PIEDMONT LOBLOLLY PINE SITE PREPARATION STUDY:

RESULTS THROUGH AGE 15

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PMRC Technical Report 2002 - 3
April 16, 2002

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1 INTRODUCTION

The successful establishment and subsequent growth of loblolly pine plantations begins with site preparation. Site preparation treatments are designed to dispose of debris, reduce competition and prepare the soil for planting (Smith, 1962). Decisions regarding site preparation methods have consequences that will last throughout the life of a plantation. Since site preparation costs must be capitalized and therefore carried through the rotation, it is important to justify these compounded expenses in terms of future revenue. Reliable information on the effects of site preparation on survival and growth are required to evaluate the future value of different silvicultural systems.

In 1986, the Plantation Management Research Cooperative (PMRC) at the University of Georgia established a study to evaluate the effects of various mechanical and chemical site preparation methods on the growth and yield of loblolly pine plantations (*Pinus taeda* L.) in the southeastern Piedmont region. The data from this study will also be used in the development of plantation growth and yield models that will account for the effects of site preparation on survival and growth.

2 STUDY DESCRIPTION

The SAGS Site Preparation Study was installed at 25 locations throughout the Piedmont and upper coastal plain regions of South Carolina, Georgia and Alabama. The existing stand at each location was harvested in 1984 and scheduled for planting during the 1985-1986 planting season. Sites were selected to ensure reasonable uniformity in site quality and competing vegetation characteristics across the study area. At each location, seven ½ acre plots were established, each with an interior 1/5 acre measurement plot. One of the following six site preparation treatments was randomly assigned to each plot:

- Burn (B): Broadcast burn in August.
- Chop and burn (C&B): Single pass with a drum roller chopper in June followed by a broadcast burn in August.
- Shear, pile and disk (S,P&D): Sheared with KG blade. The site was flat harrowed in June following debris removal.
- Chop, herbicide and burn (C,H&B): Single pass with a drum roller chopper in June followed by a broadcast herbicide treatment of 3% Roundup® in August after hardwood resprouting. A broadcast burn was carried out one month later.

- Herbicide and burn (H&B): Chemical site preparation treatment consisting of 20 pounds of Tordon® 10K and 20 pounds Pronone® per acre applied in April, followed by a broadcast burn in August.
- Herbicide, burn, herbicide (H,B&H): Same as treatment #5, but followed up annually with directed spraying to eliminate all competing vegetation throughout the life of the study.

To account for the error within locations, one of the treatments was replicated at each installation.

The plots were hand planted with first-generation, improved planting stock during the winter of 1985-1986 at an 8' x 10' spacing. Two seedlings were planted at each planting spot and, if both survived after the first growing season, one was subsequently eliminated. This resulted in reasonably uniform stocking of 545 trees per acre across all installations.

Analysis of the age 12 SAGS site preparation data indicated the need for fertilization. At first, it was proposed that the study be divided into paired sites where the response to mid-rotation fertilization could be assessed. This idea was abandoned, however, due to concerns over the statistical validity of the remaining measurements. The decision was made to fertilize all plots in the study using an "industry standard" prescription of 200 lbs N/acre and 25 lbs P/acre. This treatment was carried out prior to the 14th growing season using 125 lbs/acre DAP and 385 lbs/acre Urea.

3 MEASUREMENTS AND RESULTS

After the third growing season, tree heights were measured, crown class was recorded and all trees were examined for the incidence of fusiform rust (*Cronartium quercum* f.sp. *fusiforme*). After the sixth, ninth, twelfth and fifteenth growing season, Dbh's of all trees were recorded and heights were measured on every other tree. A height/diameter regression equation was fit to the data for each plot at each measurement age:

$$\ln(H) = a + b\,\frac{1}{Dbh} \qquad \textbf{(1)}$$

where *H* = tree height,

Dbh = tree Dbh,

a,ß = parameters estimated from each plot at each age.

The height/diameter equation was used to estimate the heights of trees not measured for volume and weight calculations. Total and merchantable (3-inch top) outside bark volumes and green weights were calculated using the equations from Pienaar *et al*. (1987).

Analysis of variance was used to detect significant differences between site preparation treatments. To ensure the statistical validity of region-wide inferences and to allow for the unbalanced design, a mixed model approach was used. The location and location x treatment interaction were treated as random factors since each location can be considered as part of a random sample of all possible locations (Parrish and Ware, 1989).

Analyses were carried out on average Dbh, average height, per-acre basal area, per-acre total and merchantable volumes, survival, percent rust infection, Dbh distribution range, Dbh distribution skewness and Dbh distribution kurtosis. Orthogonal contrasts were used to isolate the effects of particular site preparation treatments. Differences among treatments are reported in terms of least-squares means. All statistical tests were conducted at the a=0.05 significance level.

Table 1 shows the degrees of freedom, F statistics and resulting p-values for each of the dependent variables for the age 15 data. The F statistic pertains to the test of the main effect, site preparation treatment.

Table 1. Type III tests of site preparation treatment for each dependent variable. Significant effects are marked with *.

Dependent Variable	Numerator df	Denominator df	Type III F	Pr > F
Average Dbh*	5	107	35.58	0.0001
Range in Dbh	5	113	1.18	0.3227
Dbh Skewness*	5	107	5.57	0.0001
Dbh Kurtosis	5	112	0.74	0.5951
Average Height*	5	103	43.13	0.0001
Basal Area*	5	108	12.07	0.0001
Total Volume*	5	107	23.33	0.0001
Merch. Volume*	5	107	24.02	0.0001
Trees per acre*	5	106	9.64	0.0001
Percent rust	5	104	2.17	0.0626

3.1 Average Dbh

Table 1 shows that site preparation significantly affected average Dbh. Average Dbh values for ages 6, 9, 12 and 15 years are shown by treatment in Figure 1. The addition of a chop treatment (C&B) increased average Dbh by 0.95” over the burn only treatment (B). The addition of a herbicide treatment (H&B) increased average Dbh by 1.25" over burn only (B). The operational chemical site preparation treatment (H&B) increased average Dbh by 0.26" over the average of mechanical treatments (C&B, S,P&D). Complete vegetation control (H,B&H), in addition to the operational chemical site preparation treatment (H&B) increased average Dbh by 0.7". Table 2 shows a summary of arithmetic mean Dbh's by treatment and age.

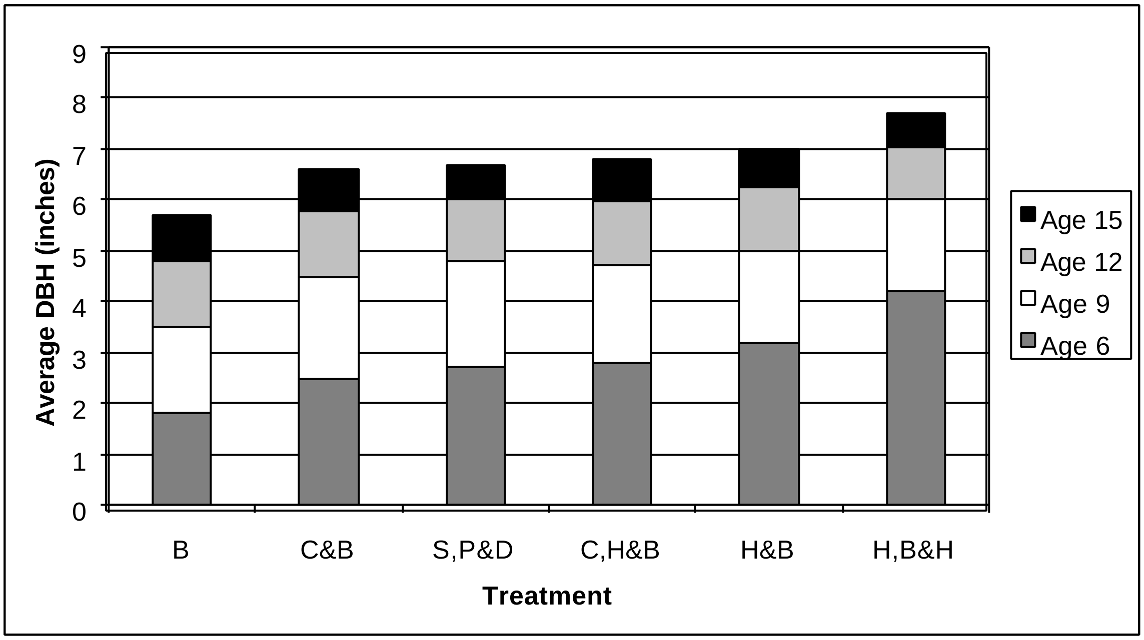

Figure 1. Least-squares means for Dbh (inches) by age and treatment.

Table 2. Arithmetic means and coefficients of variation (CV) by treatment and age for average Dbh (inches).

Treatment	Age 6		Age 9		Age 12		Age 15	
	Mean	CV %	Mean	CV %	Mean	CV %	Mean	CV %
B	1.8	35.8	3.5	28.2	4.8	23.8	5.7	19.4
C&B	2.5	23.5	4.5	13.3	5.8	9.6	6.6	8.2
S,P&D	2.7	27.1	4.8	16.8	6.0	12.1	6.7	10.5
C,H&B	2.8	21.6	4.7	12.8	6.0	8.6	6.8	7.3
H&B	3.2	17.1	5.0	11.1	6.3	8.9	7.0	8.3
H,B&H	4.2	12.7	6.0	10.8	7.0	9.8	7.7	9.8

3.2 Dbh Distributions

Differences in diameter distributions among treatments were examined using the range, skewness and kurtosis statistics. The range is indicative of the overall spread of the Dbh distribution and is calculated as the difference between the maximum and minimum Dbh's. Range was not significantly affected by site preparation treatment. Skewness measures the tendency of a distribution to lack symmetry or to be more spread out on one side than the other. Positive skewness indicates that values located to the right of the mean are more spread out than are values located to the left of the mean. Negative skewness indicates the opposite. The burn only treatment (B) was the only treatment to exhibit positive skewness. Contrast analysis indicated that the addition of chopping (C&B) and a herbicide treatment (H&B) in addition to burning resulted in negative skewness significantly different from the burn only treatment (B). Kurtosis is a measure of the heaviness of the tails of a distribution, with larger values indicating heavier tails. There were no significant differences detected in Dbh distribution kurtosis due to site preparation treatment.

3.3 Average Height

For each treatment, average heights were computed from all trees measured for total height. Average height tended to increase with the intensity of site preparation treatments. Chopping in addition to burning (C&B) increased average height by 5.6' over burn only (B). The operational brown and burn treatment (H&B) increased average height by 2.1' over the average of mechanical treatments (C&B, S,P&D) and by 8.2' over the burn only treatment (B). The addition of complete vegetation control (H,B&H) increased average height by 4.2' over the operational brown and burn treatment (H&B). Least squares means for average height by age and treatment are shown in Figure 2. Arithmetic means and CV's are summarized in Table 3.

Table 3. Arithmetic means and coefficients of variation (CV) by treatment and age for average height (feet).

Treatment	Age 6		Age 9		Age 12		Age 15	
	Mean	CV %	Mean	CV %	Mean	CV %	Mean	CV %
B	12.6	23.8	21.7	22.7	32.0	21.6	39.2	17.6
C&B	15.2	19.6	25.8	16.0	36.9	13.9	44.8	12.6
S,P&D	16.1	22.3	26.7	17.8	37.8	15.1	45.3	14.0
C,H&B	16.5	18.3	27.2	15.1	38.3	12.6	46.2	11.3
H&B	18.1	16.2	29.2	12.8	40.0	11.6	47.8	9.8
H,B&H	21.6	14.2	33.0	11.6	43.7	10.5	51.4	10.6

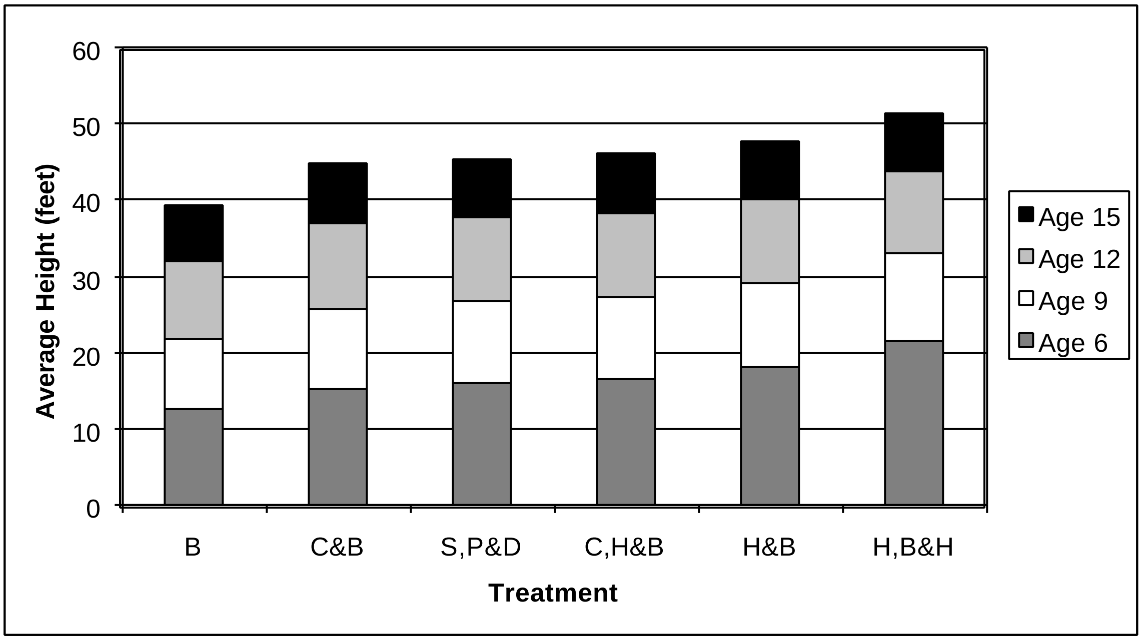

Figure 2. Least-squares means for average height (feet) by age and treatment.

3.4 Per-Acre Basal Area

Site preparation treatment significantly affected per-acre basal area. Chopping and burning increased basal area by 23 ft^2/ac over burning only. There was no significant difference in basal area between the operational brown and burn treatment and the average of the mechanical treatments. The addition of a herbicide treatment increased basal area by 39.7 ft^2/ac over the burn only treatment. Complete vegetation control increased basal area by 24.3 ft^2/ac over the operational chemical site preparation treatment. Arithmetic means by age and treatment are shown in Table 4. Least squares mean basal areas are illustrated in Figure 3.

Table 4. Arithmetic means and coefficients of variation (CV) by treatment and age for basal area (ft^2/ac).

Treatment	Age 6		Age 9		Age 12		Age 15	
	Mean	CV %	Mean	CV %	Mean	CV %	Mean	CV %
B	9.9	72.8	31.9	53.3	55.4	48.3	86.6	75.6
C&B	17.7	52.6	52.6	35.1	84.2	26.4	110.1	22.9
S,P&D	22.7	53.2	63.6	36.2	98.3	27.4	121.7	22.6
C,H&B	22.9	49.4	61.1	34.7	93.3	26.8	118.3	23.4
H&B	29.8	38.5	70.4	25.8	103.8	19.7	128.2	16.4
H,B&H	48.6	29.8	96.4	22.6	127.0	19.7	149.4	18.1

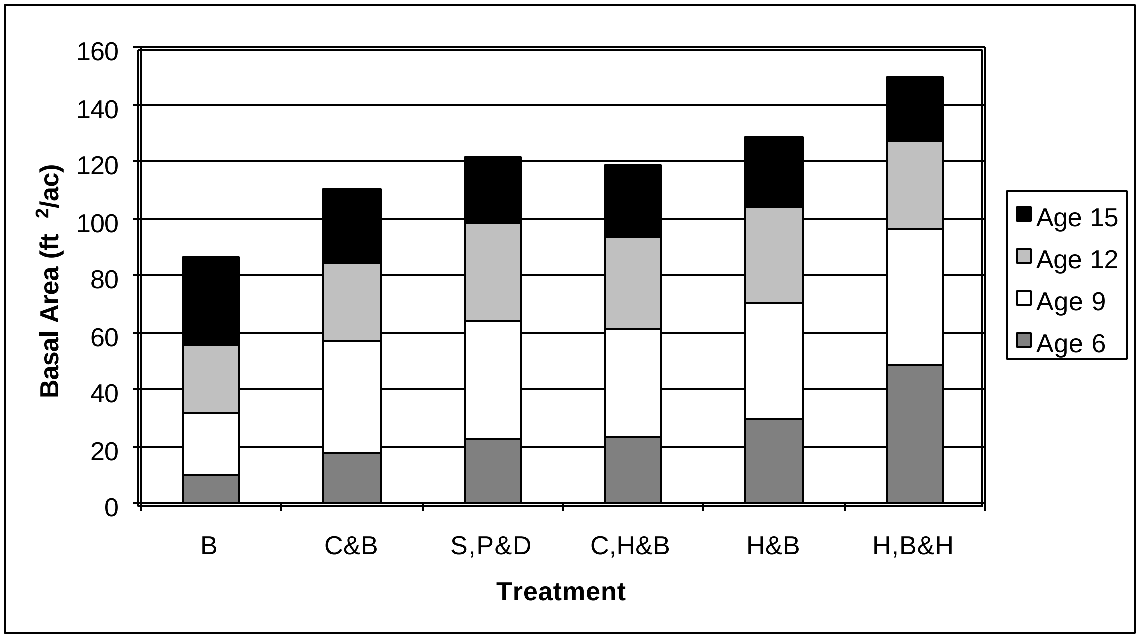

Figure 3. Least-squares means for basal area (ft^2/ac) by age and treatment.

3.5 Per-Acre Total Volume

Total volume increased with increasing intensity of the site preparation treatment. Total volumes ranged from 1739 ft^3/ac for the burn only treatment to 3647 ft^3/ac for the complete vegetation control treatment. The addition of the chop treatment increased total volume by 649 ft^3/ac and the addition of the herbicide treatment increased total volume by 1131 ft^3/ac over the burn only treatment. Complete vegetation control increased total volume by 777 ft^3/ac over the operational chemical site preparation treatment. The contrast analysis detected no significant difference between the operational chemical and mechanical treatments. Mean total volumes and CV's are shown in Table 5 and least squares means are illustrated in Figure 4 by age and treatment.

Table 5. Arithmetic means and coefficients of variation (CV) by treatment and age for total volume (ft^3/ac).

Treatment	Age 6		Age 9		Age 12		Age 15	
	Mean	CV %	Mean	CV %	Mean	CV %	Mean	CV %
B	88	81.2	416	63.9	976	57.7	1737	72.2
C&B	172	62.6	739	45.3	1569	35.1	2403	30.6
S,P&D	229	63.9	912	46.1	1864	36.8	2683	31.8
C,H&B	232	61.5	891	44.7	1793	34.9	2643	30.4
H&B	318	49.8	1070	34.4	2047	27.3	2934	23.5
H,B&H	571	37.7	1576	28.6	2652	25.4	3593	25.1

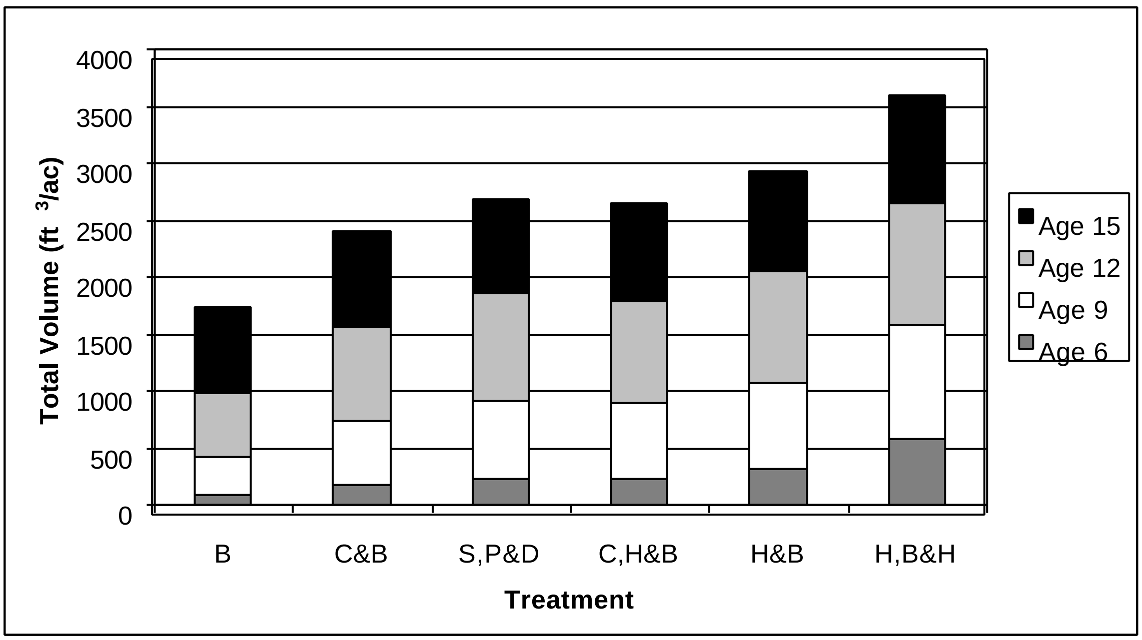

Figure 4. Least-squares means for total volume (ft^3/ac) by age and treatment.

3.6 Per-Acre Merchantable Volume

The results for merchantable volume were essentially the same as for total volume. Chop and burn increased merchantable volume by 655 ft^3/ac over burning only. The herbicide and burn treatment increased merchantable volume by 1131 ft^3/ac over the burn only treatment. Complete vegetation control resulted in an increase of 791 ft^3/ac over the herbicide and burn treatment. Table 6 shows the arithmetic mean merchantable volumes and least squares means are illustrated in Figure 5.

Table 6. Arithmetic means and coefficients of variation (CV) by treatment and age for merchantable volume (ft^3/ac).

Treatment	Age 6		Age 9		Age 12		Age 15	
	Mean	CV %	Mean	CV %	Mean	CV %	Mean	CV %
B	30	132	276	88	846	65	1614	77
C&B	48	108	593	56	1445	37	2282	32
S,P&D	91	102	768	57	1740	39	2561	33
C,H&B	80	134	751	53	1669	37	2542	31
H&B	121	117	929	40	1919	29	2810	24
H,B&H	429	48	1472	31	2546	26	3486	26

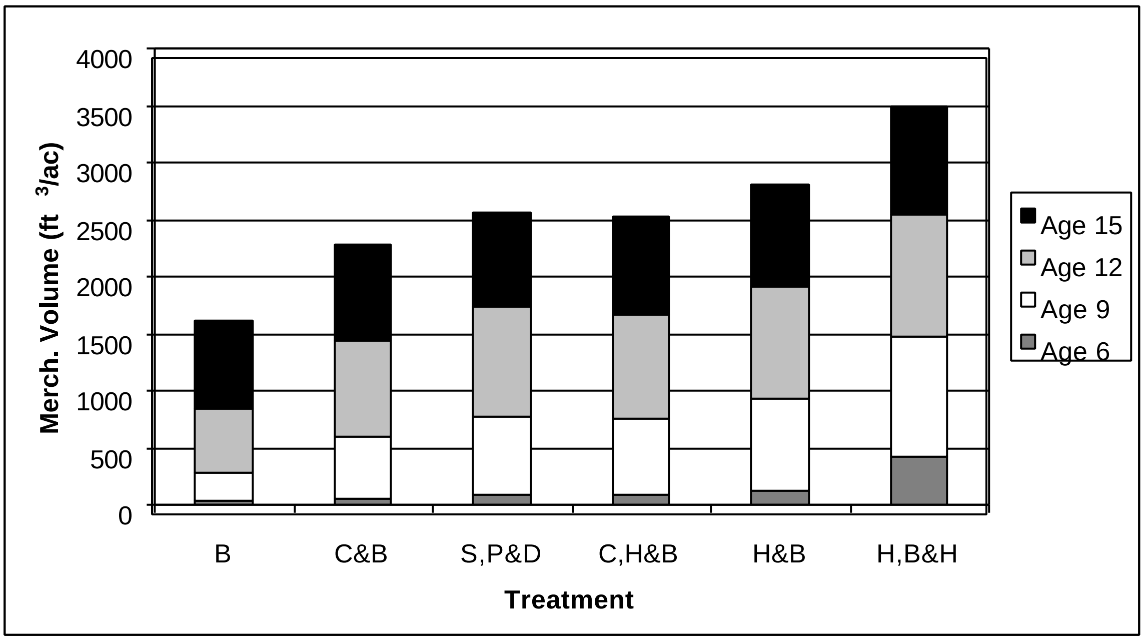

Figure 5. Least-squares means for merchantable volume (ft^3/ac) by age and treatment.

3.7 Trees Per Acre

Site preparation treatment was found to significantly affect survival. Average trees per acre ranged from 354 for the burn only treatment to 464 for the most intensive mechanical treatment (S,P&D). The contrast analysis indicated significant survival differences due to chopping (61 trees per acre) and a herbicide application (94 trees per acre) over the burn only treatment. Arithmetic mean trees per acre and CV's are shown in Table 7. Survival trends by treatment over time are illustrated in Figure 6.

Table 7. Arithmetic means and coefficients of variation (CV) by treatment and age for trees per acre.

Treatment	Age 6		Age 9		Age 12		Age 15	
	Mean	CV %	Mean	CV %	Mean	CV %	Mean	CV %
B	370	29.1	368	27.3	358	30.7	353	30.6
C&B	434	18.8	426	17.5	421	17.8	417	18.0
S,P&D	471	16.0	471	15.4	467	15.2	465	15.0
C,H&B	452	18.9	444	19.4	438	19.6	432	20.7
H&B	473	13.4	463	14.1	455	15.7	450	15.2
H,B&H	470	15.3	467	15.2	455	15.1	450	14.7

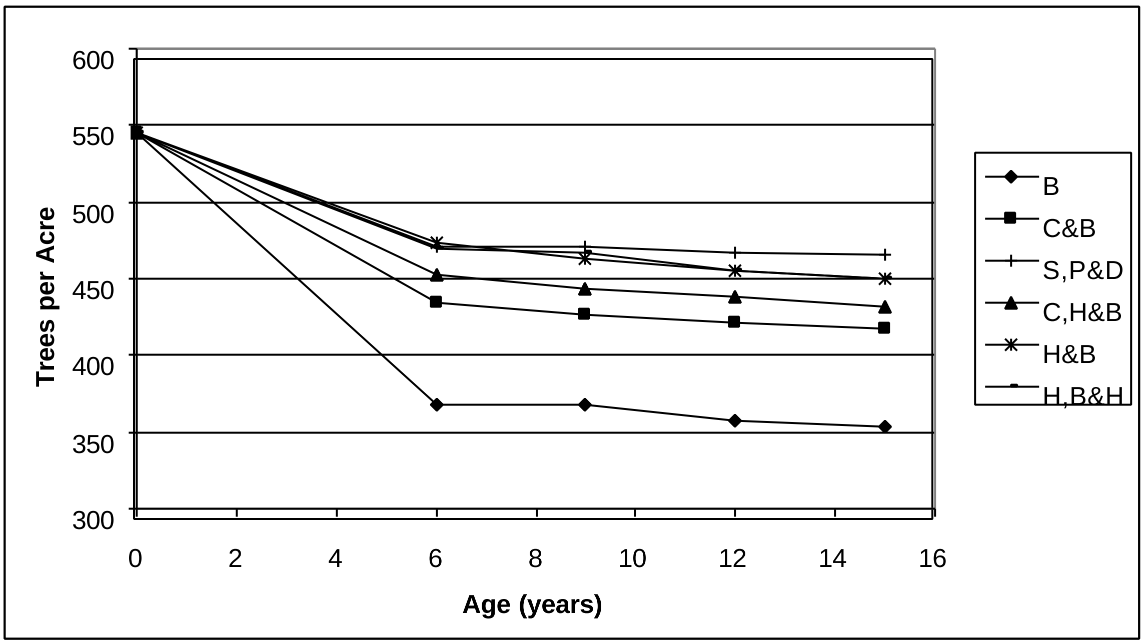

Figure 6. Survival trends over time by treatment. Trees per acre values are least squares means.

3.8 Percent Rust Infection

There were no significant differences detected among site preparation treatments for percent rust infection. Infection rates were moderate, ranging from 10.3% for the H&B treatment to 14.7% for the H,B&H treatment. Many studies have shown that percent rust infection tends to increase when treatments that result in accelerated height growth are applied (Zutter *et al.,* 1987; Shiver and Harrison, 2000). Although the most intensive site preparation treatment did have the highest infection rate, the fact that the study was planted with improved loblolly pine seedlings may account for the lack of significant differences in percent rust infection. Table 8 shows the arithmetic means and CV's by age and treatment for percent rust infection.

Table 8. Arithmetic means and coefficients of variation (CV) by treatment and age for percent rust infection.

Treatment	Age 6		Age 9		Age 12		Age 15	
	Mean	CV %	Mean	CV %	Mean	CV %	Mean	CV %
B	8.7	80	6.5	90	10.8	94	14.0	82
C&B	6.4	123	5.0	102	9.4	105	11.7	91
S,P&D	6.1	114	4.8	142	8.4	120	11.3	95
C,H&B	6.9	147	6.9	137	12.7	94	13.9	93
H&B	4.0	96	4.2	101	8.7	108	10.3	86
H,B&H	5.9	133	5.7	130	12.4	102	14.7	91

4 THREE-YEAR PERIODIC GROWTH

An analysis was carried out to examine the periodic growth between ages 6-9, 9-12 and 12–15 years in terms of average Dbh, average height, per-acre basal area, per-acre total volume and per-acre merchantable volume. The objective was to determine if the differences among treatments are increasing, decreasing or maintaining the same trends over time. Note that the more intensive treatment plots are further along in stand development. The growth on these plots should, therefore, be slowing down in comparison to the less intensive treatment plots.

4.1 Periodic Average Dbh Growth

The average Dbh growth values by treatment and growth period are shown in Table 9 and illustrated in Figure 7. There were no significant differences in average Dbh growth between the burn only treatment and the most intensive treatment (H,B&H) during the 6-9 year period. For the 9-12 year period, all treatments except H&B and H,B&H had the same DBh growth of 1.3". For both periods between 9 and 15 years, the most intensive treatment grew significantly less than all other treatments.

Table 9. Average Dbh growth (inches) by period and treatment. Different letters indicate significant differences between site preparation treatments.

Period	B	C&B	S,P&D	C,H&B	H&B	H,B&H
6 to 9	1.7 (a)	2.0 (b)	2.1 (b)	2.0 (b,d)	1.8 (c,d)	1.8 (a,c)
9 to 12	1.3 (a)	1.3 (a)	1.3 (a,b)	1.3 (a,b)	1.2 (b)	1.0 (c)
12 to 15	1.0 (a)	0.9 (b)	0.8 (b)	0.9 (b)	0.8 (b)	0.6 (c)

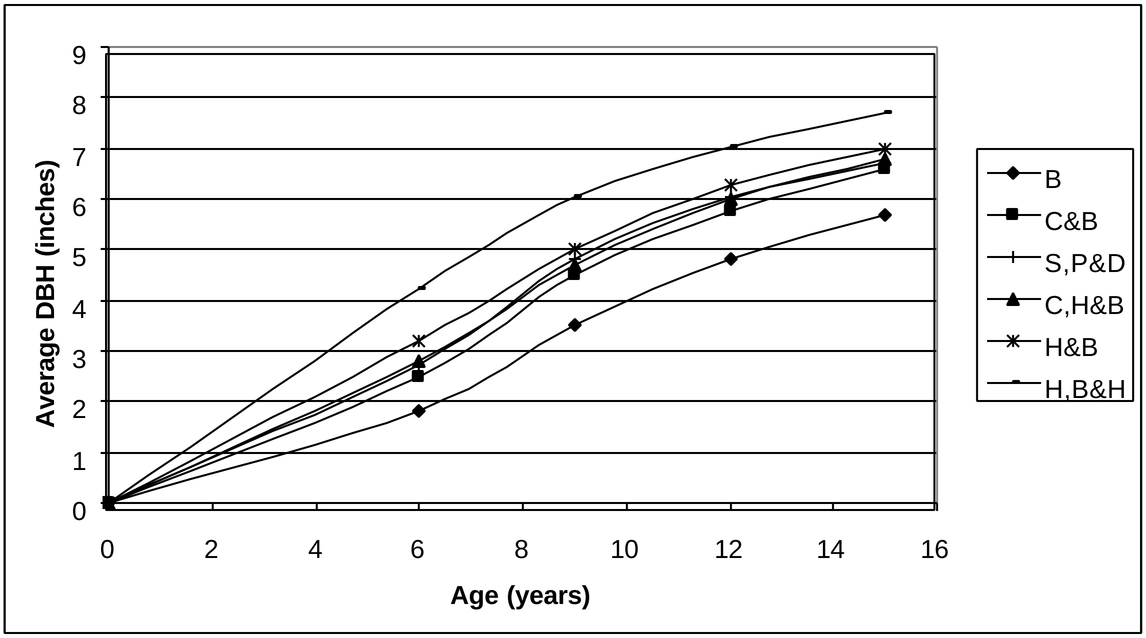

Figure 7. Average Dbh growth trends by site preparation treatment.

4.2 Periodic Average Height Growth

The average height growth values by treatment and growth period are shown in Table 10 and illustrated in Figure 8. For the period between 6 and 9 years of age, the most intensive treatments achieved greater rates of height growth, even though the average heights on the more intensive treatments were already much higher. Average height growth rate continued to increase between 9 and 12 years of age, but the differences among treatments decreased. In the period between 12 to 15 years, the height growth rates for all treatments were nearly equal.

Table 10. Average height growth (feet) by period and treatment. Different letters indicate significant differences between site preparation treatments.

Period	B	C&B	S,P&D	C,H&B	H&B	H,B&H
6 to 9	9.1 (a)	10.6 (b)	10.6 (b)	10.7 (b)	10.9 (b,c)	11.3 (c)
9 to 12	10.2 (a)	11.1 (b)	11.2 (b)	11.0 (b)	10.8 (a,b)	10.8 (a,b)
12 to 15	8.0 (a)	8.0 (a)	7.8 (a)	8.0 (a)	8.0 (a)	7.8 (a)

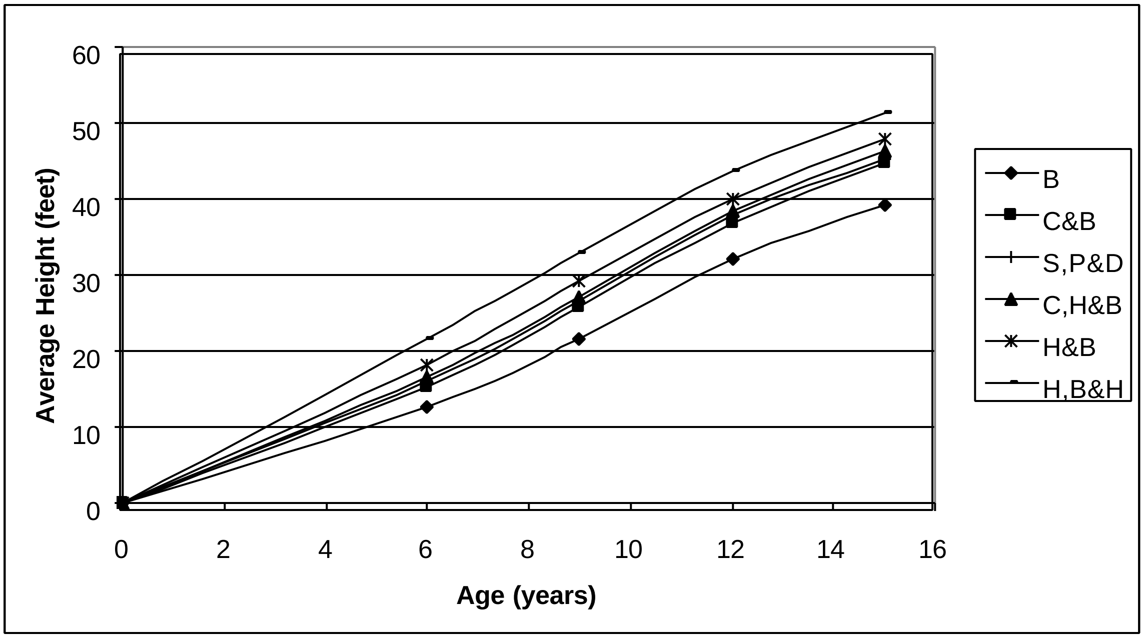

Figure 8. Average height growth trends by site preparation treatment.

4.3 Periodic Average Basal Area Growth

The average per-acre basal area growth values by treatment and growth period are shown in Table 11 and illustrated in Figure 9. For the two periods between 6 and 12 years of age, the basal area growth rate increased with increasing management intensity, with the S,P&D, H&B and H,B&H exhibiting the highest basal area growth rates. For the period between the ages of 12 and 15, there were no significant differences in basal area growth rate among treatments. The burn only treatment, however, had the highest per-acre basal area growth rate.

Table 11. Average basal area growth (ft^2/ac) by period and treatment. Different letters indicate significant differences between site preparation treatments.

Period	B	C&B	S,P&D	C,H&B	H&B	H,B&H
6 to 9	22.0 (a)	35.1 (b)	41.1 (c)	37.9 (b,c)	40.0 (c)	48.1 (d)
9 to 12	23.5 (a)	31.6 (b)	34.8 (c)	31.9 (b,c)	33.2 (b,c)	30.8 (b)
12 to 15	33.5 (a)	26.1 (a)	25.2 (a)	26.0 (a)	25.2 (a)	23.2 (a)

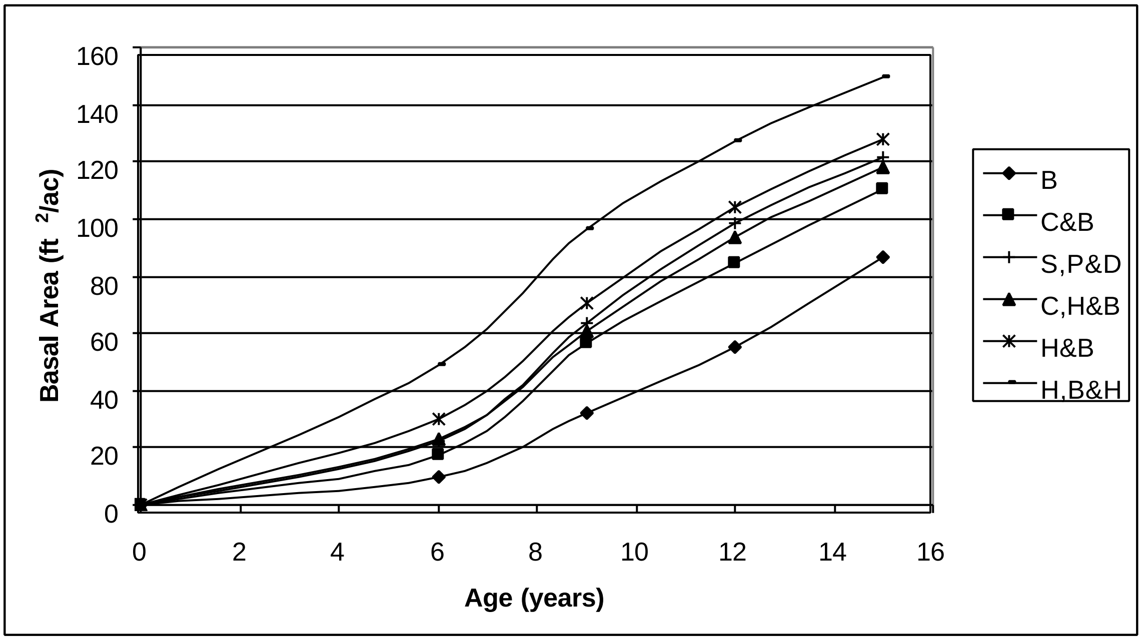

Figure 9. Average per-acre basal area growth trends by site preparation treatment.

4.4 Periodic Average Total Volume Growth

The average per-acre total volume growth values by treatment and growth period are shown in Table 12 and illustrated in Figure 10. For the three, three-year periods between 6 and 15 years of age, total volume growth increased with increasing site preparation intensity. Between 6 and 12 years, the H,B&H treatment grew significantly more volume than all other treatments. For the period between 12 and 15 years, there were no significant differences in total volume growth among site preparation treatments.

Table 12. Average total volume growth (ft^3/ac) by period and treatment. Different letters indicate significant differences between site preparation treatments.

Period	B	C&B	S,P&D	C,H&B	H&B	H,B&H
6 to 9	329 (a)	569 (b)	686 (c,d)	653 (c)	736 (d)	1017 (e)
9 to 12	560 (a)	828 (b)	959 (c)	891 (b,c)	960 (c)	1089
12 to 15	814 (a)	838 (a)	865 (a)	876 (a)	910 (a)	965 (a)

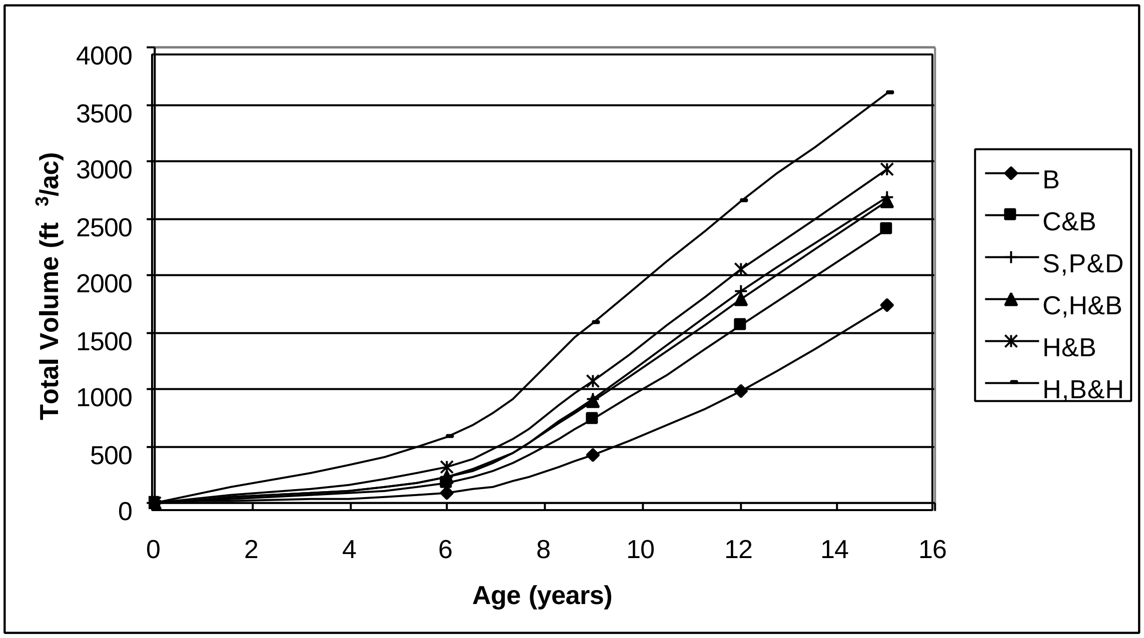

Figure 10. Average per-acre total volume growth trends by site preparation treatment.

4.5 Periodic Average Merchantable Volume Growth

The average per-acre merchantable volume growth values by treatment and growth period are shown in Table 13 and illustrated in Figure 11. The results for merchantable volume are nearly identical to the results for total volume. For the three, three-year periods between 6 and 15 years of age, merchantable volume growth increased with increasing site preparation intensity. Between 6 and 12 years, the H,B&H treatment grew significantly more merchantable volume than all other treatments. For the period between 12 and 15 years, there were no significant differences in merchantable volume growth among site preparation treatments.

Table 13. Average merchantable volume growth (ft^3/ac) by period and treatment. Different letters indicate significant differences between site preparation treatments.

Period	B	C&B	S,P&D	C,H&B	H&B	H,B&H
6 to 9	329 (a)	569 (b)	686 (c,d)	653 (c)	736 (d)	1017 (e)
9 to 12	560 (a)	828 (b)	959 (c)	891 (b,c)	960 (c)	1089
12 to 15	814 (a)	838 (a)	865 (a)	876 (a)	910 (a)	965 (a)

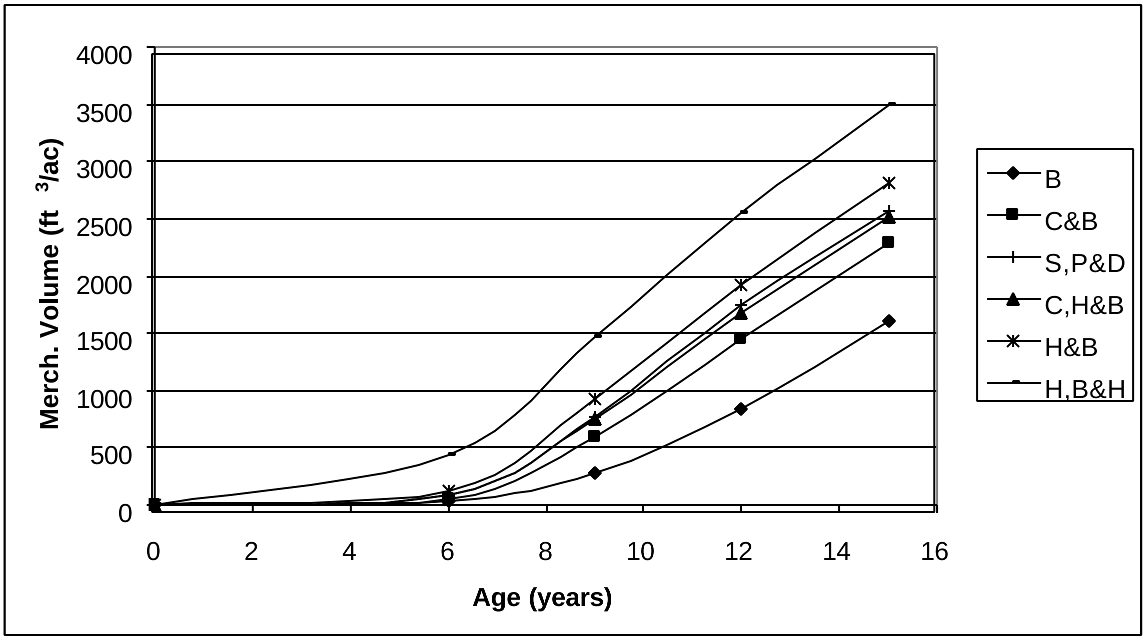

Figure 11. Average per-acre total volume growth trends by site preparation treatment.

5 COMPETING HARDWOOD VEGETATION

The amount and composition of hardwood and herbaceous competition on the SAGS site preparation plots have been monitored through the years with nine, 4-foot radius subplots on each measurement plot. The measurements on each subplot fall into three categories: herbaceous, small hardwood and large hardwood. Herbaceous competition was assessed on a subplot basis where the cover percent and average height of herbaceous vegetation types were measured for the subplot. The following quantities were recorded:

- Percent *andropogon* (broomsedge) cover,
- Average *andropogon* height,
- Percent other grass cover,
- Average other grass height,

- Percent broadleaf cover,
- Average broadleaf height,

Small hardwoods were defined as those stems with a Dbh less than 4". The following measurements were taken on individual stems or rootstocks:

- Species,
- Height,
- Crown length,
- Crown width,

Large hardwoods were defined as those hardwood stems with Dbh greater than 4". The following measurements were taken on each large hardwood stem:

- Species,
- Dbh,
- Height,
- Bole height,
- Crown width.

The competition data for each remeasurement were summarized in an attempt to develop some average or per-acre competition variables that correlate with pine growth. At this stage in the life of the study, herbaceous competition seems to have a diminishing affect on pine survival and growth. This is probably due to crown closure and herbaceous weed density declining from shade. Past studies have indicated that the sum of live heights of the tallest stem of a single or multiple-stem rootstock (Knowe and Shiver, 1988) and the proportion of hardwood basal area relative to total basal area (Quicke *et.al*, 1996) can be used to assess the effect of hardwood on pine growth. These variables can also be used to compare the effectiveness of various treatments designed to control hardwood competition. Figure 12 shows the sum of live heights by age and treatment. The Burn, Chop + Burn and Herb + Burn treatments all began with a live hardwood height of around 40,000 feet/ac at age six. This declined to around 20,000 feet/ac for the Chop + Burn and Herb + Burn and to 30,000 feet/ac for the Burn only. The intensive mechanical treatment (Shear + Pile + Disk) began at around 25,000 feet/ac and declined to 15,000 feet/ac. The Chop + Herb + Burn started at around 20,000 feet/ac and remained near that level through age 15.

Figure 13 shows the hardwood basal area proportion by age and treatment. Proportions at age six ranged from 62.6% for the Burn treatment to 12.7% for the Herb + Burn. Hardwood proportions for all treatments declined and then stabilized by age 12. Hardwood proportion levels at age 15 ranged from 34% for the Burn only treatment to 6.8% for the intensive mechanical treatment (Shear + Pile + Disk).

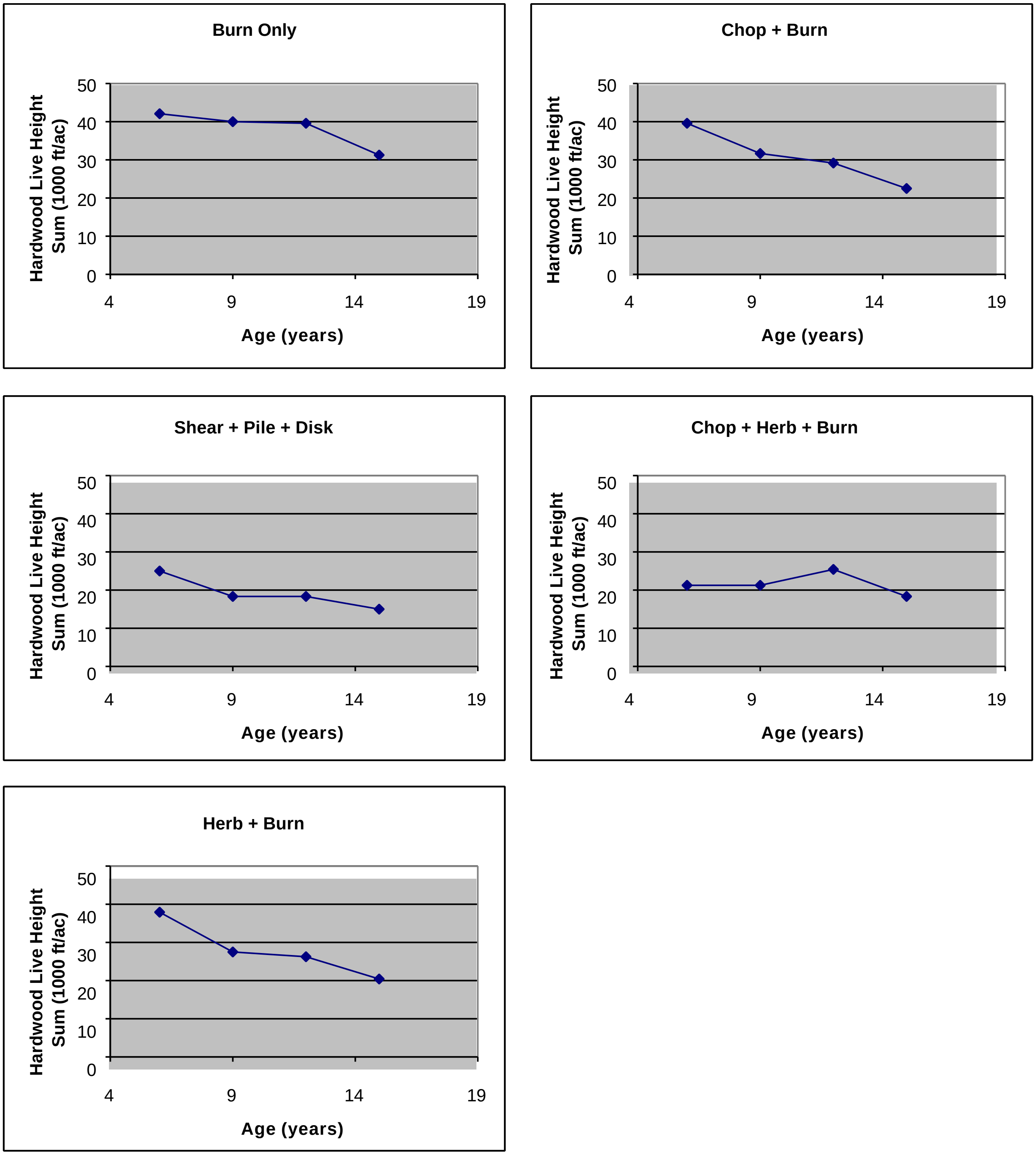

Figure 12. Sum of hardwood live heights by age and treatment for the SAGS Site Preparation Study.

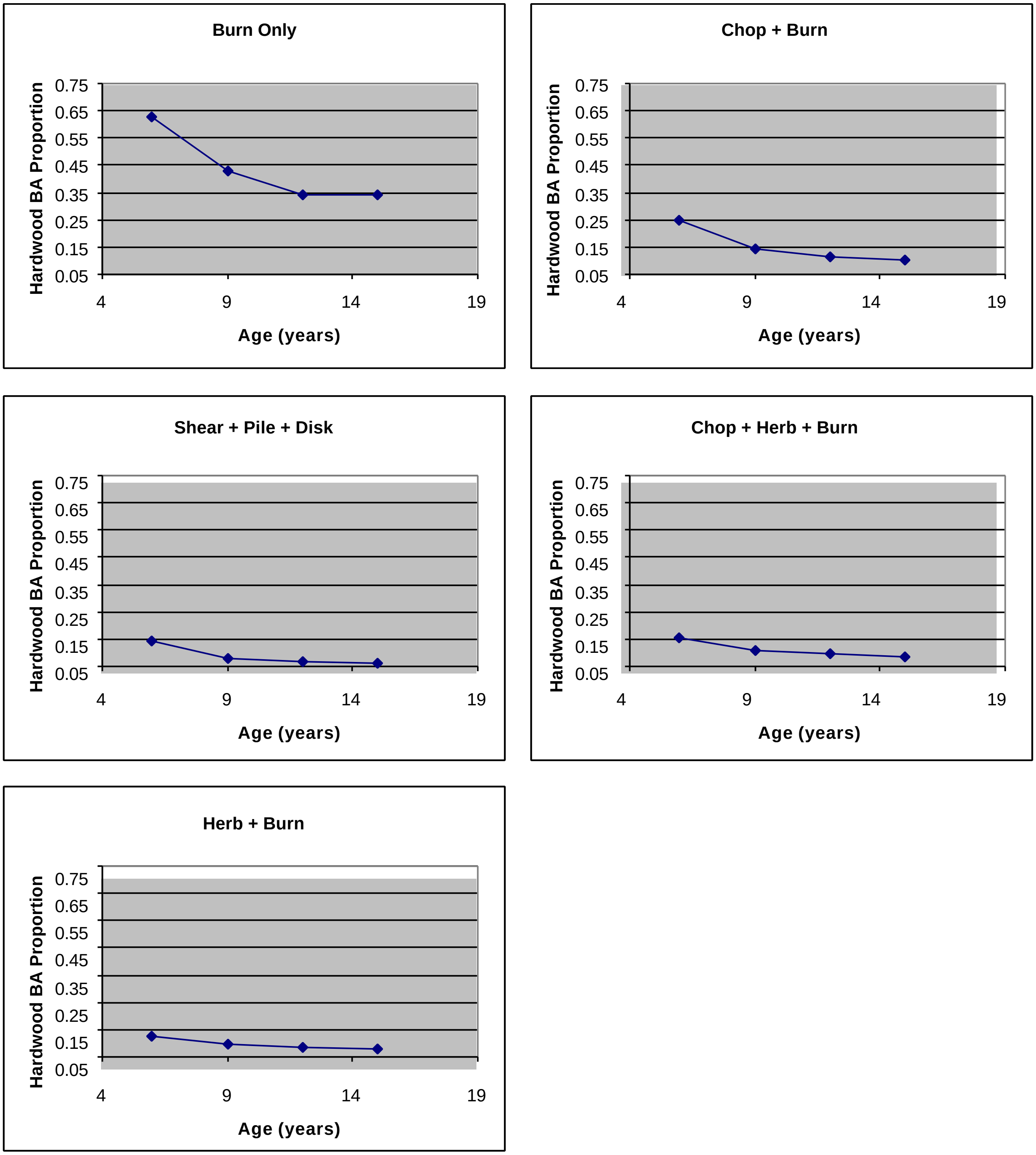

Figure 13. Hardwood basal area as a proportion of total basal area by age and treatment for the SAGS Site Preparation Study.

6 FINANCIAL ANALYSIS

To make an informed decision regarding a site preparation method, the cost must be considered in addition to stand growth and future product distributions. To account for the initial investment in site preparation and the future value of timber products, the internal rate of return (IRR) was used. The IRR is defined as the discount rate at which the bare land value (BLV) is equal to zero. The IRR and its associated optimum economic rotation (OER) was determined for each site preparation treatment using the following formula:

$$\frac{SY_r - R}{(1+i*)^r - 1} - R - \frac{A}{i*} = 0 \qquad \textbf{(2)}$$

where Y_r = yield (tons/acre) at rotation age,
S = stumpage price (\$/ton),
R = regeneration cost (\$/acre),
r = rotation age (years),
A = annual tax and administration cost (\$/acre),
$i*$ = inflation-free discount rate.

An iterative simulation procedure was used to determine the combination of *i** and *R* that satisfied equation (2) for each site preparation treatment. The plot data for each treatment at age 15 were projected using the system of equations described by Harrison and Borders (1996). The effects of chemical weed control treatments on future pine growth and yield were estimated using the equations from Borders *et al.* (2001). Rotation ages from 20 to 40 were evaluated in 1-year increments and equation (2) was solved for *i** at each iteration. The maximum *i** (IRR) and the associated rotation age (OER) were identified for each plot. Averages IRR's and OER's were computed for each treatment. Site preparation costs were obtained from Dubois *et al*. (2001) and current timber prices were obtained from Timber-Mart South (2001). Economic assumptions used in this analysis are shown in Table 14.

Average optimal internal rates of return and associated rotation ages are shown in Table 15. The chop and burn treatment, with a moderate cost and poor competition control, resulted in the lowest average IRR. The intensive mechanical treatment was the most expensive and resulted in a moderate, average rate of return of 12%. This treatment had the longest average rotation at 22.2 years. The herbicide and burn treatment resulted in the highest average rate of return of 15.3%. Note that this analysis assumed that immediate regeneration would take place following a clearcut. A reasonable alternative would be to assume that a one-year delay would occur between harvest and subsequent site preparation and regeneration. This assumption can be reflected in equation (2) by replacing *r* with (*r+1*). This will result in a higher estimated return on investment compared to immediate regeneration.

Table 14. Economic assumptions for the analysis of future returns.

Site Preparation Costs by Treatment ($/acre)	
Burn Only	$ 22.13
Chop + Burn	$103.59
Shear + Pile + Disk	$200.00
Chop + Herbicide + Burn	$204.89
Herbicide + Burn	$123.43
Herbicide + Burn + Herbicide	$123.43 + $50/yr in yrs 1-4
Product Stumpage Values ($/o.b. green ton)	
Pulpwood (Dbh > 4” to 2” top)	$ 6.20
Chip-N-Saw (8” < Dbh < 12” to a 6” top)	$23.72
Sawtimber (Dbh > 12” to an 8” top)	$35.95
Other Assumptions	
Annual tax and administration cost ($/acre)	$ 4.50

Table 15. Average rates of return and associated rotation ages by site preparation treatment.

Site Preparation Treatment	IRR (%)	OER (years)
Burn Only	11.4	20.4
Chop + Burn	9.6	20.4
Shear + Pile + Disk	12.0	22.2
Chop + Herbicide + Burn	12.1	21.5
Herbicide + Burn	15.3	20.3
Herbicide + Burn + Herbicide	13.6	20.5

7 DISCUSSION AND CONCLUSIONS

The SAGS Site Preparation Study was established in 1986 to study the effects of different site preparation methods on the growth, stand structure, yields and economics of loblolly pine plantations in the southeastern Piedmont. Treatments ranged in intensity from a burn only to a chemical site preparation treatment followed by complete vegetation control. This report summarizes the results of the study after 15 growing seasons.

Tests of the main effect, site preparation treatment, were carried out on average Dbh, range in DBh, skewness in Dbh, kurtosis in Dbh, average height, per-acre basal area, per-acre total volume, per-acre merchantable volume, survival and percent rust infection. Orthogonal contrasts were also conducted for these variables to isolate the effects of particular treatments or treatment combinations. Contrasts included chop vs. no chop, chemical vs. mechanical, herbicide vs. no herbicide with burn, herbicide vs. no herbicide with mechanical, and herbicide + burn vs. herbicide + burn + complete vegetation control.

Site preparation treatment significantly affected average Dbh, Dbh skewness, average height and all per-acre stand characteristics. For all analysis variables where treatment was significant, the addition of either a chop or a herbicide treatment to the burn only treatment achieved significant improvement. These treatments reduce the effect of large hardwoods that overtop the pines and impact survival and growth. The herbicide + burn treatment had significantly greater Dbh's and height's than the mechanical treatments. The addition of complete vegetation control to the herbicide + burn treatment resulted in increased average Dbh, average height, per-acre basal area and per-acre volumes. The general trends with respect to treatment differences in Dbh and average height, observed after 15 growing seasons, were already evident after only six growing seasons. Total and merchantable volumes for the most intensive treatments, however, seem to still be diverging from the least intensive treatments.

The survival between ages 6 and 15 was good for all treatments. Significant mortality due to competition has yet to appear on most plots. The intensive mechanical treatment achieved the best survival over the life of the study. The burn only treatment experienced a high degree of mortality prior to age six, but seems to have stabilized since.

The growth in average tree and stand characteristics between the ages of 12 and 15 years were analyzed to determine if treatment effects were increasing, decreasing or maintaining the same trends over time. The most intensive treatment, herbicide + burn + herbicide, exhibited significantly less average Dbh growth over the three-year period. This should not be surprising since these treatment plots are much further along in stand development and should be slowing down. No significant differences were detected for average height growth, per-acre basal area growth and per-acre volume growth between the ages of 12 and 15 years.

Subplots were located on each site preparation study plot to assess competing vegetation. Competition was classified as grass, herbaceous other than grass, small hardwood (Dbh < 4”) and large hardwoods. These data were summarized by treatment. No statistical tests were conducted, but plots of average competition variables show the effects of site preparation treatment on the amount of competing vegetation over time. For example, consider the hardwood basal area expressed a percentage of total basal area (hardwood + pine). The percent hardwood basal area was 64% for the burn only treatment at age five. This value declined and stabilized at 35% by age 12. For the herbicide + burn, chop + herbicide + burn and the shear + pile + disk treatments, percent hardwood basal area was approximately 15% at age five and declined to just over 5% by age 15.

While these trends are interesting, the utility of these data for growth and yield modeling remains in question due to a very high degree of variability. These data will be merged with data from the Auburn Herbicide Cooperative’s RL-4I study. This combined dataset will be used to refine these relationships and to build models to reflect the development of hardwoods and pines together.

An analysis of expected future returns was conducted to further refine the characterization of different site preparation methods. Internal rates of return (IRR) were computed as the discount rate at which the bare land value was equal to zero. Rates of return were computed over a range of rotation ages from 20 to 40 years. Yields and future cash flows were computed using appropriate growth and yield models and current product stumpage values. The chop + burn treatment resulted in the lowest average IRR (9.6%) and the herbicide + burn treatment had the highest IRR of 15.3%

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