}$ = volume above a threshold dbh (d inches) to a top diameter limit (t inches o.b.) (ft^3/ac),

V = total volume (ft^3/ac),

D_q = quadratic mean Dbh (inches).

The product breakdown model shown above contains no specific provision for soil types or treatments. An attempt to account for these effects was made but, in most cases, problems with the significance of parameter estimates were encountered. The residuals, separated by soil type and treatment, were examined for undesirable trends and were found to be acceptable.

3.5 Model Comparisons

Models similar to the ones listed above were developed for the slash pine site preparation study using the 14-year measurement data. A single set of models was developed for all soil groups. These models were reported on in Shiver *et.al*. (1994). Graphical comparisons were carried out between the age 14 models and the age 17 models. Growth projections were started with the observed numbers of trees per acre for various treatments at age five. Survival was projected using the Pienaar *et.al*. (1996) equation. Average dominant height, per-acre basal area and per-acre total volume were projected with the two systems of slash pine site preparation study models. Total volume growth curves and MAI curves for different site preparation treatments are shown in Figures 19-34.

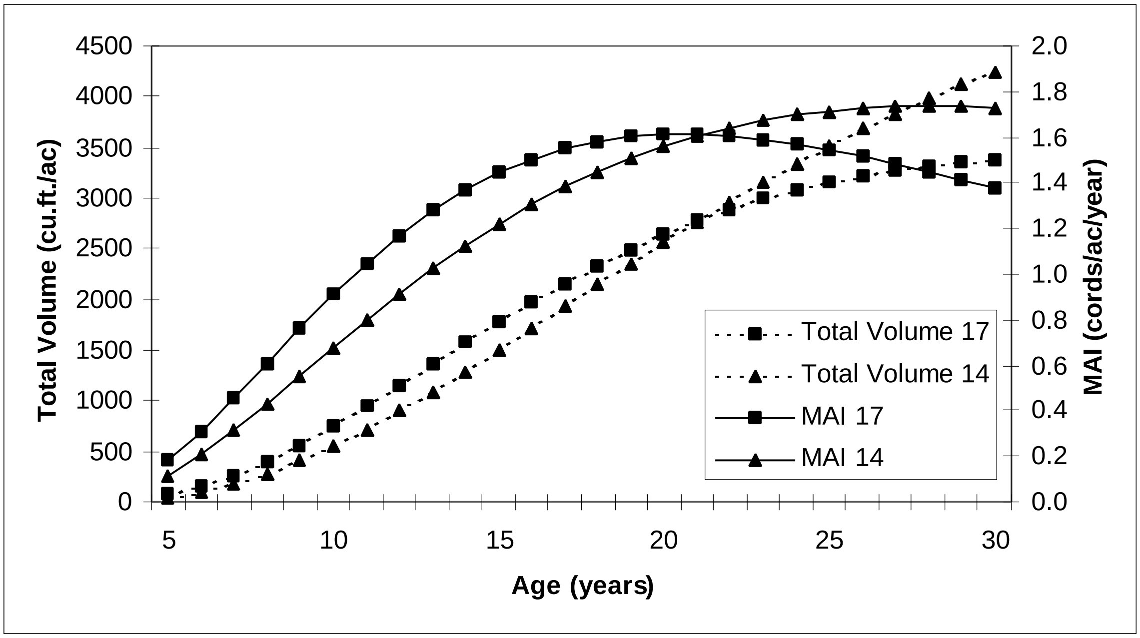

Figure 19. Volume growth and MAI development curves for unfertilized, chop and burn site preparation treatments for nonspodosols.

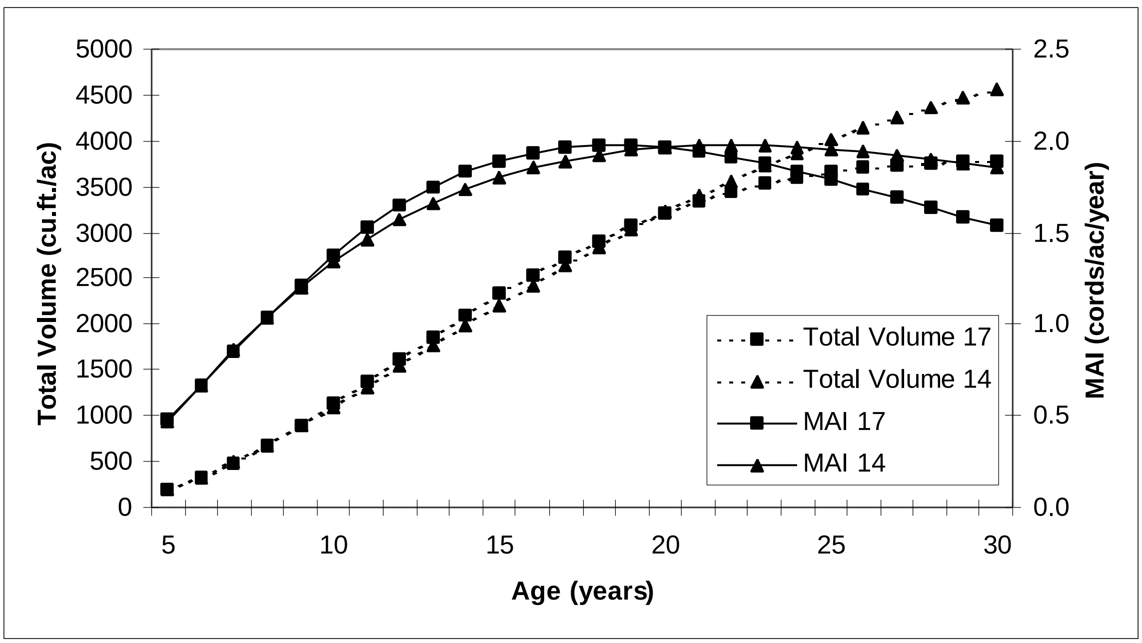

Figure 20. Volume growth and MAI development curves for unfertilized, chop, burn and herbicide site preparation treatments for nonspodosols.

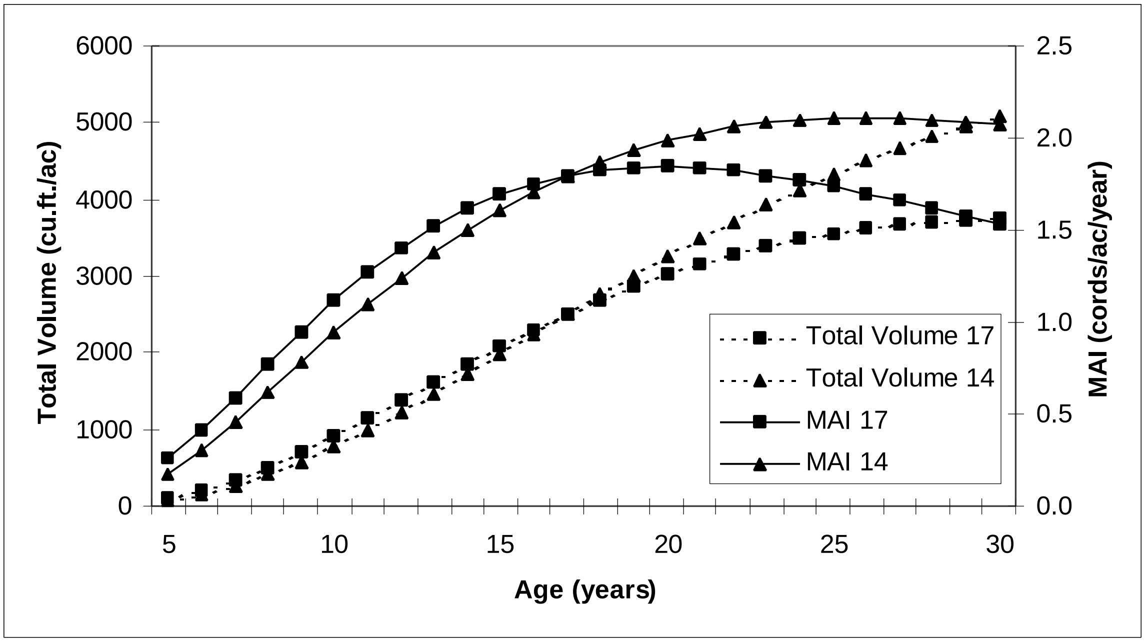

Figure 21 . Volume growth and MAI development curves for unfertilized, chop, burn and bed site preparation treatments for nonspodosols.

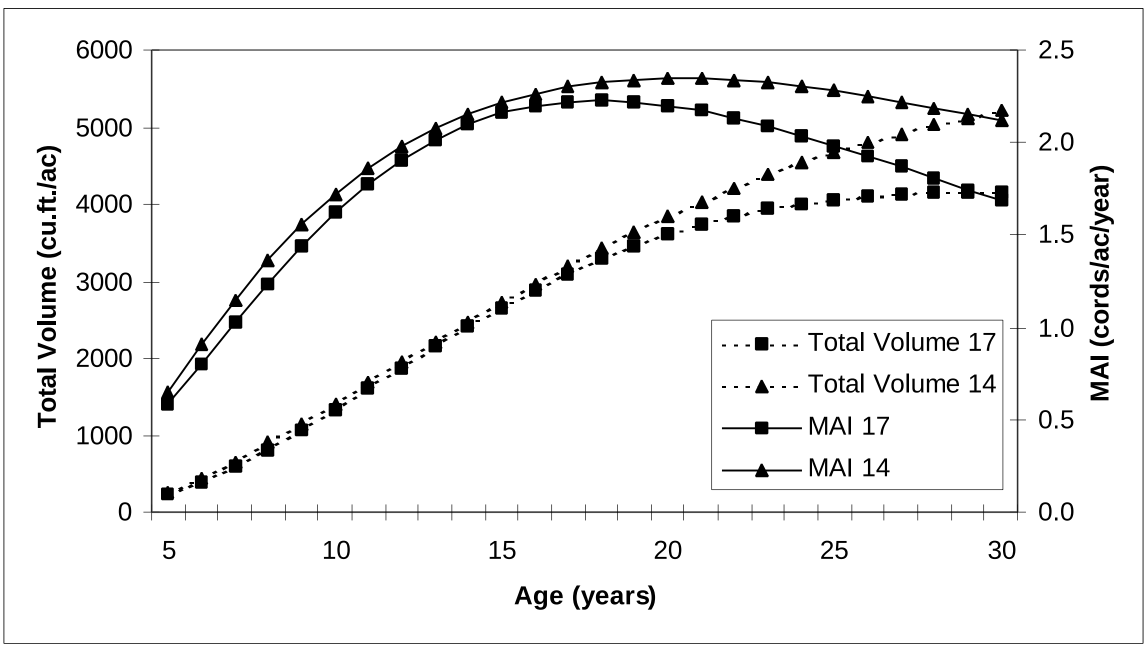

Figure 22 . Volume growth and MAI development curves for unfertilized, chop, burn, herbicide and bed site preparation treatments for nonspodosols.

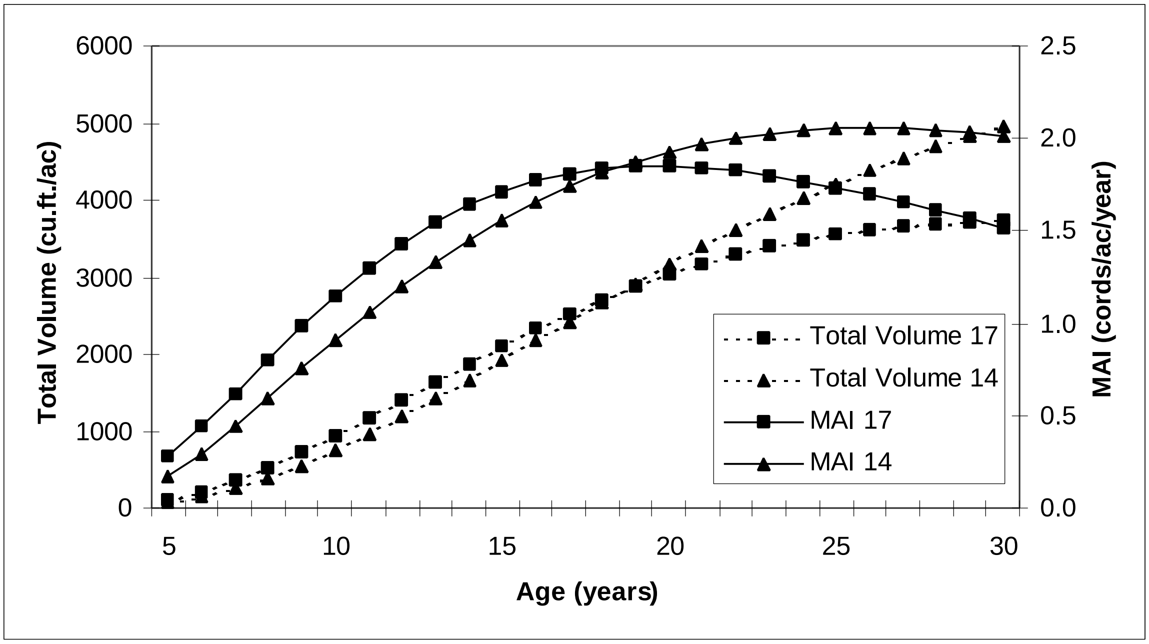

Figure 23. Volume growth and MAI development curves for fertilized, chop and burn site preparation treatments for nonspodosols.

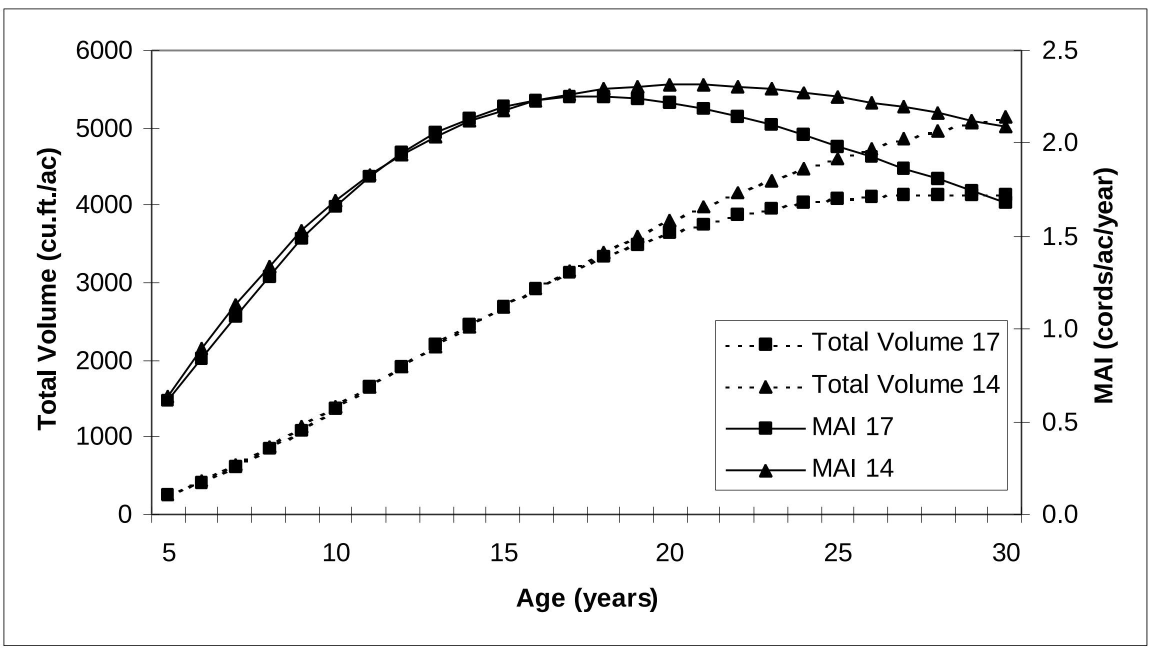

Figure 24. Volume growth and MAI development curves for fertilized, chop, burn and herbicide site preparation treatments for nonspodosols.

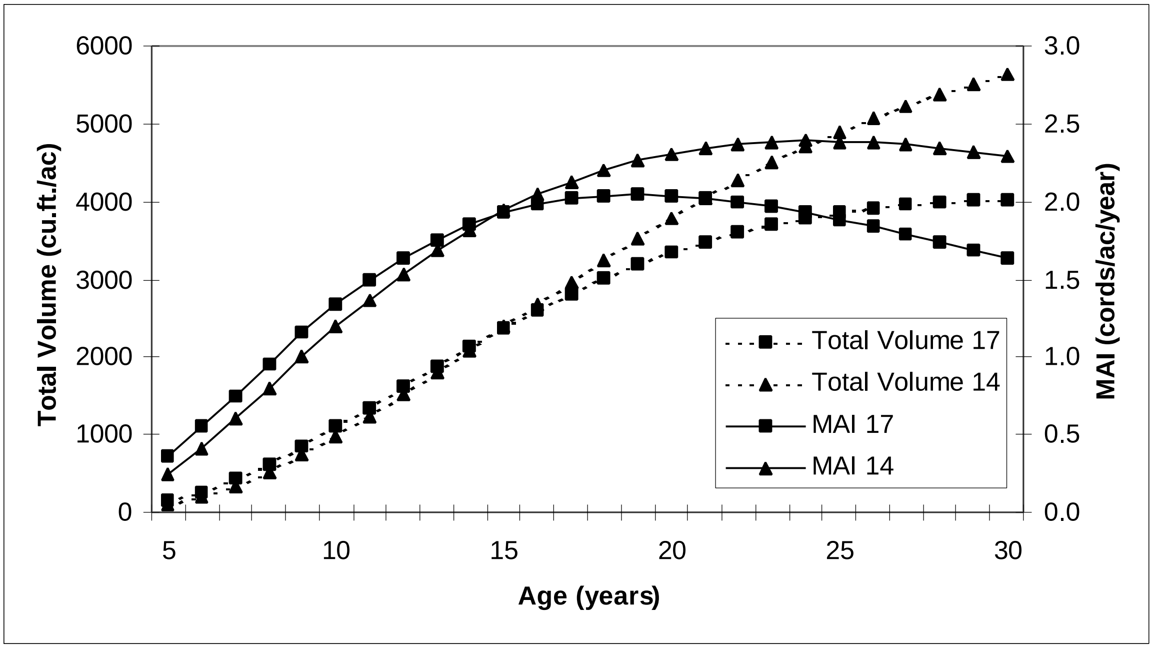

Figure 25. Volume growth and MAI development curves for fertilized, chop, burn and bed site preparation treatments for nonspodosols.

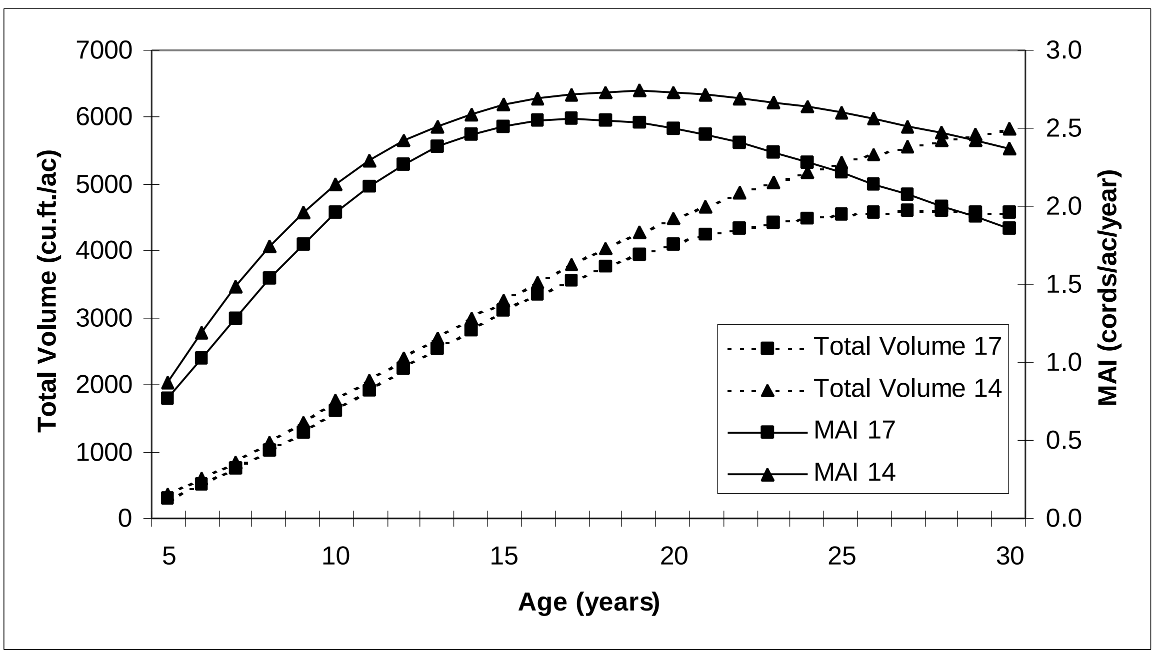

Figure 26. Volume growth and MAI development curves for fertilized, chop, burn, herbicide and bed site preparation treatments for nonspodosols.

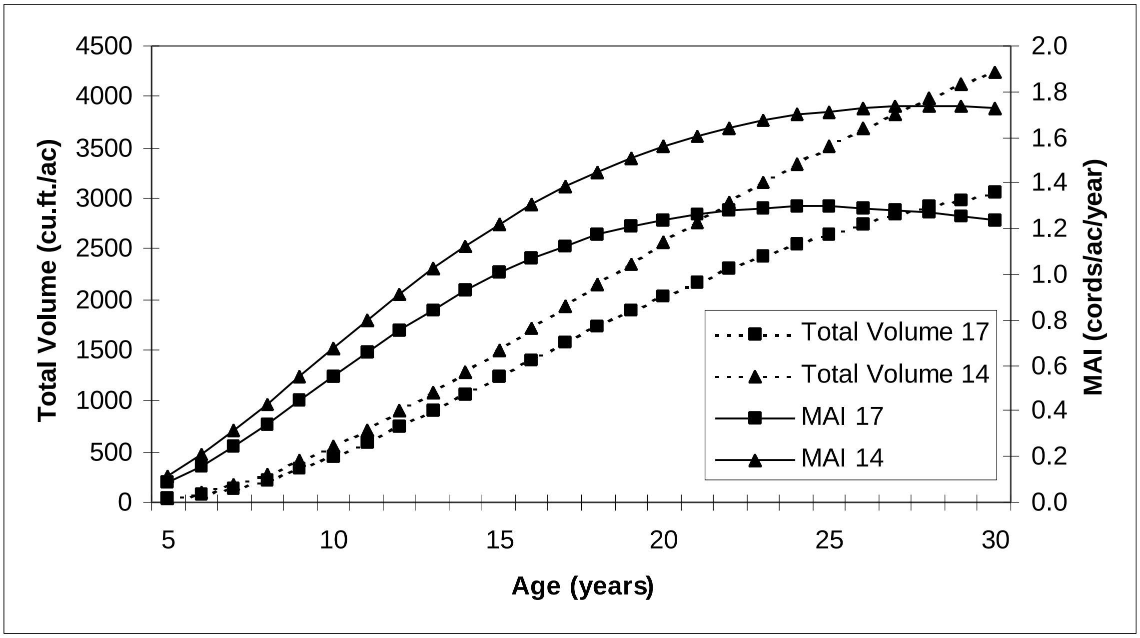

Figure 27. Volume growth and MAI development curves for unfertilized, chop and burn site preparation treatments for spodosols.

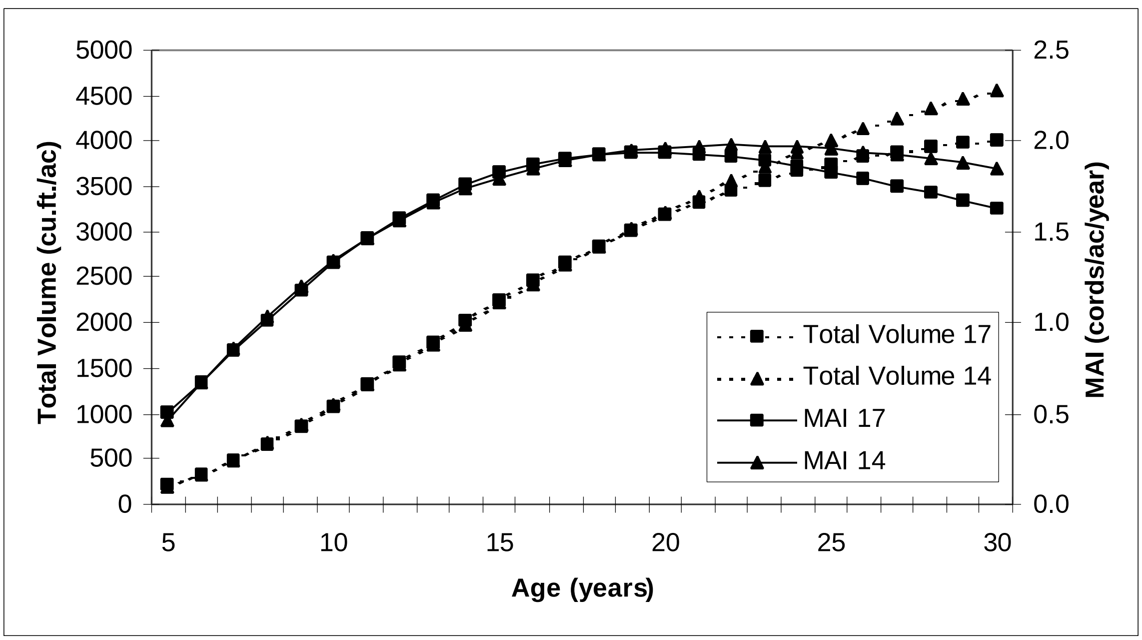

Figure 28. Volume growth and MAI development curves for unfertilized, chop, burn and herbicide site preparation treatments for spodosols.

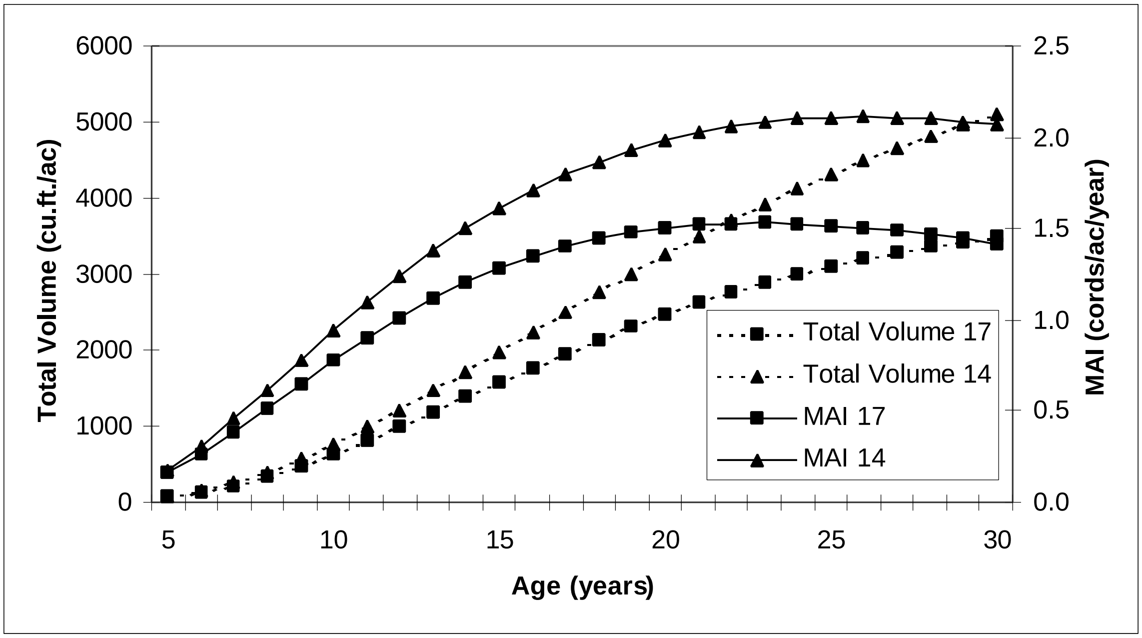

Figure 29. Volume growth and MAI development curves for unfertilized, chop, burn and bed site preparation treatments for spodosols.

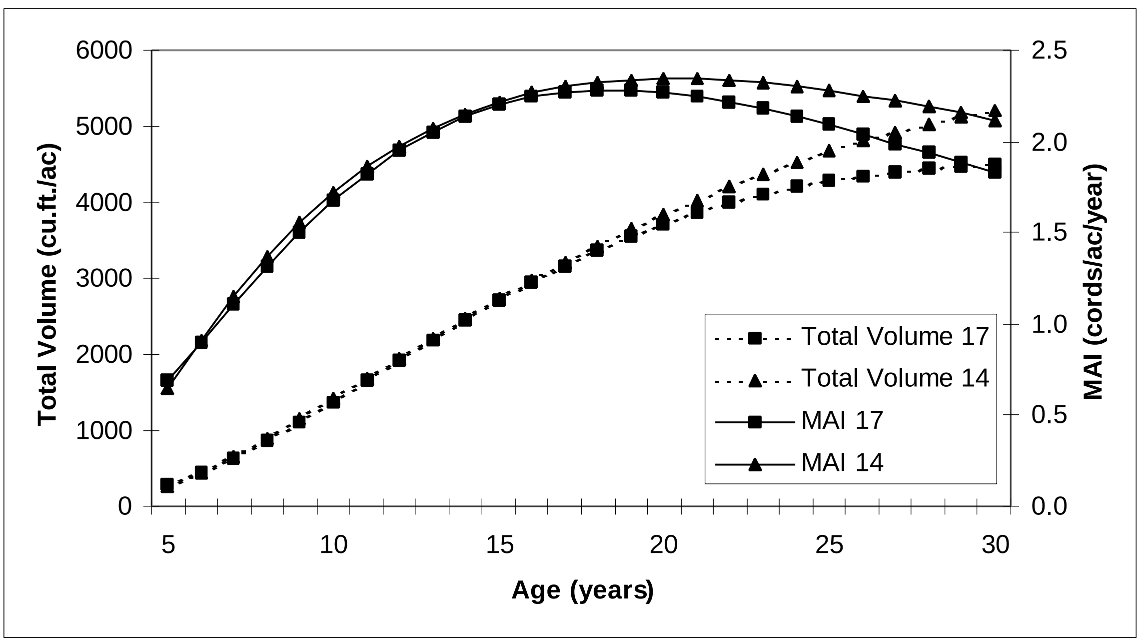

Figure 30. Volume growth and MAI development curves for unfertilized, chop, burn, herbicide and bed site preparation treatments for spodosols.

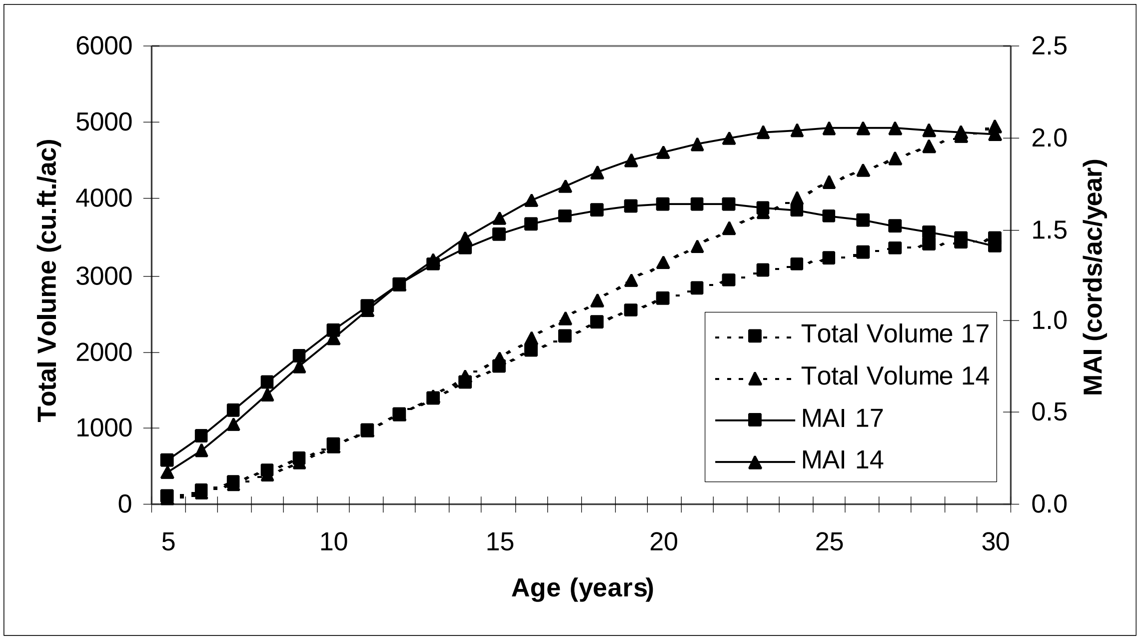

Figure 31. Volume growth and MAI development curves for fertilized, chop and burn site preparation treatments for spodosols.

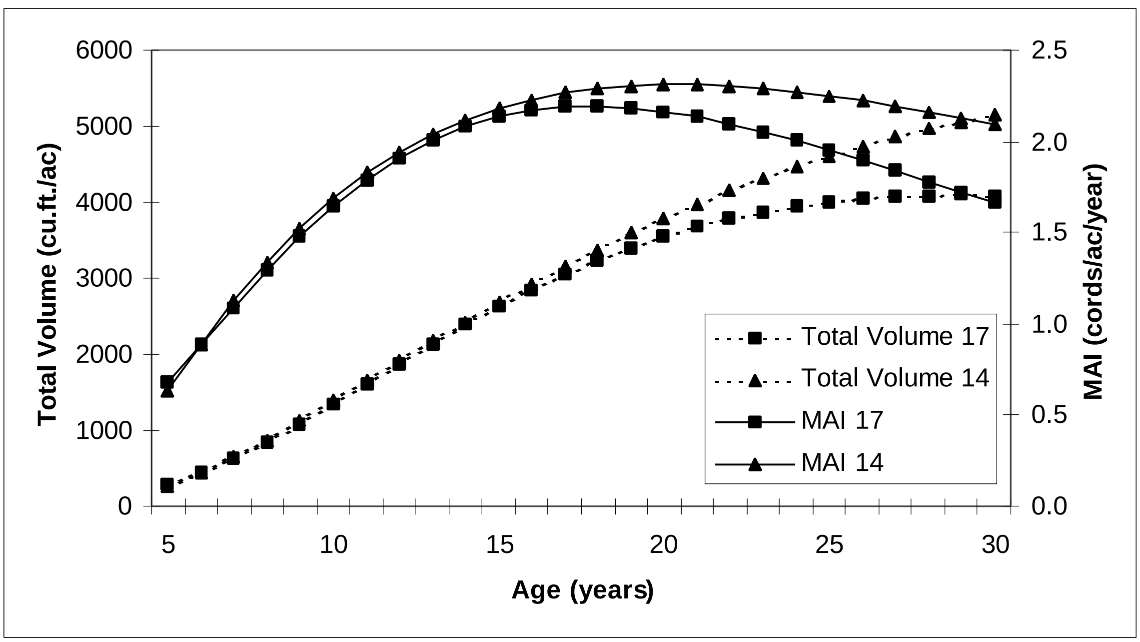

Figure 32. Volume growth and MAI development curves for fertilized, chop, burn and herbicide site preparation treatments for spodosols.

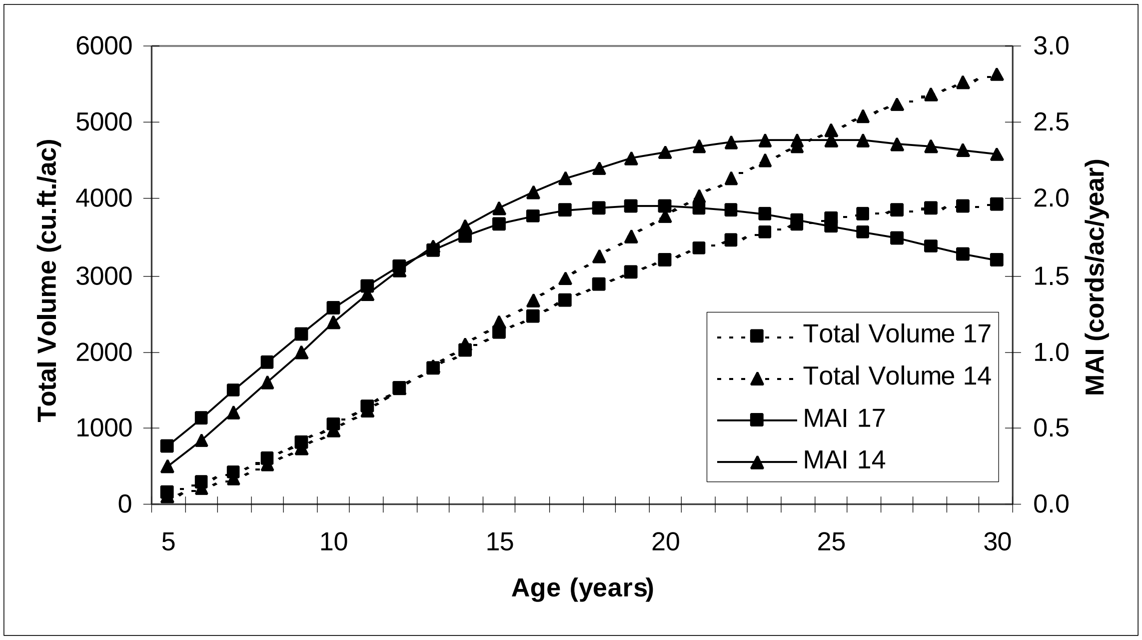

Figure 33. Volume growth and MAI development curves for fertilized, chop, burn and bed site preparation treatments for spodosols.

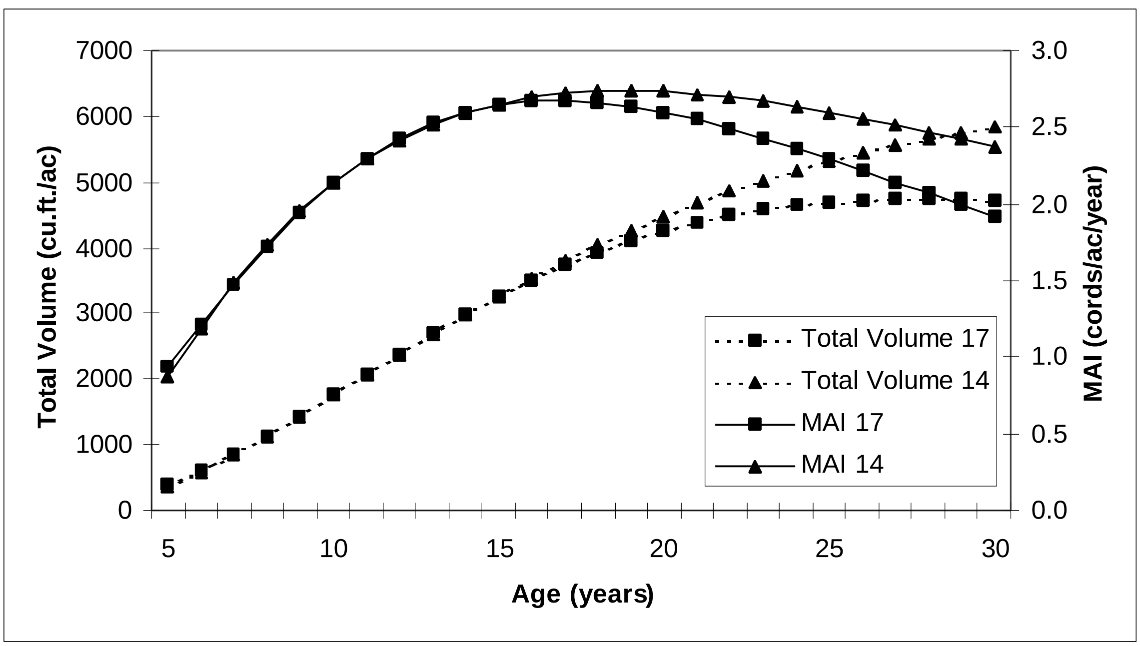

Figure 34. Volume growth and MAI development curves for fertilized, chop, burn, herbicide and bed site preparation treatments for spodosols.

4 ECONOMIC ANALYSIS

Forest managers contemplating the establishment of slash pine plantations in the Southeastern coastal plain should certainly be interested in the economic implications of various site preparation treatments. To address questions concerning the economic feasibility of these treatments, an analysis of bare land values and optimum economic rotation ages was carried out. Yield estimates were calculated using the average dominant height, basal area, total volume and volume breakdown models listed above. Survival was calculated using the equation from Pienaar *et.al*. (1996) and the observed number of trees per acre at age five for each treatment combination. Consequently, the yield estimates for the more intensive treatments, especially those with vegetation control, may be somewhat conservative since survival can be significantly improved with vegetation control (Shiver *et.al*., 1990; Creighton *et.al*., 1987). Initial trees per acre estimates were computed by averaging the survival values at age five for various treatment types including combinations of chop and burn, bedding, fertilization and vegetation control. A one-year regeneration delay was assumed in each case. Product volumes were calculated for pulpwood (trees $ 4” to a 2” top o.b.) and for chip-n-saw (trees $ 8” to a 6” top o.b.). In order to account for some measure of defect in chip-n-saw sized trees, 30% of the chip-n-saw volume was allocated to pulpwood and evaluated accordingly.

Site preparation costs were obtained for the various treatment combinations from Dubois *et.al*. (1997). Pulpwood and chip-n-saw prices were obtained from Timber Mart South (1997). Price levels across the Southeast were lowest in the South Carolina coastal plain and highest in the Georgia coastal plain. The prices from these two regions as well as Southeast-wide averages were used in the analysis. Cost and price data and other economic assumptions are shown in Table 14.

Tables 15-20 show the results of the economic analysis for each combination of discount rate, soil type and stumpage level. The tables include the maximum bare land value (BLV) ($/acre), the age at which it occurs (OER), the harvest income ($/acre) and product volumes (cords/acre) at the optimum economic rotation age. In order to interpret the results of the economic analysis, we rely on the explanation from Clutter *et.al*. (1983). The maximum BLV at the OER implies that, for the given economic conditions, a firm could afford to pay the BLV price level for land that would produce the given level of yield, grow plantations at the optimum rotation age with the specified costs and stumpage values, and earn an inflation-free rate of return equal to the specified discount rate. So, for example, BLV’s which are close to zero imply that, for fee lands, a rate of return close to the discount rate could be achieved by carrying out the given treatments and managing according to the OER under the given yield levels and economic assumptions.

Table 14. Prices, costs and other data used in the economic analysis.

Description	Value
Chop and burn	$ 50.88
Bedding	$ 40.00
Fertilization (site preparation)	$ 59.07
Fertilization (mid-rotation)	$ 54.95
Complete vegetation control	$150.00
Seedlings (@ 545/acre)	$ 34.34
Machine planting	$ 48.69
Annual tax and administration cost	$ 4.50
GA Pulpwood stumpage ($/cord @ 80 ft^3/cord)	$ 48.08
GA Chip-n-saw stumpage ($/cord @ 84 ft^3/cord)	$113.65
SC Pulpwood stumpage ($/cord @ 80 ft^3/cord)	$ 30.22
SC Chip-n-saw stumpage ($/cord @ 84 ft^3/cord)	$ 82.53
Coastal Plain average pulpwood stumpage ($/cord @ 80 ft^3/cord)	$ 38.20
Coastal Plain average chip-n-saw stumpage ($/cord @ 84 ft^3/cord)	$ 87.22
Discount rates (%)	5, 7**2**, 10, 12**2**

Table 15. Economic analysis results for nonspodosols using South Georgia prices (max).

	Unfertilized				Fertilized			
	Ch,Bu	Ch,Bu, He	Ch,Bu, Be	Ch,Bu, He,Be	Ch,Bu	Ch,Bu, He	Ch,Bu, Be	Ch,Bu, He,Be
Results at 5% discount rate								
Max BLV ($/ac)	442	837	822	940	831	965	893	1110
OER (years)	25	20	21	19	21	19	20	19
Income ($/ac)	1924	2747	2401	2907	2504	3028	2627	3431
Pulp (cords/ac)	7.7	20.0	26.7	22.8	24.6	20.8	26.2	23.4
Chip-n-Saw (cords/ac)	16.5	19.0	11.9	19.3	14.1	21.6	14.6	23.4
Results at 7.5% discount rate								
Max BLV ($/ac)	111	256	302	291	296	297	309	353
OER (years)	24	18	20	18	19	18	19	17
Income ($/ac)	1785	2366	2231	2694	2148	2817	2432	2955
Pulp (cords/ac)	7.6	21.0	27.0	23.3	25.3	21.4	26.6	24.6
Chip-n-Saw (cords/ac)	15.1	14.4	9.9	16.7	9.9	19.0	12.3	18.9
Results at 10% discount rate								
Max BLV ($/ac)	-19	11	85	15	73	11	62	29
OER (years)	23	17	18	17	18	17	18	17
Income ($/ac)	1634	2149	1858	2460	1951	2582	2221	2955
Pulp (cords/ac)	7.5	21.4	27.0	23.7	25.4	21.9	26.8	24.6
Chip-n-Saw (cords/ac)	13.6	11.9	6.0	14.0	7.8	16.3	9.9	18.9
Results at 12.5% discount rate								
Max BLV ($/ac)	-78	-110	-21	-123	-37	-132	-59	-134
OER (years)	22	17	17	16	17	16	17	16
Income ($/ac)	1472	2149	1663	2209	1746	2328	1999	2679
Pulp (cords/ac)	7.3	21.4	26.5	24.1	25.3	22.4	26.9	25.1
Chip-n-Saw (cords/ac)	11.9	11.9	4.1	11.2	5.7	13.3	7.5	15.7

Table 16. Economic analysis results for spodosols using South Georgia prices (max).

	Unfertilized				Fertilized			
	Ch,Bu	Ch,Bu, He	Ch,Bu, Be	Ch,Bu, He,Be	Ch,Bu	Ch,Bu, He	Ch,Bu, Be	Ch,Bu, He,Be
Results at 5% discount rate								
Max BLV ($/ac)	481	823	544	1004	631	909	808	1246
OER (years)	26	21	24	20	22	19	21	18
Income ($/ac)	2152	2903	2259	3219	2262	2935	2644	3420
Pulp (cords/ac)	21.7	19.4	25.9	22.3	24.3	20.6	25.8	23.3
Chip-n-Saw (cords/ac)	11.8	21.0	10.8	22.9	11.6	20.7	14.9	24.5
Results at 7.5% discount rate								
Max BLV ($/ac)	132	239	143	316	187	266	261	432
OER (years)	23	19	22	18	20	18	19	17
Income ($/ac)	1745	2510	1957	2767	1947	2762	2276	3167
Pulp (cords/ac)	22.9	20.6	26.5	23.6	24.9	21.1	26.5	23.9
Chip-n-Saw (cords/ac)	6.9	16.1	7.3	17.4	8.0	18.2	10.6	21.5
Results at 10% discount rate								
Max BLV ($/ac)	-3	-4	-15	27	6	-7	34	80
OER (years)	21	18	20	17	19	17	18	16
Income ($/ac)	1457	2291	1640	2515	1777	2497	2074	2888
Pulp (cords/ac)	22.8	21.2	26.2	24.2	24.9	21.6	26.7	24.4
Chip-n-Saw (cords/ac)	3.9	13.5	4.1	14.4	6.2	15.5	8.4	18.2
Results at 12.5% discount rate								
Max BLV ($/ac)	-64	-123	-86	-116	-80	-144	-78	-99
OER (years)	19	17	18	16	18	16	17	15
Income ($/ac)	1180	2061	1329	2249	1602	2249	1863	2587
Pulp (cords/ac)	21.5	21.6	24.5	24.6	24.6	22.1	26.5	24.9
Chip-n-Saw (cords/ac)	1.6	10.9	1.6	11.4	4.5	12.7	6.3	14.8

Table 17. Economic analysis results for nonspodosols using South Carolina prices (min).

	Unfertilized				Fertilized			
	Ch,Bu	Ch,Bu, He	Ch,Bu, Be	Ch,Bu, He,Be	Ch,Bu	Ch,Bu, He	Ch,Bu, Be	Ch,Bu, He,Be
Results at 5% discount rate								
Max BLV ($/ac)	213	349	410	386	406	391	418	454
OER (years)	25	21	22	20	22	20	21	19
Income ($/ac)	1338	1991	1714	2115	1796	2207	1892	2347
Pulp (cords/ac)	7.7	19.5	26.3	22.2	24.1	20.2	2537	23.4
Chip-n-Saw (cords/ac)	16.5	21.0	13.8	21.6	16.0	23.9	16.7	24.6
Results at 7.5% discount rate								
Max BLV ($/ac)	4	3	91	0	79	-6	63	7
OER (years)	25	19	20	19	20	19	20	18
Income ($/ac)	1338	1743	1480	1977	1560	2071	1764	2185
Pulp (cords/ac)	7.7	20.6	27.0	22.8	25.0	20.8	26.2	24.0
Chip-n-Saw (cords/ac)	16.5	16.8	9.9	19.3	12.0	21.6	14.6	21.9
Results at 10% discount rate								
Max BLV ($/ac)	-76	-139	-39	-158	-55	-170	-82	-180
OER (years)	23	18	19	18	19	18	19	17
Income ($/ac)	1132	1599	1350	1823	1427	1918	1624	2004
Pulp (cords/ac)	7.5	21.0	27.1	23.3	25.3	21.4	26.6	24.6
Chip-n-Saw (cords/ac)	13.6	14.4	7.9	16.7	9.9	19.0	12.3	18.9
Results at 12.5% discount rate								
Max BLV ($/ac)	-110	-207	-100	-234	-118	-248	-151	-270
OER (years)	22	17	18	17	18	17	18	17
Income ($/ac)	1018	1443	1214	1655	1286	1750	1473	2004
Pulp (cords/ac)	7.3	21.4	27.0	23.7	25.4	21.9	26.8	24.6
Chip-n-Saw (cords/ac)	11.9	11.9	6.0	14.0	7.8	16.3	9.9	18.9

Table 18. Economic analysis results for spodosols using South Carolina prices (min).

	Unfertilized				Fertilized			
	Ch,Bu	Ch,Bu, He	Ch,Bu, Be	Ch,Bu, He,Be	Ch,Bu	Ch,Bu, He	Ch,Bu, Be	Ch,Bu, He,Be
Results at 5% discount rate								
Max BLV ($/ac)	223	349	231	437	272	354	361	547
OER (years)	27	22	25	21	23	20	22	19
Income ($/ac)	1534	2112	1605	2343	1614	2141	1894	2502
Pulp (cords/ac)	21.2	18.7	25.4	21.6	23.9	20.0	25.3	22.6
Chip-n-Saw (cords/ac)	13.4	23.1	12.5	25.3	13.3	23.0	16.9	27.2
Results at 7.5% discount rate								
Max BLV ($/ac)	7	-5	-11	21	6	-26	31	59
OER (years)	24	20	23	19	21	19	20	18
Income ($/ac)	1251	1851	1397	2044	1402	2006	1650	2340
Pulp (cords/ac)	22.6	20.0	26.3	23.0	24.7	20.6	26.2	23.3
Chip-n-Saw (cords/ac)	8.5	18.6	9.0	20.2	9.8	20.7	12.8	24.5
Results at 10% discount rate								
Max BLV ($/ac)	-74	-147	-103	-149	-99	-182	-102	-146
OER (years)	23	19	22	18	20	18	19	17
Income ($/ac)	1150	1703	1286	1874	1286	1855	1514	2157
Pulp (cords/ac)	22.9	20.6	26.5	23.6	24.9	21.1	26.5	23.9
Chip-n-Saw (cords/ac)	6.9	16.1	7.3	17.4	8.0	18.2	10.6	21.5
Results at 12.5% discount rate								
Max BLV ($/ac)	-108	-214	-142	-229	-146	-257	-164	-247
OER (years)	21	18	20	17	19	17	18	16
Income ($/ac)	946	1545	1062	1692	1165	1690	1369	1957
Pulp (cords/ac)	22.8	21.2	26.2	24.2	24.9	21.6	26.7	24.4
Chip-n-Saw (cords/ac)	3.9	13.5	4.1	14.4	6.2	15.5	8.4	18.2

Table 19. Economic analysis results for nonspodosols using coastal plain average prices.

	Unfertilized				Fertilized			
	Ch,Bu	Ch,Bu, He	Ch,Bu, Be	Ch,Bu, He,Be	Ch,Bu	Ch,Bu, He	Ch,Bu, Be	Ch,Bu, He,Be
Results at 5% discount rate								
Max BLV ($/ac)	274	498	552	554	548	561	574	651
OER (years)	25	20	21	20	21	19	21	19
Income ($/ac)	1493	2142	1882	2415	1960	2359	2192	2673
Pulp (cords/ac)	7.7	20.0	26.7	22.2	24.6	20.8	25.7	23.4
Chip-n-Saw (cords/ac)	16.5	19.0	11.9	21.6	14.1	21.6	16.7	24.6
Results at 7.5% discount rate								
Max BLV ($/ac)	33	83	167	92	154	87	147	114
OER (years)	24	19	20	18	20	18	19	18
Income ($/ac)	1386	2003	1751	2104	1828	2197	1906	2500
Pulp (cords/ac)	7.6	20.6	27.0	23.3	25.0	21.4	26.6	24.0
Chip-n-Saw (cords/ac)	15.1	16.8	9.9	16.7	12.0	19.0	12.3	21.9
Results at 10% discount rate								
Max BLV ($/ac)	-60	-90	-8	-102	-9	-113	-31	-113
OER (years)	23	18	18	17	18	17	18	17
Income ($/ac)	1269	1849	1464	1924	1533	2017	1743	2307
Pulp (cords/ac)	7.5	21.0	27.0	23.7	25.4	21.9	26.8	24.6
Chip-n-Saw (cords/ac)	13.6	14.4	6.0	14.0	7.8	16.3	9.9	18.9
Results at 12.5% discount rate								
Max BLV ($/ac)	-101	-174	-69	-197	-88	-211	-117	-225
OER (years)	22	17	17	16	17	16	17	16
Income ($/ac)	1144	1682	1312	1731	1375	1821	1572	2095
Pulp (cords/ac)	7.3	21.4	26.5	24.1	25.3	22.4	26.9	25.1
Chip-n-Saw (cords/ac)	11.9	11.9	4.1	112	5.7	13.3	7.5	15.7

Table 20. Economic analysis results for spodosols using coastal plain average prices.

	Unfertilized				Fertilized			
	Ch,Bu	Ch,Bu, He	Ch,Bu, Be	Ch,Bu, He,Be	Ch,Bu	Ch,Bu, He	Ch,Bu, Be	Ch,Bu, He,Be
Results at 5% discount rate								
Max BLV ($/ac)	310	489	339	606	394	517	509	751
OER (years)	26	21	24	20	22	19	21	18
Income ($/ac)	1685	2261	1771	2508	1772	2287	2068	2664
Pulp (cords/ac)	21.7	19.4	25.9	22.3	24.3	20.6	25.8	23.3
Chip-n-Saw (cords/ac)	11.8	21.0	10.8	22.9	11.6	20.7	14.9	24.5
Results at 7.5% discount rate								
Max BLV ($/ac)	52	69	45	113	70	63	110	172
OER (years)	23	20	22	19	21	18	20	17
Income ($/ac)	1372	2117	1539	2342	1655	2127	1933	2470
Pulp (cords/ac)	22.9	20.0	26.5	23.0	24.7	21.1	26.2	23.9
Chip-n-Saw (cords/ac)	6.9	18.6	7.3	20.2	9.8	18.2	12.8	21.5
Results at 10% discount rate								
Max BLV ($/ac)	-46	-102	-69	-92	-60	-127	-53	-76
OER (years)	21	18	20	18	19	17	18	16
Income ($/ac)	1150	1791	1294	2161	1398	1950	1629	2255
Pulp (cords/ac)	22.8	21.2	26.2	23.6	24.9	21.6	26.7	24.4
Chip-n-Saw (cords/ac)	3.9	13.5	4.1	17.4	6.2	15.5	8.4	18.2
Results at 12.5% discount rate								
Max BLV ($/ac)	-90	-184	-119	-192	-121	-220	-132	-200
OER (years)	19	17	18	17	18	16	17	15
Income ($/ac)	934	1614	1053	1967	1263	1760	1466	2023
Pulp (cords/ac)	21.5	21.6	24.5	24.2	24.6	22.1	26.5	24.9
Chip-n-Saw (cords/ac)	1.6	10.9	1.6	14.4	4.5	12.7	6.3	14.8

5 DISCUSSION AND 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. Due to some dramatic differences in growth reported on early in the life of the study, it has been followed with great interest. The question has always been “will the growth responses due to intensive management be sustained or will they diminish or increase?”. In order to address this question, analysis of variance and orthogonal contrasts were carried out on the age 17 data. In addition to this analysis, the data from ages five through 17 were used to develop yield prediction models that account for different site preparation treatments. For both the analysis of variance and the modeling effort, differences between spodosols and nonspodosols were examined.

Analysis of variance was conducted to evaluate the effects of chopping, burning, bedding, fertilization and vegetation control on average tree height, average dbh, average crown length and average crown ratio. Site preparation treatment was found to be the only significant source of variation. Soil group was not significant and there were no soil group x treatment interactions.

Chopping had no significant effect of any of the average individual tree characteristics while burning had a significant, positive impact on average tree height. Bedding significantly increased average height but had a negative effect on crown length and crown ratio. Vegetation control and fertilization significantly increased average height, dbh and crown length. Both treatments had a negative impact on average crown ratio but there was, in general, very little variation in crown ratio throughout the study.

As has been reported in other studies, treatments that promoted rapid height growth tended to result in higher rates of cronartium infection. The vegetation control treatment had the only significant effect on cronartium infection, increasing the rate by 7%.

In order to examine, albeit indirectly, the effect of treatments on survival patterns and diameter distributions, analysis of variance was carried out on per-acre stand characteristics including basal area, total volume and merchantable volume. Site preparation treatment affected each of these measures. In addition, significant interactions between treatment and soil group were found in some cases.

The same pattern of significant effects was observed for each of the whole-stand variables. On nonspodosols, burning, bedding, fertilization and vegetation control significantly increased per-acre basal area and volume. Similar results were found for spodosols with the exception of burning which had no significant impact. In general, without vegetation control and fertilization, the nonspodosols appeared to be the most productive sites. When vegetation control was applied, however, the spodosols were superior.

The slash pine site preparation study data through age 17 were used to develop a set of growth and yield models for spodic and nonspodic soil groups. Existing model forms were modified to account for the cumulative responses due to various site preparation treatments. Average dominant / codominant height growth was modeled with a Chapman-Richards equation including response variables for chopping, burning, bedding, fertilization and vegetation control. The average residual (observed – predicted) over all treatments was approximately –0.3 feet for both soil groups.

A stand-level basal area prediction model was fit to the slash pine data. Treatment effects were accounted for to some extent since the model includes average dominant / codominant height as a predictor variable. Additional response terms were required, however, including terms for fertilization and vegetation control for spodosols and vegetation control for nonspodosols. Average residuals were 2.0 ft^2/ac and 1.4 ft^2/ac for nonspodosols and spodosols, respectively.

A per-acre total volume prediction equation was fit to the slash pine site preparation study data for both soil groups. Since the average dominant / codominant height and per-acre basal area are included in the prediction model, no additional adjustments were necessary to account for site preparation treatment effects. For nonspodosols, the average residual over all treatments was 19 ft^3/ac using observed height, number of trees and basal area and 8 ft^3/ac when the dominant height and basal area were predicted. For spodosols, the average residuals were 18 ft^3/ac and 64 ft^3/ac using observed and predicted values, respectively.

An existing product breakdown equation developed from slash pine growth and yield plots was tested against the site preparation study data. The model was found to be almost completely, positively biased for chip-n-saw product volumes. For this reason, the model was fit to the site preparation data. The resulting model contains no specific provisions for soil type or treatment but residual analysis revealed no problems in product volume predictions across soil and treatment groups.

The set of models developed from the data through age 17 (1998) were graphically compared to models developed previously where the oldest age was 14 years (1994). A common survival prediction equation was used for both model systems. The two sets of models showed similar trends through age 17. Most of the differences in the predicted volume and MAI development curves occurred after extrapolation past the range of ages in the input data.

For nonspodosols, treatments including bedding and/or vegetation control had similar volume growth and MAI development curves through age 20. After age 20, however, the 1998 models showed a slower growth rate than the 1994 models. For the chop and burn treatment, the 1998 model showed an MAI culmination age at least seven years prior to the MAI culmination predicted by the 1994 model. These trends are similar for fertilized and unfertilized treatments.

For spodosols, treatments including vegetation control had very similar growth curves but other treatment groups had more disparate curves compared to nonspodosols. By age 30, the 1998 models showed approximately 30% less total volume than the 1994 models for treatments including chopping, burning and bedding only. The same trends were observed for fertilized and unfertilized treatments.

In order to evaluate the feasibility and/or desirability of various site preparation treatment combinations, an economic analysis was conducted. Bare land values, optimum economic rotation age, timber income and product volumes were reported for eight treatment groups, four discount rates, three price levels and two soil groups. In general, the trends in the economic analysis results are reasonable according to accepted principles. The bare land values increase with increasing price level and decrease with increasing discount rate. The optimum economic rotation ages decrease with increasing discount rate, management intensity and stumpage price level.

For nonspodosols at all price levels, the most intensive site preparation treatment (chop, burn, bed, fertilize, herbicide) had the highest bare land value at only the lowest discount rate (5%). In most other cases, the unfertilized, chop, burn and bed treatment had the highest bare land values.

For spodosols, the most intensive site preparation treatment resulted in the highest bare land value for all price levels at discount rates of 5% and 7.5%. In most other cases, the least intensive treatment (unfertilized, chop, burn) resulted in the highest bare land value.

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