PIEDMONT LOBLOLLY PINE SITE PREPARATION STUDY:

RESULTS THROUGH AGE 18

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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.

After 18 growing seasons 23 of the original 25 installations are viable. Two installations were lost after they were thinned. Thus, averages at age 18 are based on a different set of plots than averages at age 15. To obtain appropriate growth information from age 15 to age 18 it is necessary to look at the 23 installations available at both ages.

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, fifteenth, and eighteenth 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 height. 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. Note that in each table of means presented below, means for ages 6 through 15 years are based on 25 installations whereas means for age 18 years are based on 23 installations. To have a more clear indication of the average change in each variable from age 15 to age 18 years an additional set of means referred to as Age 15 (net) were calculated. This set of means are the age 15 means of the 23 installations that were available at age 18.

Table 1 shows the degrees of freedom, F statistics and resulting p-values for each of the dependent variables addressed for the age 18 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 after 18 growing seasons. Significant effects are marked with *.

Dependent Variable	Numerator df	Denominator df	Type III F	Pr > F
Average Dbh*	5	98	25.62	0.0001
Range in Dbh	5	129	1.98	0.0860
Dbh Skewness*	5	126	5.56	0.0001
Dbh Kurtosis	5	128	1.73	0.1329
Average Height*	5	96	34.12	0.0001
Basal Area*	5	98	26.4	0.0001
Total Volume*	5	99	29.2	0.0001
Merch. Volume*	5	99	29.8	0.0001
Trees per acre*	5	98	7.2	0.0001
Percent rust	5	89	1.57	0.1758

3.1 Average Dbh

Table 1 shows that site preparation significantly affected average Dbh. Average Dbh values for ages 6, 9, 12, 15 and 18 years are shown by treatment in Figure 1 and Table 2. As expected, the burn (B) only treatment shows the smallest average dbh through age 18 years and the most intensive treatment (H,B&H) has the largest average dbh through age 18 years. As the treatment intensity increased average dbh also increased during the early years of the study. However, by age 12 average diameter for the chop and burn (C&B), shear-pile-disk (S,P&D), chop-herbicide-burn (C,H&B) treatments were becoming very similar with values of 5.8, 6.0 and 6.0 inches, respectively. After 18 years the burn only treatment has the smallest average dbh of 6.6", the most intensive treatment (H,B&H) has the largest average dbh of 8.2" whereas the other treatments have very similar average dbh values of 7.6 and 7.7 inches.

Table 2. 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

Treatment	Age 18		Age 15 (net)					
	Mean	CV %	Mean	CV %				
B	6.6	17.43	5.6	20.23				
C&B	7.6	5.8	6.7	6.28				
S,P&D	7.6	8.8	6.8	9.64				
C,H&B	7.7	6.5	6.9	6.72				
H&B	7.7	7.3	7.0	7.49				
H,B&H	8.2	10.0	7.6	10.02				

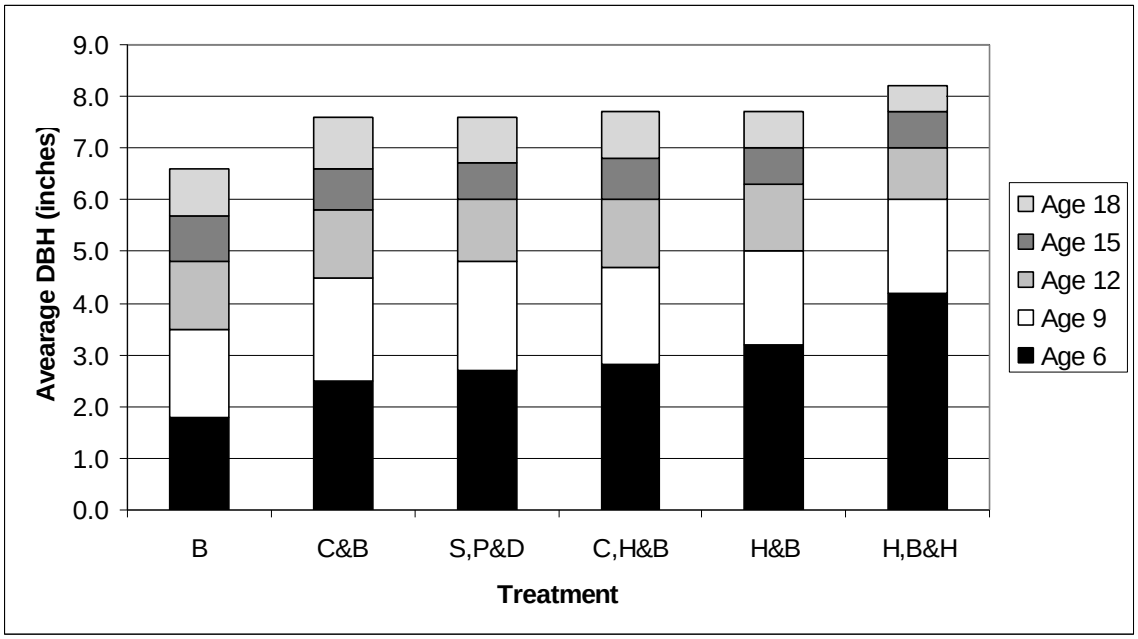

Figure 1. Means for Dbh (inches) by age and treatment.

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. All treatments except the burn only (B) exhibited negative skewness at age 18 indicating that some small diameter trees are continuing to survive in these treatments. For the burn only treatment (B) the distribution was symmetric about its mean with no significant skewness in either direction. Similar to the findings at age 15, 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 symmetric 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. As for average dbh, average height for treatments falling between the burn (B) only and the most intensive (H,B&H) treatment is becoming more similar as the stands age (Figure 2, Table 3). However, differences between the C&B, S,P&D, C,H&B and H&B treatments still exist at age 18, although they are small. At age 18, the most intensive treatment shows an increase of 3.3 feet over the operational brown and burn (H&B) treatment and 12.2 feet over the minimal burn only (B) treatment.

Table 3. 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

Treatment	Age 18		Age 15 (net)					
	Mean	CV %	Mean	CV %				
B	47.2	16.6	38.0	19.3				
C&B	54.2	8.8	44.7	9.5				
S,P&D	55.2	12.1	45.7	13.3				
C,H&B	55.3	9.3	46.0	10.5				
H&B	56.1	9.3	46.7	10.3				
H,B&H	59.4	10.4	50.7	11.9				

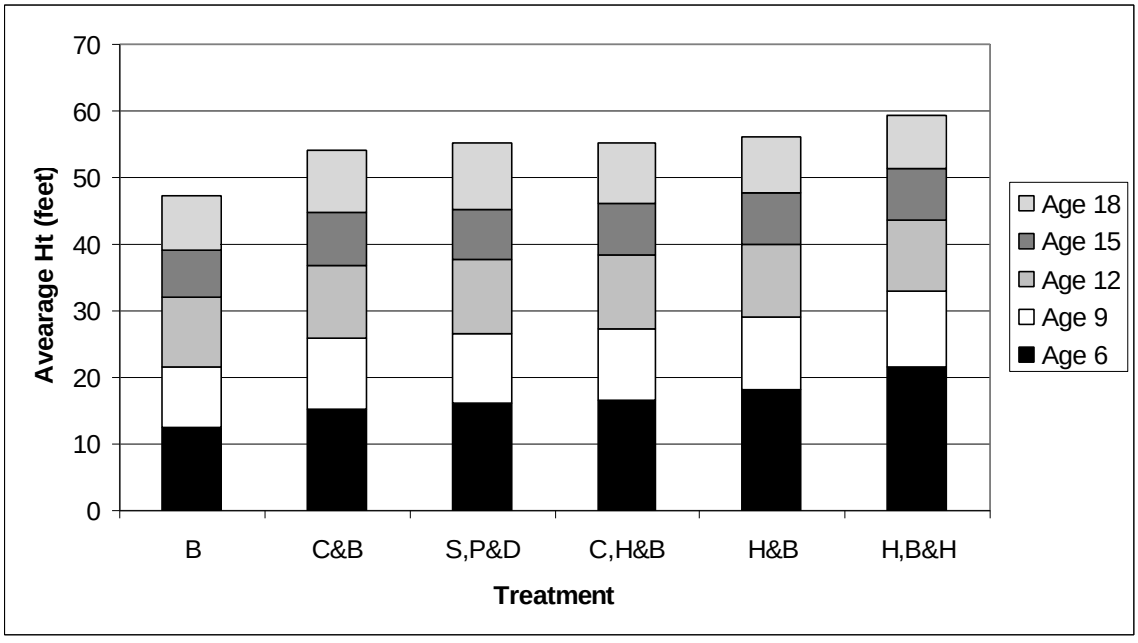

Figure 2. Means for average height (feet) by age and treatment.

3.4 Per-Acre Basal Area

Site preparation treatment significantly affected per-acre basal area. Of course, the largest increase in per-acre basal area is associated with the complete vegetation control treatment (H,B&H) at all ages through 18 years (Figure 3, Table 4). After 18 years, Chopping and burning increased basal area by 46 ft^2/ac over burning only whereas the operational herbicide application following a burn (H&B) shows an increase of 58 ft^2/ac over the burn only treatment. There was no significant difference in basal area between the operational brown and burn treatment (H&B) and the average of the mechanical treatments. Complete vegetation control has 18 ft^2/ac more than the operational brown and burn (H&B) treatment at age 18 which is smaller than the 21.2 ft^2/ac difference at age 15.

Table 4. 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

Treatment	Age 18		Age 15 (net)					
	Mean	CV %	Mean	CV %				
B	88.9	43.3	71.1	45.6				
C&B	135.4	18.7	111.8	18.8				
S,P&D	147.2	17.0	126.1	19.3				
C,H&B	140.6	17.6	118.2	20.6				
H&B	147.0	16.1	126.2	16.4				
H,B&H	165.0	17.2	148.0	18.3				

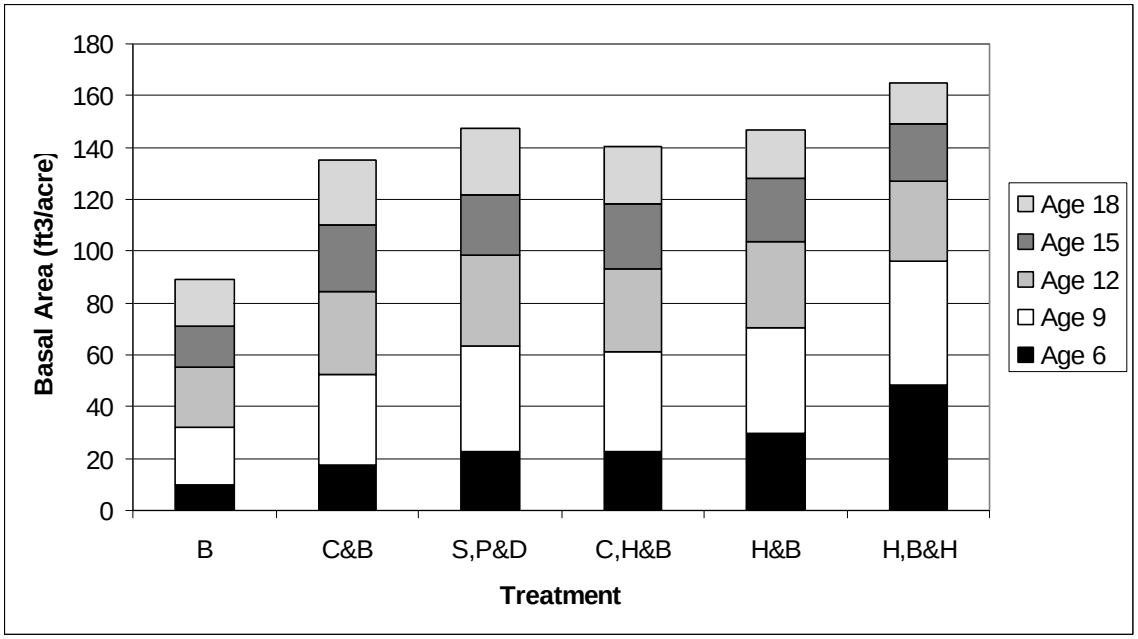

Figure 3. Means for basal area (ft^2/ac) by age and treatment.

3.5 Per-Acre Total Volume

Total volume increased with increasing intensity of the site preparation treatment (Table 5, Figure 4). Total volumes ranged from 2216 ft^3/ac for the burn only treatment to 4702 ft^3/ac for the complete vegetation control treatment. As for basal area per acre, the two treatments that include operational herbicide application (C,H&B and H&B) and the intensive mechanical treatment (S,P&D) have similar volume production through 18 growing seasons. These treatments have significantly more volume than the Chop only and Chop and Burn treatments and significantly less volume than the complete vegetation control treatment (H,B&H). The Chop only treatment continues to fall further behind all other treatments.

Table 5. 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

Table 5. (continued)

Treatment	Age 18		Age 15 (net)					
	Mean	CV %	Mean	CV %				
B	2216	50.2	1496	53.77				
C&B	3610	23.2	2534	23.99				
S,P&D	3977	25.2	2903	28.37				
C,H&B	3796	22.5	2737	26.6				
H&B	3995	22.1	2949	23.31				
H,B&H	4702	22.9	3691	25.52				

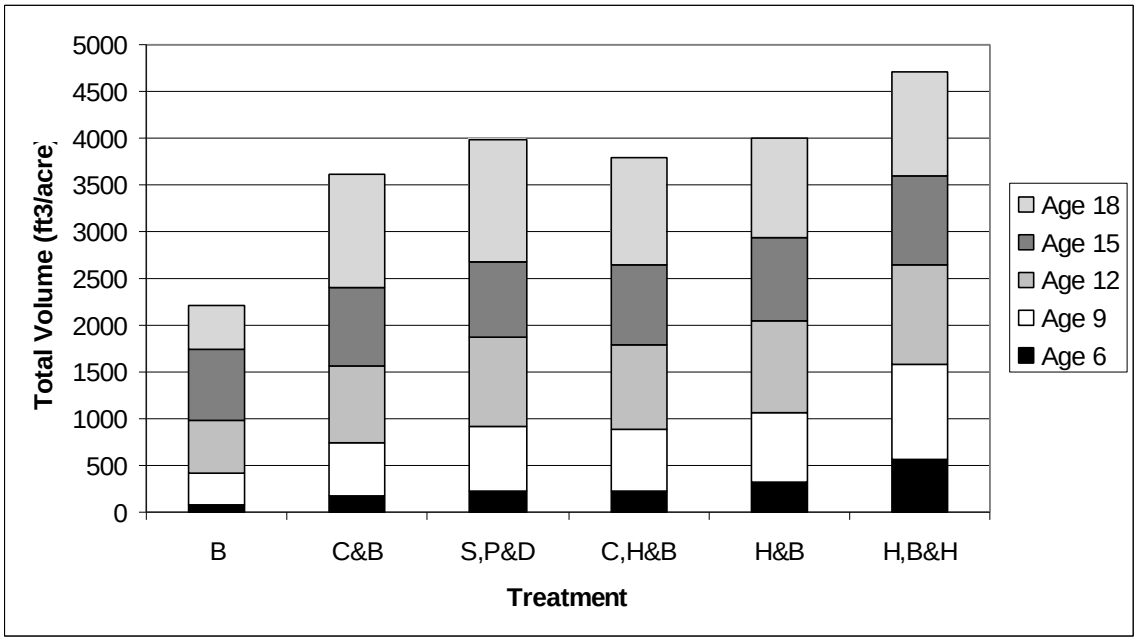

Figure 4. Means for total volume (ft3/ac) by age and treatment**.**

3.6 Per-Acre Merchantable Volume

The results for merchantable volume were essentially the same as for total volume since merchantable volume is defined as the cubic volume of all stems larger than 4.5" dbh to a 2" top dob (Table 6, Figure 5). Chop and burn increased merchantable volume by more than 1400 ft^3/ac over burning only after 18 years. The herbicide and burn treatment increased merchantable volume by almost 1800 ft^3/ac over the burn only treatment. Complete vegetation control resulted in an increase of 711 ft^3/ac over the herbicide and burn treatment which is slightly lower than the difference at age 15.

Table 6. 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

Treatment	Age 18		Age 15 (net)					
	Mean	CV %	Mean	CV %				
B	2162	51.7	1431	56.9				
C&B	3573	23.5	2489	24.4				
S,P&D	3943	25.6	2865	29.0				
C,H&B	3761	22.7	2695	27.1				
H&B	3963	22.4	2908	23.7				
H,B&H	4674	23.1	3661	25.8				

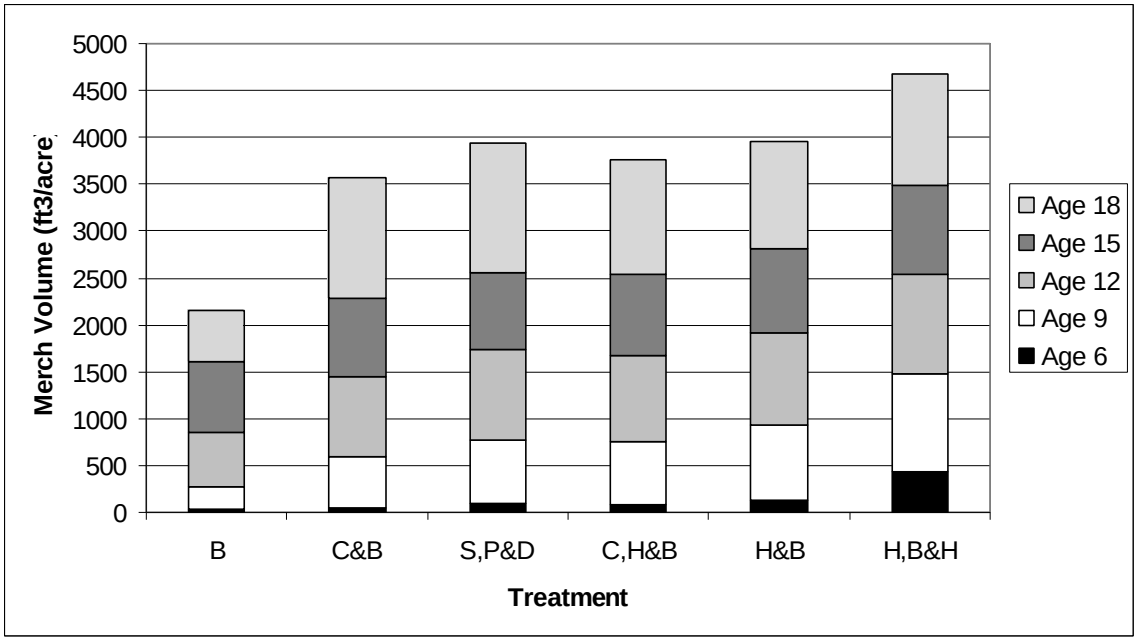

Figure 5. Means for merchantable volume (ft^3/ac) by age and treatment.

3.7 Trees Per Acre

Site preparation treatment was found to significantly affect survival. Average trees per acre ranged from 339 for the burn only treatment to 455 for the most intensive mechanical treatment (S,P&D). The contrast analysis indicated significant survival differences due to chopping (73 trees per acre) and a herbicide application (95 trees per acre) over the burn only treatment (Table 7). Note that survival S,P&D, C,H&B, H&B and H,B&H are not significantly different after 18 growing seasons. 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

Treatment	Age 18		Age 15 (net)					
	Mean	CV %	Mean	CV %				
B	339	33.1	360	30.8				
C&B	412	19.3	430	17.8				
S,P&D	455	12.0	476	11.3				
C,H&B	420	19.8	438	18.7				
H&B	434	15.9	460	15.3				
H,B&H	433	17.2	451	15.3				

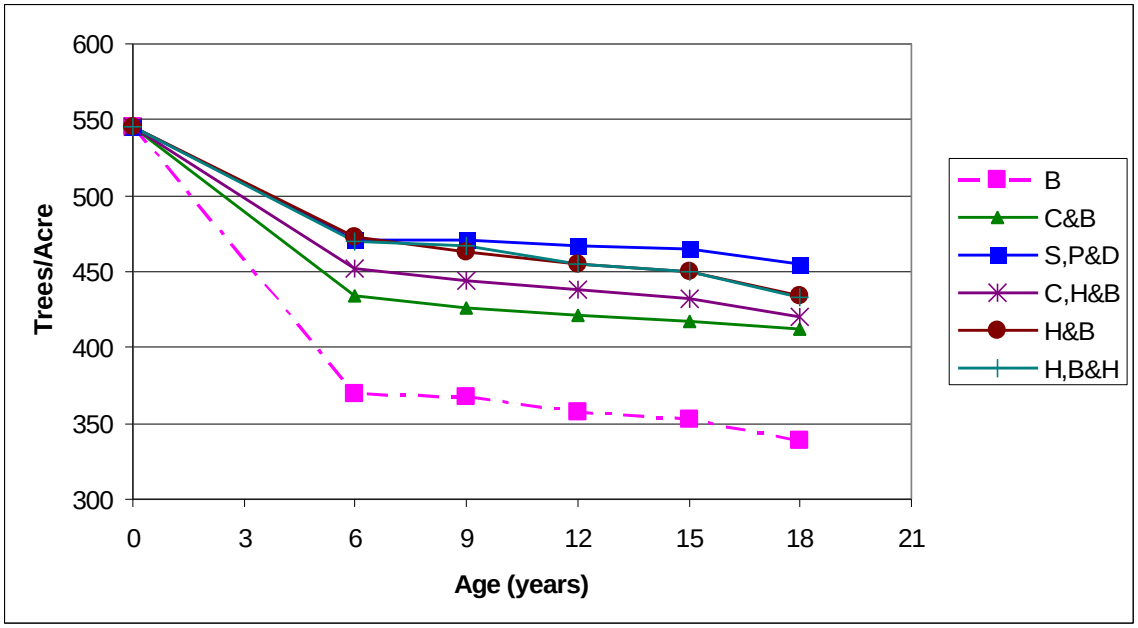

Figure 6. Survival trends over time by treatment.

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 12.7% for the H&B treatment to 16% for the B and C,H&B treatment (Table 8) for the 23 locations available at age 18 years. 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). 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. 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

Treatment	Age 18							
	Mean	CV %						
B	16.0	78						
C&B	15.3	79						
S,P&D	14.1	90						
C,H&B	16.0	88						
H&B	12.7	101						
H,B&H	15.9	88						

4 THREE-YEAR PERIODIC GROWTH

An analysis was carried out to examine the periodic growth between ages 6-9, 9-12,12–15 and 15-18 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. From age 15 to 18 years dbh growth was not significantly different for S,P&D, C,H&B, H&B and H,B&H treatments. Where as the C and C&B treatments are showing more dbh growth during this time.

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)
15 to 18	0.9 (a)	0.7 (a,b)	0.6 (b,c)	0.7 (b,c)	0.6 (b,c)	0.5 (c)

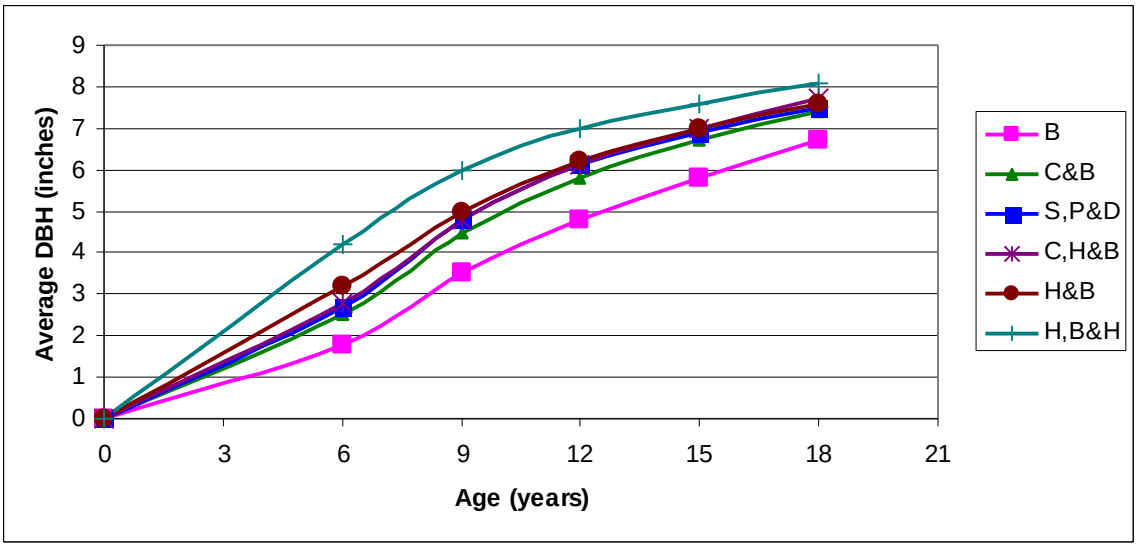

Figure 7. Average Dbh growth trends by site preparation treatment.

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 and for the 15 to 18 year period height growth was again very similar for all treatments. This trend indicates that the early height gains are being maintained through 18 years.

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)
15 to 18	9.0 (a)	9.6 (a)	9.4 (a)	9.4 (a)	9.3 (a)	8.6 (a)

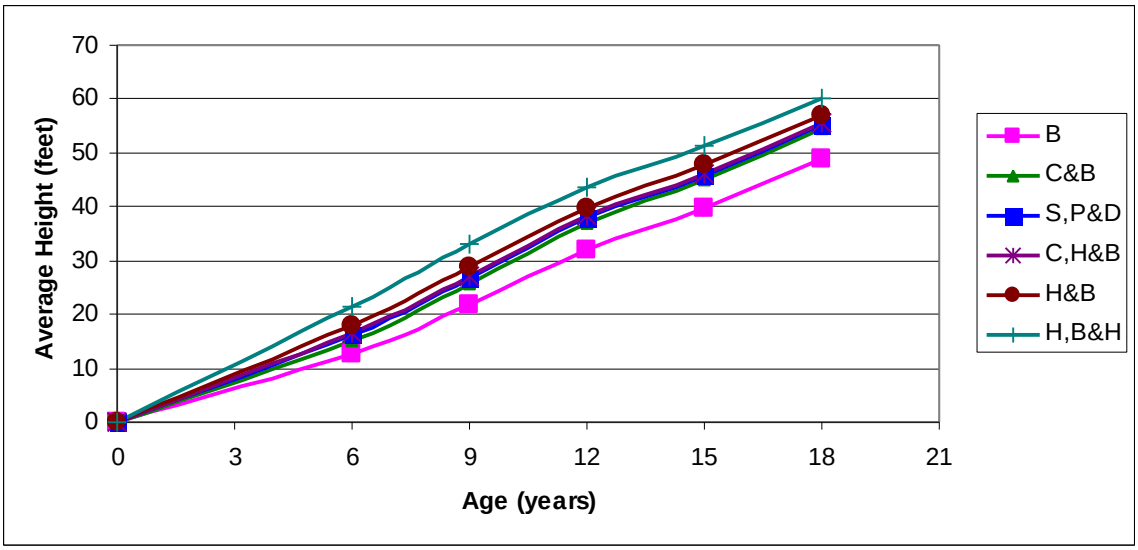

Figure 8. Average height growth trends by site preparation treatment.

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 from 12 to 15 years. From 15 to 18 years the burn only treatment and the most intensive treatment, H,B&H, had the lowest increase in basal area. The treatments between these two extremes were not significantly different from one another in terms of basal area growth during this most recent period. However, these treatments showed more basal area growth than the most intensive treatment indicating that they will are starting to approach the most intensive treatment in terms of stand basal area.

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)
15 to 18	17.8 (b)	23.8 (a)	21.4 (a,b)	21.8 (a,b)	21.0 (a,b)	17.3 (b)

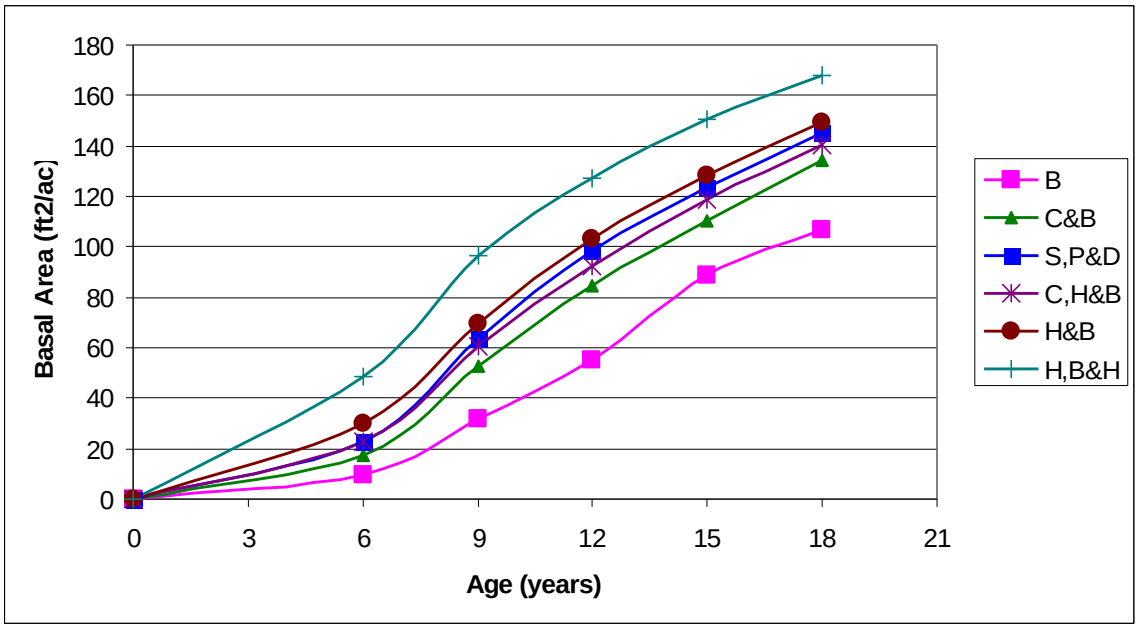

Figure 9. Average per-acre basal area growth trends by site preparation treatment.

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. However, for the 15 to 18 year period volume production was significantly lower in the burn only treatment than for all other treatments which were not significantly different from one another.

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)
15 to 18	719 (b)	1079 (a)	1057 (a)	1049 (a)	1059 (a)	1016 (a)

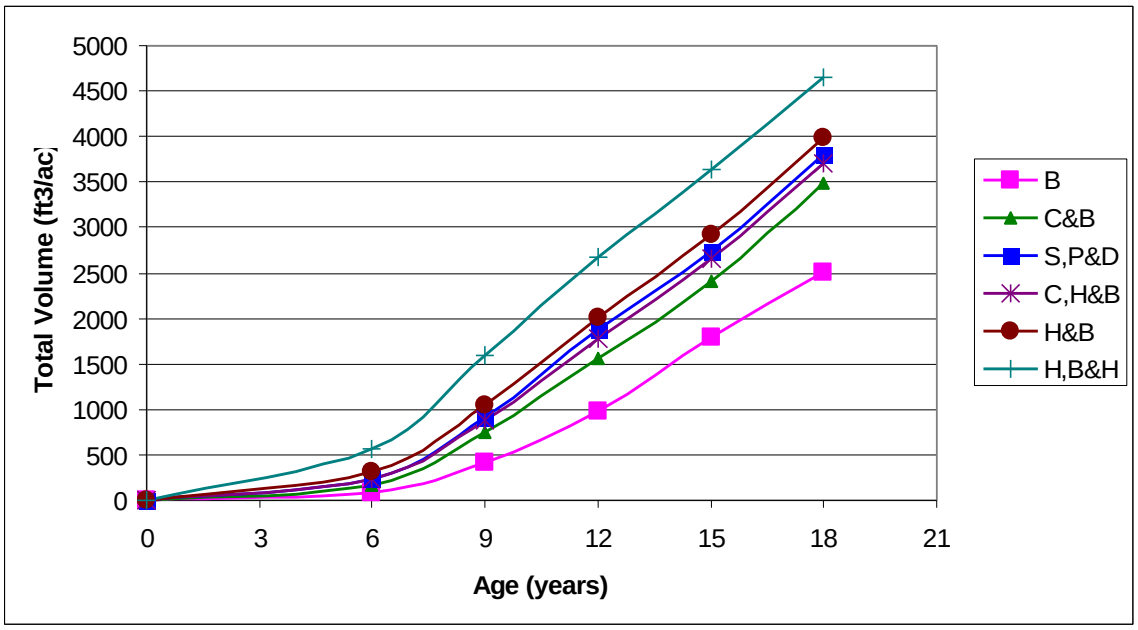

Figure 10. Average per-acre total volume growth trends by site preparation treatment.

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. However, from 15 to 18 years the burn only treatment produced significantly less volume than the other 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)
15 to 18	731 (b)	1088 (a)	1061 (a)	1057 (a)	1067 (a)	1018 (a)

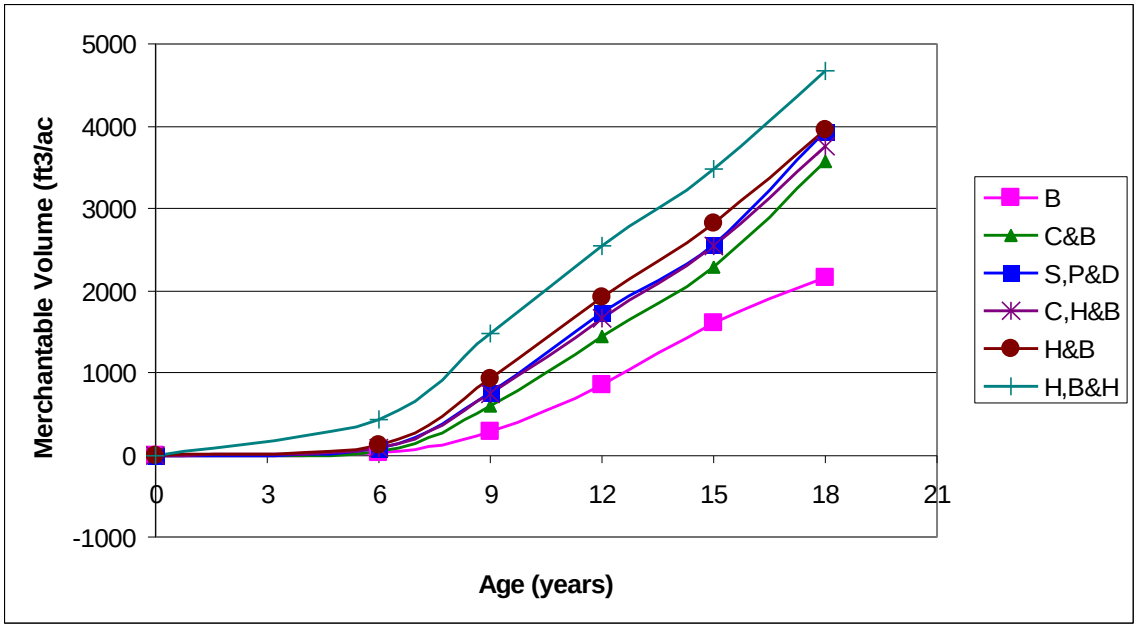

Figure 11. Average per-acre merchantable volume growth trends by site preparation treatment.

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.

Recently, it has been shown that the variable defined as hardwood basal area as a proportion of total pine and hardwood basal area is useful for modeling pine basal area development (Borders et al. 2003). The proportion of hardwood basal area at each measurement age by site preparation treatment is shown in Table 14 and Figure 12.

In the complete vegetation control treatment (H,B&H) has 0 hardwood basal area at all ages. For the other treatments, proportion of hardwood basal area at age six ranged from 0.63 for the Burn treatment to 0.13 for the Herb + Burn. Hardwood proportions for all treatments declined and then stabilized by age 12. Hardwood proportion levels at age 18 ranged from 0.31 for the Burn only treatment to 0.06 for the intensive mechanical treatment (Shear + Pile + Disk). The other treatments had hardwood basal area proportions of 0.07 to 0.08.

Table 14. Hardwood basal area proportion by measurement age and site preparation treatment.

AGE	B	C&B	S,P&D	C,H&B	H&B	H,B&H
6	0.63	0.25	0.15	0.15	0.13	0
9	0.43	0.14	0.08	0.11	0.10	0
12	0.34	0.10	0.05	0.10	0.05	0
15	0.34	0.10	0.06	0.08	0.08	0
18	0.31	0.08	0.06	0.08	0.07	0

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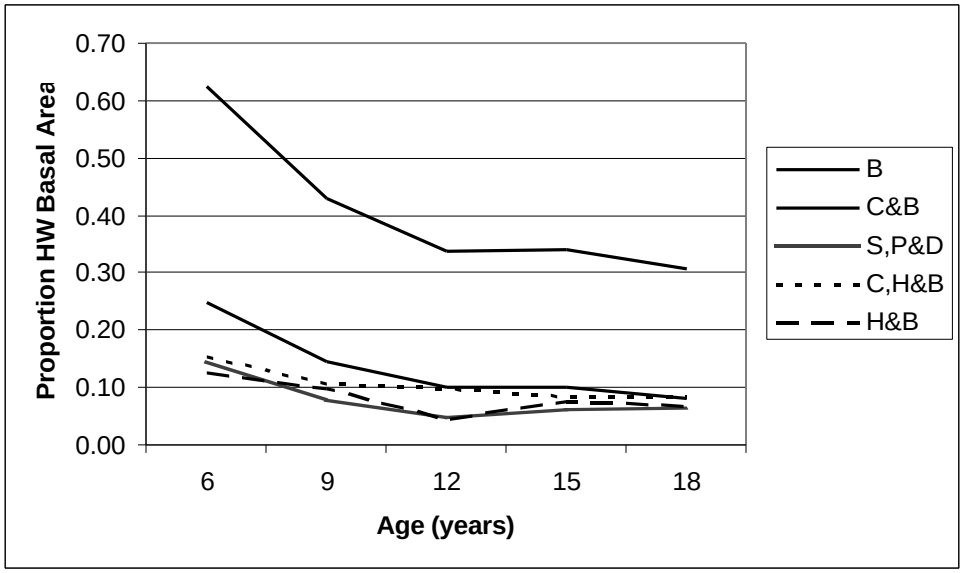

Figure 12. Hardwood basal area as a proportion of total basal area by age and treatment for the SAGS Site Preparation Study.

6 FINANCIAL ANALYSIS

To make an informed decision regarding a site preparation method, cost must be considered in addition to stand growth and future product distributions. To compare treatments in an equitable fashion the net present value (NPV) and internal rate of return (IRR) were calculated using product volumes present after 18 growing seasons. Three products were defined as:

Pulpwood – 4.5" < DBH <= 7.5" - 2" top dob

Chip-N-Saw – 7.5" < DBH <= 11.5" – 4" top dob

Sawtimber – 11.5" < DBH – 6" top dob

Note that we have no quality information with which to reduce chip-n-saw and sawtimber volumes, therefore dbh limits only define the product tonnages (Table 15).

Table 15. Product tonnage at age 18 by treatment.

Site Preparation Treatment	Pulpwood (tons/ac)	Chip-N-Saw (tons/ac)	Sawtimber (tons/ac)
Burn Only	34.2	20.6	0.8
Chop + Burn	50.0	43.0	0.8
Shear + Pile + Disk	60.7	39.3	1.1
Chop + Herbicide + Burn	53.6	42.8	2.4
Herbicide + Burn	56.9	47.9	1.8
Herbicide + Burn + Herbicide	51.1	65.1	6.1

Site preparation costs were obtained from Dubois *et al*. (2001). Planting costs were calculated assuming a cost of $40/1000 seedlings (planting density of 545 trees/acre) and a planting cost 78.20 for a total cost of planted seedlings of $90 per acre. Annual costs of $4.50 were assumed. All economic assumptions are summarized in Table 16. The fertilization treatment after the 13th growing season was assumed to cost $90 per acre. Using the stumpage values from table 16 total standing timber value at age 18 is over $1900 per acre for the H,B&H treatment and only $658 per acre for the burn only treatment (Table 17). The H&B treatment has the second highest timber value of approximately $1400 per acre while the other three treatments have timber values of $1200 to $1300 per acre.

The H&B treatment has the highest IRR (9.3%) and the second highest NPV which is only slightly behind the most intensive H,B&H treatment (Table 18). The chop and burn treatment has the third highest NPV and second highest IRR. The S,P&D, C,H&B and B treatments have the lowest NPV and IRR values. The B treatment values are low due to low volume production

whereas the S,P&D and C,H&B have low values (relative to other treatments) because their volume production was similar to the less costly H&B treatment but their cost was much higher.

Table 16. Economic assumptions for the analysis of future returns.

Site Preparation Costs by Treatment ($/acre)	
Seedlings & Planting Costs	$ 90.00
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
Fertilization (200 lbs/ac N + 25 lbs/ac P)	$90.00
Product Stumpage Values ($/o.b. green ton)	
Pulpwood (Dbh > 4” to 2” top)	$ 5.00
Chip-N-Saw (8” < Dbh < 12” to a 6” top)	$22.00
Sawtimber (Dbh > 12” to an 8” top)	$40.00
Other Assumptions	
Annual tax and administration cost ($/acre)	$ 4.50

Table 17. Standing timber value at age 18 years.

Site Preparation Treatment	Timber Value ($/ac)
Burn Only	658.05
Chop + Burn	1229.08
Shear + Pile + Disk	1210.64
Chop + Herbicide + Burn	1303.93
Herbicide + Burn	1409.12
Herbicide + Burn + Herbicide	1931.54

Table 18. NPV (i=6%) and IRR based on standing age 18 product volumes and costs outlined above.

Site Preparation Treatment	NPV (i=6%)	IRR (%)
Burn Only	$25.38	6.9
Chop + Burn	$143.98	8.9
Shear + Pile + Disk	$41.11	6.7
Chop + Herbicide + Burn	$68.90	7.1
Herbicide + Burn	$187.22	9.3
Herbicide + Burn + Herbicide	$196.99	8.4

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 18 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 18 growing seasons, were already evident after only six growing seasons. Total and merchantable volumes for the most intensive treatments, were still diverging

from less intensive treatments through 15 years, but at the end of 18 growing seasons the most intensive treatment is slowing down relative to less intensive treatments and they are now producing about the same amount of volume per year. This is most likely because the most intensive treatment is approaching its carrying capacity and is slowing production which implies that this treatment may benefited from a thinning sometime around 15 to 17 years of age.

The survival between ages 6 and 18 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 and from 15 to 18 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 these two three-year periods. 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, or per-acre volume growth between the ages of 15 and 18 years. However, the H,B&H treatment showed less basal area growth during this period than all other treatments except the burn only treatment. This indicates that the most intensive treatment is approaching its upper asymptote for stand basal area and the volume production will begin to slow relative to other treatments within the next few 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 proportion of total basal area (hardwood + pine). The proportion hardwood basal area was 0.64 for the burn only treatment at age six. This value declined and stabilized at 0.35 by age 12. For the herbicide + burn, chop + herbicide + burn and the shear + pile + disk treatments, proportion of hardwood basal area was approximately 0.15 at age six and declined to 0.06 to 0.08 by age 15. This same level of hardwood basal area was maintained in these treatments through age 18.

A financial analysis of each treatment at age 18 was carried out. Net present value and Internal rates of return (IRR) were computed for each treatment. The operational type brown and burn

(H&B) treatment had the highest IRR and the chop and burn (C&B) treatment had the second highest IRR. Based on a financial analysis conducted after the age 15 measurement (using models to project yields) the C&B treatment showed the lowest IRR. The most intensive treatment produced the most timber value but was ranked third in terms of IRR due to high investment costs.

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