

**PIEDMONT AND UPPER COASTAL PLAIN  
LOBLOLLY PINE SITE PREPARATION  
STUDY:**

**RESULTS THROUGH AGE 21**

Plantation Management Research Cooperative  
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## EXECUTIVE SUMMARY

Results are reported for 19 installations of the PMRC SAGS Loblolly Pine Site Preparation Study through 21 years of age. This study, established during 1986 at a planting density of 545 trees/acre in the Upper Coastal Plain and Piedmont of the southern U.S., examined the impact of the following six site preparation treatments on loblolly pine plantation growth and yield: 1) Burn only (B), 2) Chop and burn (C&B), 3) Shear, pile and disk (S,P&D), 4) Chop, herbicide and burn (C, H&B), 5) Herbicide and burn (H&B), and 6) Herbicide and burn followed by complete weed control during the life of study (H,B&H). All plots were fertilized at age 13. Study plots were not thinned.

Stand development patterns were substantially impacted by the treatments imposed. Loblolly pine mean annual increment in total volume per acre at age 21 was 256 ft<sup>3</sup>/ac for HB&H, 230 ft<sup>3</sup>/ac for SP&D, 228 ft<sup>3</sup>/ac for H&B, 220 ft<sup>3</sup>/ac for C,H&B, 205 ft<sup>3</sup>/ac for C&B, and 159 ft<sup>3</sup>/ac for B. Complete vegetation control implemented in stands receiving operational chemical site preparation (H&B) provided a long term growth response. Operational site preparation (H&B) and heavy mechanical site preparation (S,P&D) resulted in similar yield. Chopping six to eight weeks prior to chemical site preparation and burning (C,H&B) was not as effective as the simple chemical site preparation and burning (H&B). Burning alone (B) did not effectively control the larger hardwoods; pine survival stocking and growth rates were mediocre on burn only plots.

By age 21, treatment responses for mean DBH and dominant height relative to the burn only treatment had peaked and were either being maintained or in decline; for total and merchantable volumes per acre and total and merchantable green weights per acre, only the H,B&H treatment responses had peaked and were being maintained in contrast to responses to other treatment that continued to increase. Stand age and response magnitude at age of maximum response and response type were determined for each treatment.

The temporal patterns of response to site preparation and vegetation control have implications regarding timing of treatments such as thinning and fertilization as well as financial return. The data and response trends will be used with other data to refine PMRC treatment response functions.

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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 different silvicultural systems.

In 1986, the Plantation Management Research Cooperative (PMRC) 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 Upper Coastal Plain and the Piedmont of the southern U.S. This report details results on a total of 19 installations through age 21 and follows on previous PMRC reports (Borders, 2004; Harrison, 2002; Martin and Shiver, 2000). 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 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 0.5 acre plots were established, each with an interior 0.2 acre measurement plot. The following six site preparation treatments were randomly assigned to the treatment plots at each location.

1. Burn (**B**): Broadcast burn in August.
2. Chop and burn (**C&B**): Single pass with a drum roller chopper in June followed by a broadcast burn in August.

3. Shear, pile and disk (**S,P&D**): Sheared with KG blade. The site was flat harrowed in June following debris removal.
4. 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.
5. 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.
6. 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.

Each installation also contained a replicate of one treatment to account for the error within locations. This treatment was randomly selected from treatments 2 through 6.

The plots were hand-planted with first-generation, improved planting stock during the winter of 1985-1986 at an 8' by 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 approximately 545 trees per acre across all installations.

Analysis of the age 12 SAGS site preparation data indicated the need for fertilization. All plots were fertilized at age 13. The fertilization treatment was 200 lbs N and 25 lbs P (125 lbs DAP and 385 lbs Urea) per acre.

After 21 years, 19 of the original 25 installations were viable; two were damaged by thinning between ages 15 and 18 and another four were lost by thinning or bark beetle during the age 18 to 22 year period. Only the 19 installations active at age 21 are reported here. See earlier PMRC reports for results from the more complete study set at earlier ages.

### **3 METHODS AND PROCEDURES**



After the third growing season tree heights were measured, crown class was recorded and all trees were examined for the incidence of fusiform rust stem galls (*Cronartium quercum* f.sp. *fusiforme*). After the sixth, ninth, twelfth, fifteenth, eighteenth, and twenty-first 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:

$$\ln(H) = \alpha + \beta \frac{1}{Dbh} \quad (1)$$

where  $H$  = tree height,

$Dbh$  = tree Dbh,

$\alpha, \beta$  = 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  $\times$  treatment interaction were treated as random factors, and site preparation treatment was treated as a fixed factor.

Analyses were carried out on average Dbh, average height, average dominant height, survival, percent rust infection, basal area per acre, total and merchantable volumes per acre, and total and merchantable stem green weights per acre. Pairwise comparisons were conducted to rank site preparation treatments. Orthogonal contrasts were also used to isolate the effects of particular site preparation treatments; for example an orthogonal contrast was conducted to compare the operational mechanical treatments (C&B and S,P&D) and the operational chemical site preparation treatment (H&B). Differences among treatments are reported in terms of least-squares means. All statistical tests were conducted at the  $\alpha = 0.05$  significance level. To obtain the correct degree of freedom the Satterthwaite option in SAS<sup>®</sup>'s PROC MIXED procedure was used.

Compared with the burn only treatment (**B**), the response due to other site preparation treatments were calculated as differences in least squares means. Response patterns over time were characterized by response type, maximum response and age at time of maximum response. Four general response types were identified:

Type A – response magnitude increases with time;

Type B – response peak is attained and maintained to within 90% of the maximum value;

Type C – response peaks and diminishes somewhat with time;

Type D – response peaks and with time diminishes to zero or less than zero.

## 4 RESULTS

### 4.1 Average Tree and Stand Values over Time

The p-values from the test of the main effect, site preparation treatment, for each of the dependent variables in the study at each measurement age are shown in Table 1. Site preparation treatment significantly affected all stand attributes assessed for each measurement period with the exception of percentage of trees with fusiform rust stem galls.

**Table 1. P-values of ANOVA analyses of site preparation treatment effect for each dependent variable at each measurement age.**

| Dependent Variable         | Age 6   | Age 9   | Age 12  | Age 15  | Age 18  | Age 21  |
|----------------------------|---------|---------|---------|---------|---------|---------|
| Average Dbh                | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Average Height             | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Average Dominant Height    | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Basal Area                 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Total Volume               | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Merchantable Volume        | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Total Stem Green Weight    | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Merchantable Green Weight  | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Trees per Acre             | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Percent Fusiform Infection | 0.935   | 0.5573  | 0.1104  | 0.2128  | 0.2942  | 0.2607  |

#### 4.1.1 Average Dbh

Site preparation treatment significantly affected average Dbh through age 21 years (Table 1). Average Dbh values for ages 6, 9, 12, 15, 18, and 21 years are shown by treatment in Table 2 and Figure 1. As expected, the burn only treatment (B) shows the smallest average Dbh through age 21 years and the most intensive treatment (H,B&H) has the largest average Dbh through age 21 years. Average Dbh generally increased as the treatment intensity increased. However, at age 6, no significant differences were detected between the herbicide and burn (H&B), the shear, pile and disk (S,P&D), and the chop, herbicide and burn (C,H&B), and between the chop and burn (C&B), S,P&D and C,H&B treatments. During the period from age 9 to age 18, there were no significant differences between C&B, S,P&D, C,H&B, and H&B treatments. By age 21 average diameter for C&B, S,P&D, C,H&B, and H&B treatments were becoming very similar with values of 8.5, 8.2, 8.4 and 8.4 inches, respectively. At this age the burn only treatment still has the smallest average Dbh of 7.6 inches, the most intensive treatment (H,B&H) has the largest average Dbh of 8.8 inches and no significant difference exist among the (C&B), (C,H&B) and (H&B) treatments.

**Table 2. Least square means for average Dbh (inches) by site preparation treatment and measurement age.**

| Treatment | Age 6 |    | Age 9 |   | Age 12 |   | Age 15 |   | Age 18 |   | Age 21 |    |
|-----------|-------|----|-------|---|--------|---|--------|---|--------|---|--------|----|
| B         | 1.9   | A  | 3.6   | a | 4.9    | a | 5.8    | a | 6.7    | a | 7.6    | a  |
| C&B       | 2.5   | B  | 4.6   | b | 5.9    | b | 6.8    | b | 7.7    | b | 8.5    | bc |
| S,P&D     | 2.8   | Bc | 4.8   | b | 6.1    | b | 6.8    | b | 7.5    | b | 8.2    | b  |
| C,H&B     | 2.8   | Bc | 4.8   | b | 6.0    | b | 6.9    | b | 7.7    | b | 8.4    | bc |
| H&B       | 3.1   | C  | 4.9   | b | 6.2    | b | 6.9    | b | 7.7    | b | 8.4    | bc |
| H,B&H     | 4.2   | D  | 5.9   | c | 7.0    | c | 7.6    | c | 8.2    | c | 8.8    | c  |

**Note: For a given age, different letters indicate significant differences between site preparation treatments.**

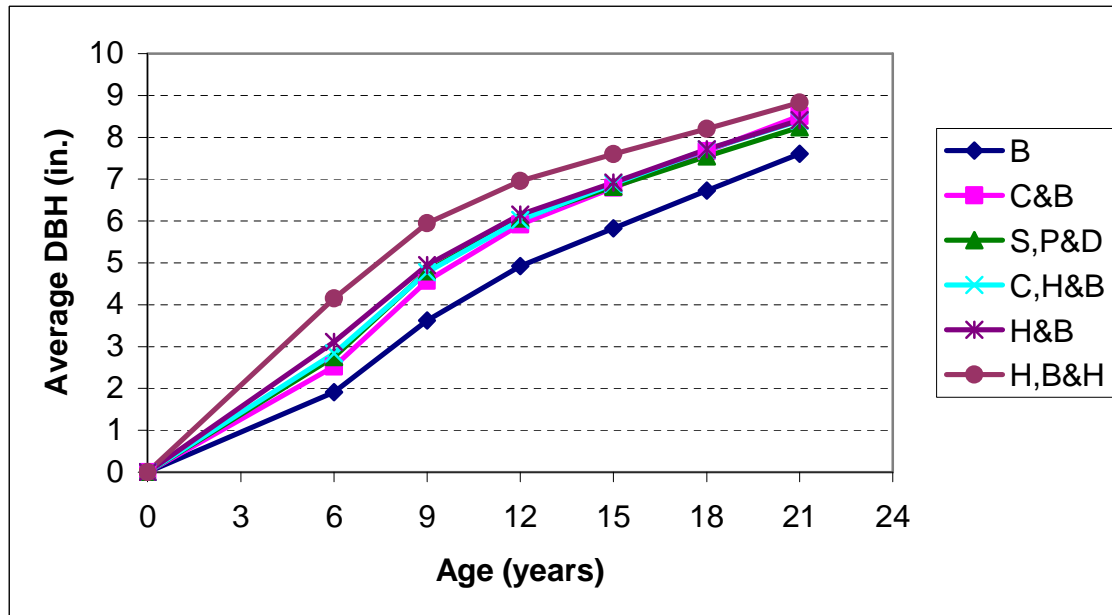


Figure 1. Average Dbh growth trends by site preparation treatment.

The contrast analysis indicated a significant difference between the operational chemical and operational mechanical preparation treatments (H&B vs. C&B + C,P&D) and the chemical treatments increased Dbh over the mechanical treatments at age 6. Thereafter, the differences in average Dbh between the operational chemical and operational mechanical preparation treatments were not significant.

Compared with the burn only treatment, average Dbh responses to other site preparation treatments are shown in Figure 2. The most intensive treatment (H,B&H) significantly improved Dbh growth and the gains from this treatment were significantly and consistently greater than that from other treatments. The maximum responses to the C&B, S,P&D, C,H&B, H&B, and H,B&H treatments were 1.0, 1.2, 1.2, 1.3, and 2.3 inches, and response types were Type B, C, C, C and C, respectively; maximum responses were observed at age 9 for all treatments.

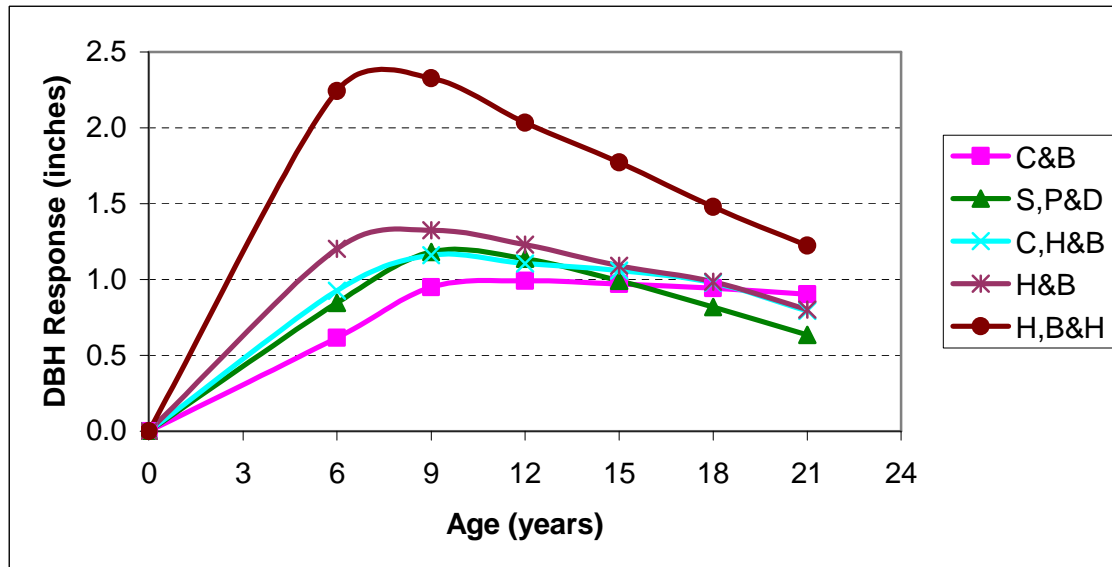


Figure 2. Dbh response as measured by the difference between the chop and burn (C&B), shear, pile and disk (S,P&D), chop, herbicide and burn (C,H&B), herbicide and burn (H&B), or herbicide, burn and herbicide (H,B&H) treatments and the burn treatment (B).

#### 4.1.2 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 (Table 3, Figure 3). As observed for average Dbh, the burn only treatment (B) shows the smallest average height through age 21 years and the most intensive treatment (H,B&H) has the largest average height through age 21 years. Significant differences between the C&B, S,P&D, C,H&B and H&B treatments exist through age 18, but the differences between the S,P&D, C,H&B and H&B treatments are not significant at age 21. At age 21, H,B&H treatment shows an increase of 2.1 feet over the H&B treatment and 8.9 feet over the B treatment. The operational chemical treatment (H&B) significantly increased average height over the operational mechanical treatments (C&B + C,P&D) at ages 6 and 9 years; thereafter, there was no significant difference in average height between them.

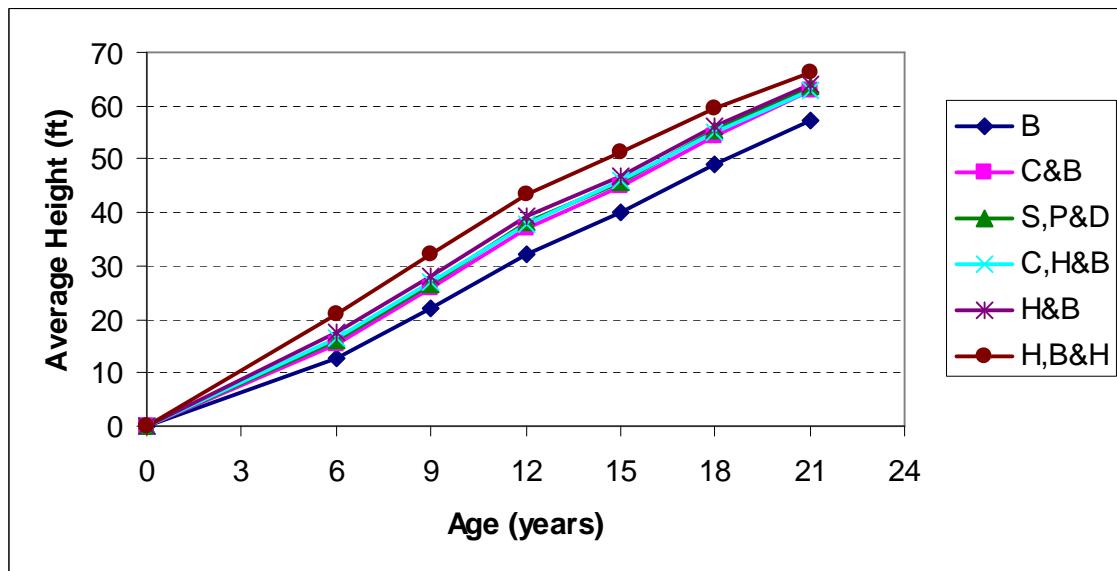
The most intensive treatment (H,B&H) significantly improved height growth and the gains from this treatment were significantly and consistently greater than that from other

treatments (Figure 4). The maximum responses to the C&B, S,P&D, C,H&B, H&B, and H,B&H treatments were 5.5, 6.3, 6.2, 7.1, and 11.2 feet, respectively; the corresponding ages at maximum responses were 21, 18, 18, 18 and 12 years, and response types were Type A, B, B, B and C, respectively.

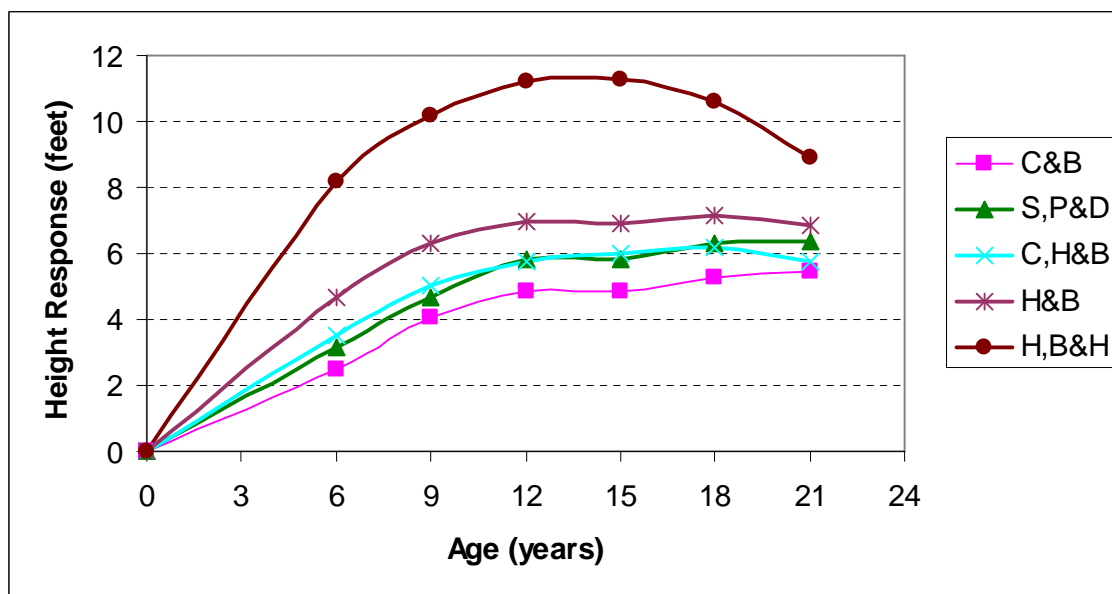
**Table 3. Least square means for average height (feet) by site preparation treatment and measurement age.**

| Treatment | Age 6 |    | Age 9 |   | Age 12 |   | Age 15 |   | Age 18 |   | Age 21 |    |
|-----------|-------|----|-------|---|--------|---|--------|---|--------|---|--------|----|
| B         | 12.8  | a  | 21.9  | a | 32.2   | a | 40.0   | a | 49.0   | a | 57.2   | a  |
| C&B       | 15.3  | b  | 26.0  | b | 37.1   | b | 44.8   | b | 54.3   | b | 62.7   | b  |
| S,P&D     | 16.0  | bc | 26.6  | b | 38.1   | b | 45.8   | b | 55.3   | b | 63.6   | bc |
| C,H&B     | 16.4  | bc | 26.9  | b | 38.0   | b | 46.0   | b | 55.2   | b | 63.0   | b  |
| H&B       | 17.5  | c  | 28.2  | b | 39.2   | b | 46.9   | b | 56.1   | b | 64.1   | bc |
| H,B&H     | 21.0  | d  | 32.1  | c | 43.4   | c | 51.2   | c | 59.6   | c | 66.2   | c  |

Note: For a given age, different letters indicate significant differences between site preparation treatments.



**Figure 3. Average height growth trends by site preparation treatment.**



**Figure 4.** Average height response as measured by the difference between the chop and burn (C&B), shear, pile and disk (S,P&D), chop, herbicide and burn (C,H&B), herbicide and burn (H&B), or herbicide, burn and herbicide (H,B&H) treatments and the burn treatment (B)

#### 4.1.3 Average Dominant Height

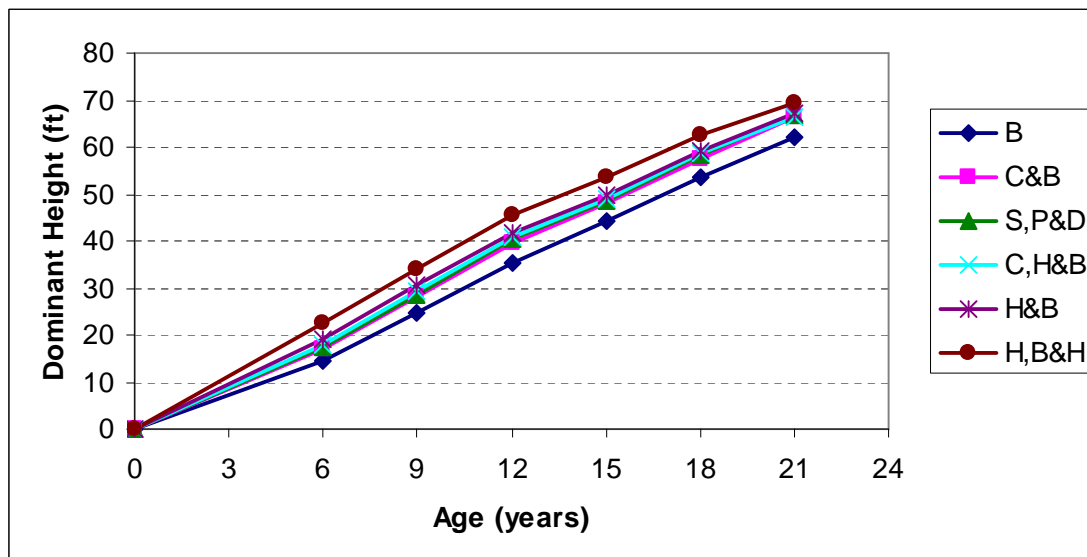
A tree was considered a dominant tree if it was in the upper 50% of diameters on the plot. Average height of these dominant trees was defined as average dominant height. Site preparation treatment significantly affected average dominant height through age 21 years (Table 1). Average dominant heights by site preparation treatment and measurement age are shown in Table 4 and Figure 5. As observed for average height, average dominant heights for treatments between the burn only treatment (B) and the most intensive treatment (H,B&H) are converging as the stands age (Table 4). At age 21, the H,B&H treatment shows an increase of 2.1 feet over H&B treatment and 7.2 feet over the B treatment. The operational chemical treatment (H&B) significantly increased average dominant height over the operational mechanical treatments (C&B + C,P&D) from ages 6 to 15 years; thereafter, no significant difference in average dominant height between them was detected.

The most intensive treatment (H,B&H) significantly improved height growth, compared with other treatments (Figure 6). The dominant height maximum responses to the C&B, S,P&D, C,H&B, H&B, and H,B&H treatments were 4.2, 4.9, 5.2, 6.3, and 10.0 feet, respectively; the age at maximum response was age 12 years, and response types were Type B, B, C,C and C, respectively.

**Table 4. Least square means for average dominant height (feet) by site preparation treatment and measurement age.**

| Treatment | Age 6 |    | Age 9 |    | Age 12 |   | Age 15 |   | Age 18 |   | Age 21 |    |
|-----------|-------|----|-------|----|--------|---|--------|---|--------|---|--------|----|
| B         | 14.7  | a  | 24.9  | a  | 35.5   | a | 44.2   | a | 53.7   | a | 62.3   | a  |
| C&B       | 16.9  | b  | 28.3  | b  | 39.7   | b | 48.0   | b | 57.6   | b | 66.4   | b  |
| S,P&D     | 17.7  | bc | 28.5  | bc | 40.4   | b | 48.6   | b | 58.3   | b | 66.7   | b  |
| C,H&B     | 18.0  | bc | 29.2  | bc | 40.7   | b | 49.1   | b | 58.5   | b | 66.6   | b  |
| H&B       | 19.2  | c  | 30.5  | c  | 41.8   | b | 49.9   | b | 59.2   | b | 67.4   | bc |
| H,B&H     | 22.6  | d  | 33.9  | d  | 45.5   | c | 53.8   | c | 62.5   | c | 69.5   | c  |

Note: For a given age, different letters indicate significant differences between site preparation treatments.



**Figure 5. Average dominant height growth trends by site preparation treatment.**



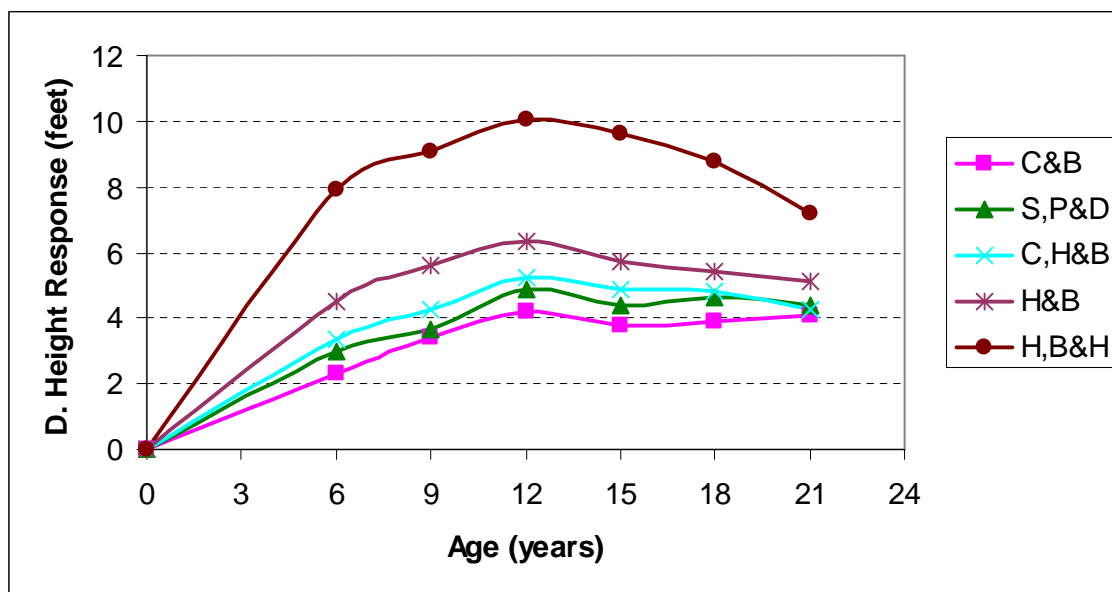


Figure 6. Dominant height response as measured by the difference between burn treatment (B) and chop and burn (C&B), shear, pile and disk (S,P&D), chop, herbicide and burn (C,H&B), herbicide and burn (H&B), or herbicide, burn and herbicide (H,B&H) treatments.

#### 4.1.4 Basal Area per Acre

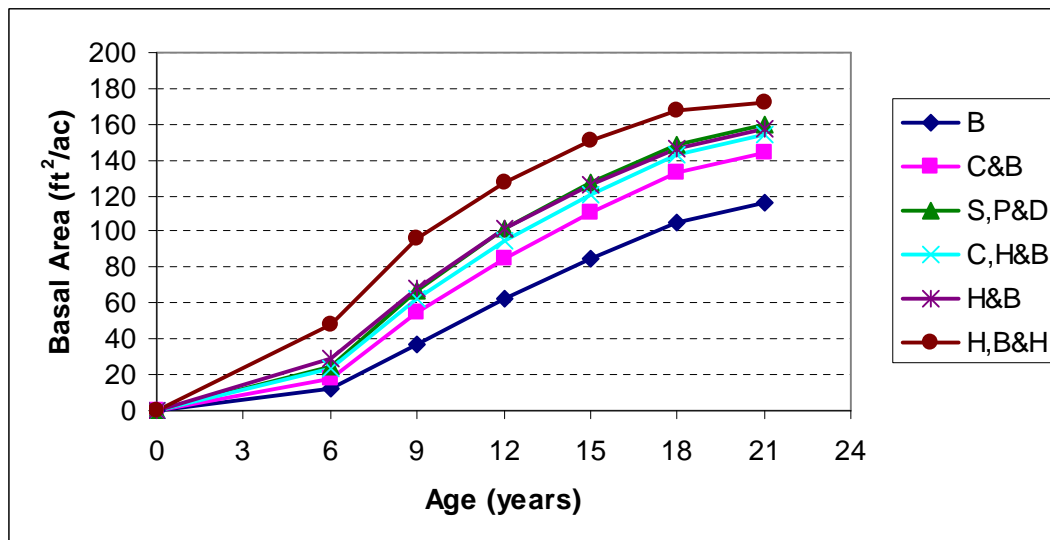
Site preparation treatment significantly affected stand basal area (Table 1). The largest increase in stand basal area is associated with the complete vegetation control treatment (H,B&H) at all ages through 21 years (Table 5 and Figure 7). At age 21 years, chopping and burning (C&B) increased basal area by 28.0 ft<sup>2</sup>/ac over burn only (B) whereas the operational herbicide application following a burn (H&B) showed an increase of 41.1 ft<sup>2</sup>/ac over the burn only treatment. Complete vegetation control (H,B&H) had 15.0 ft<sup>2</sup>/ac more than the H&B treatment at age 21 which was smaller than the 21.3 ft<sup>2</sup>/ac difference at age 18, the 24.7 ft<sup>2</sup>/ac difference at age 15, the 26.3 ft<sup>2</sup>/ac difference at age 12, and the 27.6 ft<sup>2</sup>/ac difference at age 9. At age 21, complete vegetation control treatment (H,B&H) was not significantly different from the operational herbicide application following a burn (H&B), the chop, herbicide and burn (C,H&B) treatment, and the intensive mechanical treatment (S,P&D), although it resulted in significant increase in stand basal area over the chop and burn (C&B), and burn only (B) treatments.

The operational chemical treatment (H&B) significantly increased stand basal area over the mechanical treatments (C&B + C,P&D) from ages 6 to 9 years. Thereafter, however, the differences in stand basal area between the operational chemical and operational mechanical preparation treatments were not significant.

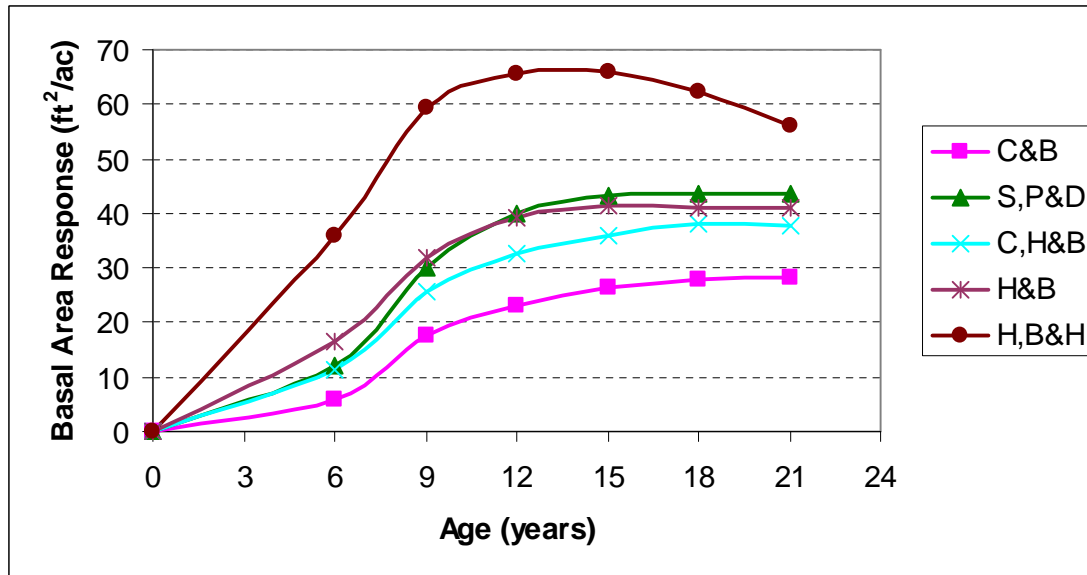
**Table 5. Least square means for basal area (ft<sup>2</sup>/ac) by site preparation treatment and measurement age.**

| Treatment | Age 6 |    | Age 9 |    | Age 12 |   | Age 15 |   | Age 18 |    | Age 21 |    |
|-----------|-------|----|-------|----|--------|---|--------|---|--------|----|--------|----|
| B         | 12.2  | a  | 36.8  | a  | 62.2   | a | 84.5   | a | 104.8  | a  | 116.4  | a  |
| C&B       | 18.2  | ab | 54.2  | b  | 85.3   | b | 111.0  | b | 132.6  | b  | 144.4  | b  |
| S,P&D     | 24.2  | bc | 66.9  | bc | 102.0  | b | 127.9  | b | 148.3  | bc | 160.1  | bc |
| C,H&B     | 23.6  | bc | 62.5  | bc | 94.8   | b | 120.5  | b | 143.0  | b  | 154.2  | bc |
| H&B       | 28.6  | c  | 68.6  | c  | 101.5  | b | 125.8  | b | 146.0  | b  | 157.5  | bc |
| H,B&H     | 48.2  | d  | 96.2  | d  | 127.8  | c | 150.5  | c | 167.2  | c  | 172.4  | c  |

**Note:** For a given age, different letters indicate significant differences between site preparation treatments.



**Figure 7. Average per-acre basal area growth trends by site preparation treatment.**



**Figure 8.** Basal area response as measured by the difference between the chop and burn (C&B), shear, pile and disk (S,P&D), chop, herbicide and burn (C,H&B), herbicide and burn (H&B), or herbicide, burn and herbicide (H,B&H) treatments and the burn treatment (B).

Compared with the burn only (B) treatment, basal area responses to other site preparation treatments are presented in Figure 8. The maximum responses of basal area to the C&B, S,P&D, C,H&B, H&B, and H,B&H treatments were 28.0, 43.8, 38.3, 41.3, and 66.0 ft<sup>2</sup>/ac; the corresponding ages at maximum responses were 21, 21, 18, 15 and 15 years, and the response types were Type A, A, B, B and C, respectively.

#### 4.1.5 Total Volume per Acre

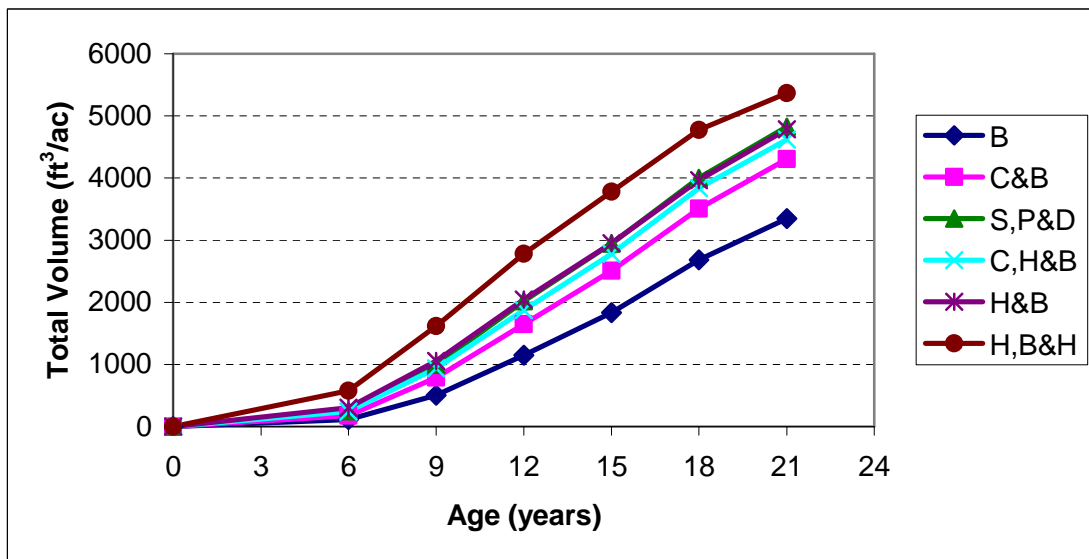
Site preparation treatment significantly affected total volume through age 21 years (Table 1). Total volume increased with increasing intensity of the site preparation treatment (Table 6 and Figure 9). At age 21 total volumes ranged from 3249 ft<sup>3</sup>/ac for the burn only treatment (B) to 5367 ft<sup>3</sup>/ac for the complete vegetation control treatment (H,B&H). The Burn only treatment had significantly less volume than all other treatment. The C&B and C,H&B treatments had no significant difference in total volume, but both had significantly less volume than the complete vegetation control treatment (H,B&H). At age 21, there were not significant differences among the S,P&D, H&B, and H,B&H treatments, although the most intensive treatment (H,B&H) had the highest total volume.

The differences in total volume between the operational chemical and operational mechanical preparation treatments (H&B vs. C&B + C,P&D) were significant from ages 6 to 9 years and the chemical treatments increased total volume over the mechanical treatments in that period. From ages 12 to 21 years, however, the differences in volume between the operational chemical and operational mechanical preparation treatments were no longer significant. The burning only treatment continued to fall further behind all other treatments.

**Table 6. Least square means for total volume (ft<sup>3</sup>/ac) by site preparation treatment and measurement age.**

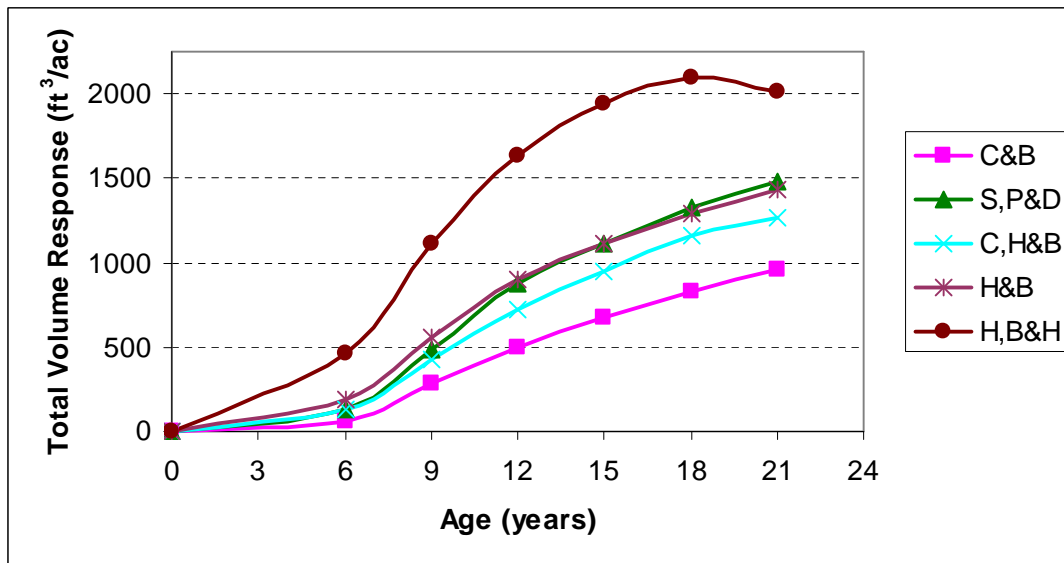
| Treatment | Age 6 |    | Age 9  |    | Age 12 |    | Age 15 |   | Age 18 |   | Age 21 |    |
|-----------|-------|----|--------|----|--------|----|--------|---|--------|---|--------|----|
| B         | 112.5 | A  | 504.5  | a  | 1146.6 | a  | 1835.0 | a | 2681.1 | a | 3348.9 | a  |
| C&B       | 176.9 | ab | 787.8  | b  | 1648.1 | b  | 2508.5 | b | 3509.2 | b | 4305.7 | b  |
| S,P&D     | 248.6 | bc | 991.8  | bc | 2017.3 | bc | 2948.4 | b | 4004.0 | b | 4825.9 | bc |
| C,H&B     | 240.2 | bc | 935.0  | bc | 1874.5 | bc | 2780.4 | b | 3839.0 | b | 4620.0 | b  |
| H&B       | 305.4 | C  | 1057.0 | c  | 2045.7 | c  | 2949.6 | b | 3967.5 | b | 4786.1 | bc |
| H,B&H     | 578.5 | D  | 1616.1 | d  | 2779.0 | d  | 3777.9 | c | 4774.7 | c | 5367.3 | c  |

Note: For a given age, different letters indicate significant differences between site preparation treatments.



**Figure 9. Average per-acre total volume growth trends by site preparation treatment.**

Total volume responses to site preparation treatments, compared with the burn only (B) treatment, are presented in Figure 10. The maximum responses to the C&B, S,P&D, C,H&B, and H&B treatments were 957, 1477, 1271, and 1437 ft<sup>3</sup>/ac at age 21 years with Type A response, respectively; The maximum response to H,B&H treatment was 2094 ft<sup>3</sup>/ac at age 18 years with Type B response.



**Figure 10.** Total volume response as measured by the difference between burn treatment (B) and chop and burn (C&B), shear, pile and disk (S,P&D), chop, herbicide and burn (C,H&B), herbicide and burn (H&B), or herbicide, burn and herbicide (H,B&H) treatments.

#### 4.1.6 Merchantable Volume per Acre

The results for merchantable volume follow identical trends 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 7 and Figure 11). The chop and burn treatment (C&B) had 971 ft<sup>3</sup>/ac more merchantable volume than the burn only treatment (B) at age 21 which was greater than the 851 ft<sup>3</sup>/ac difference at age 18 and the 700 ft<sup>3</sup>/ac difference at age 15. The herbicide and burn treatment (H&B) increased merchantable volume by 1449 ft<sup>3</sup>/ac over the burn only treatment at age 21 which was also greater than the 1311 ft<sup>3</sup>/ac difference at age 18 and the 1141 ft<sup>3</sup>/ac difference at age 15. Complete vegetation control (H,B&H) resulted in an increase of 583 ft<sup>3</sup>/ac over the herbicide and burn

treatment (H&B) at age 21 which was smaller than the 812 ft<sup>3</sup>/ac difference at age 18, the 840 ft<sup>3</sup>/ac difference at age 15, and the 751 ft<sup>3</sup>/ac difference at age 12. The burn only treatment continued to fall further behind all other treatments.

The operational chemical treatments increased merchantable volume over the operational mechanical treatments. The differences in merchantable volume between them were significant during the period from ages 6 to 9 years; thereafter, however, this difference was not significant.

**Table 7. Least square means for merchantable volume (ft<sup>3</sup>/ac) by site preparation treatment and measurement age.**

| Treatment | Age 6 |   | Age 9  |    | Age 12 |   | Age 15 |   | Age 18 |   | Age 21 |    |
|-----------|-------|---|--------|----|--------|---|--------|---|--------|---|--------|----|
| B         | 26.5  | a | 385.0  | a  | 1055.8 | a | 1765.1 | a | 2623.1 | a | 3310.5 | a  |
| C&B       | 31.7  | a | 701.7  | b  | 1597.2 | b | 2465.0 | b | 3474.3 | b | 4281.1 | b  |
| S,P&D     | 67.4  | a | 911.2  | bc | 1973.8 | b | 2912.1 | b | 3971.4 | b | 4798.2 | bc |
| C,H&B     | 70.6  | a | 857.8  | bc | 1828.1 | b | 2739.7 | b | 3805.6 | b | 4594.7 | b  |
| H&B       | 123.4 | a | 979.8  | c  | 1996.1 | b | 2907.4 | b | 3933.7 | b | 4759.3 | bc |
| H,B&H     | 464.9 | b | 1579.3 | d  | 2747.2 | c | 3747.2 | c | 4746.1 | c | 5342.3 | c  |

Note: For a given age, different letters indicate significant differences between site preparation treatments.

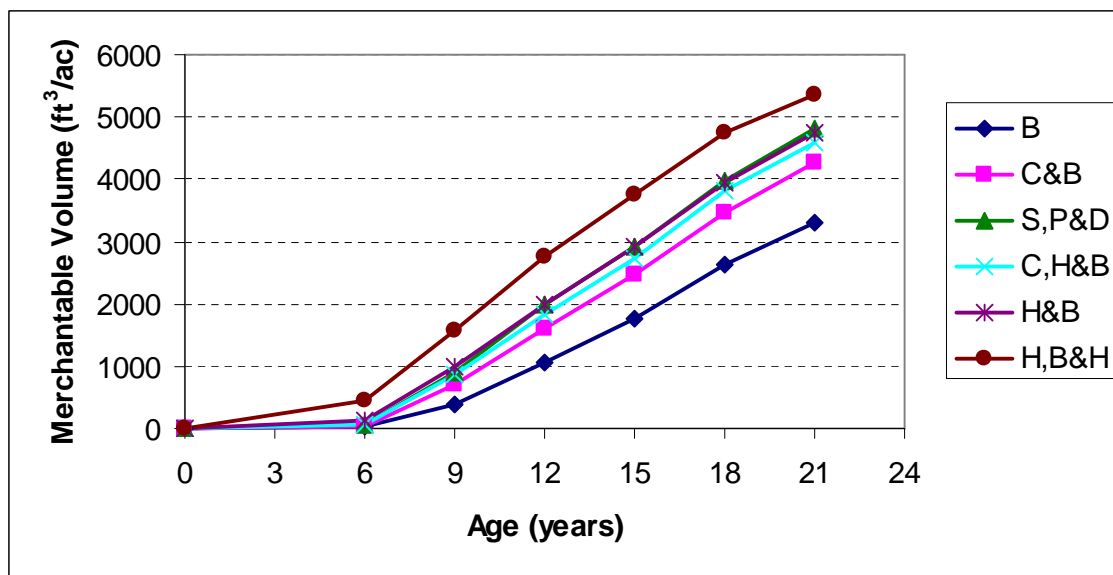
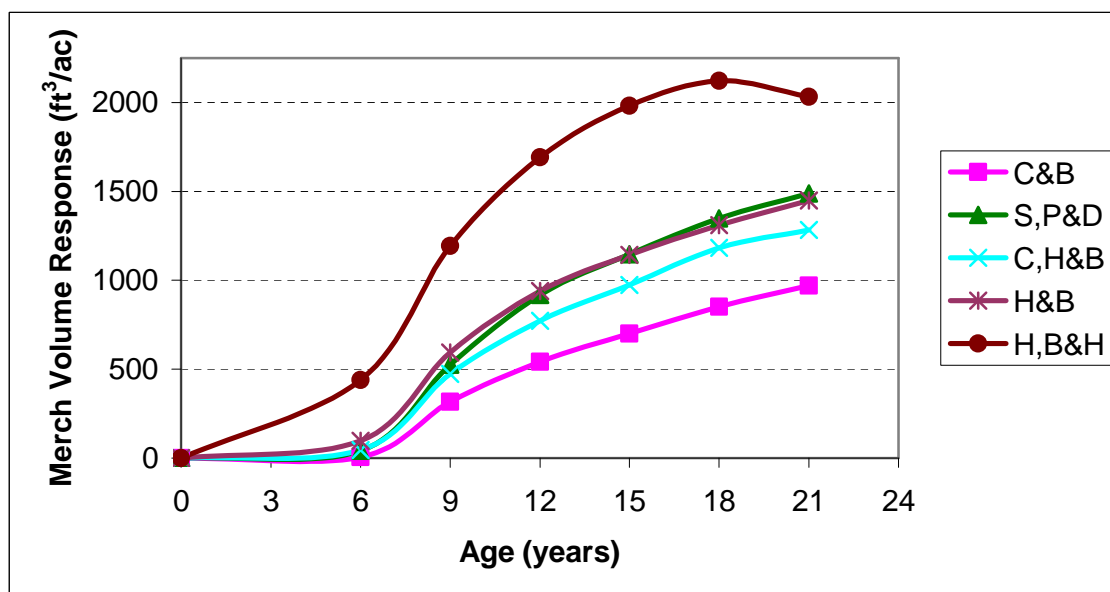


Figure 11. Average merchantable volume growth trends by site preparation treatment.



**Figure 12. Merchantable volume response as measured by the difference between burn treatment (B) and chop and burn (C&B), shear, pile and disk (S,P&D), chop, herbicide and burn (C,H&B), herbicide and burn (H&B), or herbicide, burn and herbicide (H,B&H) treatments.**

Merchantable volume responses to site preparation treatments, compared with the burn only (B) treatment, are presented in Figure 12. The merchantable volume maximum responses to the C&B, S,P&D, C,H&B, and H&B treatments were 971, 1488, 1284, and 1449 ft<sup>3</sup>/ac at age 21 years with Type A response, respectively; The maximum response to H,B&H treatment was 2123 ft<sup>3</sup>/ac at age 18 years with Type B response.

#### 4.1.7 Total Stem Green Weight per Acre

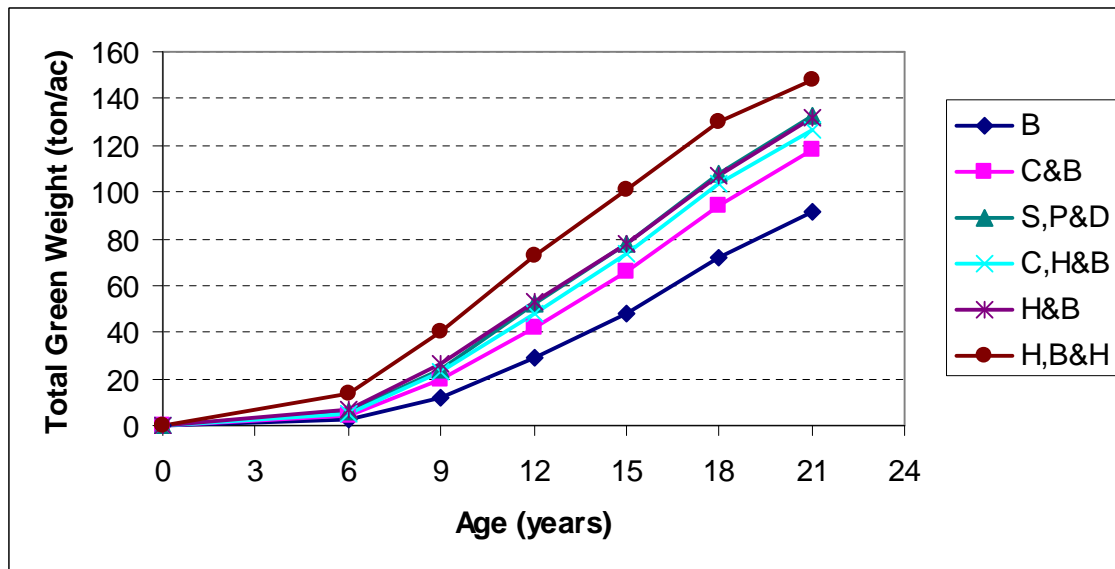
Site preparation treatment significantly affected total stem green weight through age 21 years (Table 1). As observed for total volume, total stem green weight increased with increasing intensity of the site preparation treatment (Table 8 and Figure 13). At age 21 total stem green weight ranged from 91.2 ton/ac for the burn only treatment (B) to 148.4 ton/ac for the complete vegetation control treatment (H,B&H). The Burn only treatment had significantly less volume than all other treatments. The C&B and C,H&B treatments had no significant difference in total stem green weight, but both had significantly less green weight than the complete vegetation control treatment (H,B&H). At age 21, there

were not significant differences among the S,P&D, H&B and H,B&H treatments, although the most intensive treatment (H,B&H) had the highest total stem green weight.

**Table 8. Least square means for total stem green weight (ton/ac) by site preparation treatment and measurement age.**

| Treatment | Age 6 |    | Age 9 |    | Age 12 |    | Age 15 |   | Age 18 |   | Age 21 |    |
|-----------|-------|----|-------|----|--------|----|--------|---|--------|---|--------|----|
| B         | 2.6   | a  | 12.3  | a  | 29.2   | a  | 47.9   | a | 71.7   | a | 91.2   | a  |
| C&B       | 4.1   | ab | 19.3  | b  | 42.2   | b  | 65.8   | b | 94.4   | b | 118.0  | b  |
| S,P&D     | 5.8   | bc | 24.4  | bc | 51.8   | bc | 77.6   | b | 108.0  | b | 132.3  | bc |
| C,H&B     | 5.6   | bc | 23.0  | bc | 48.2   | bc | 73.2   | b | 103.5  | b | 126.8  | b  |
| H&B       | 7.2   | c  | 26.2  | c  | 52.8   | c  | 77.9   | b | 107.2  | b | 131.6  | bc |
| H,B&H     | 13.8  | d  | 40.6  | d  | 72.6   | d  | 100.9  | c | 130.1  | c | 148.4  | c  |

Note: For a given age, different letters indicate significant differences between site preparation treatments.



**Figure 13. Average total stem green weight growth trends by site preparation treatment.**



The differences in total stem green weight between the operational chemical and operational mechanical preparation treatments (H&B vs. C&B + C,P&D) were significant from ages 6 to 9 years and the chemical treatments increased total stem green weight over the mechanical treatments in that period. After that period, however, the differences in total green weight between the operational chemical and operational mechanical site preparation treatments were no longer significant. The burn only treatment continued to fall further behind all other treatments.

Compared with the burn only (B) treatment, total green weight responses to site preparation treatments are presented in Figure 14. The maximum responses to the C&B, S,P&D, C,H&B, and H&B treatments were 26.8, 41.1, 35.6, and 40.4 ton/ac at age 21 years with Type A response, respectively; The maximum response to H,B&H treatment was 58.4 ton/ac at age 18 years with Type B response.

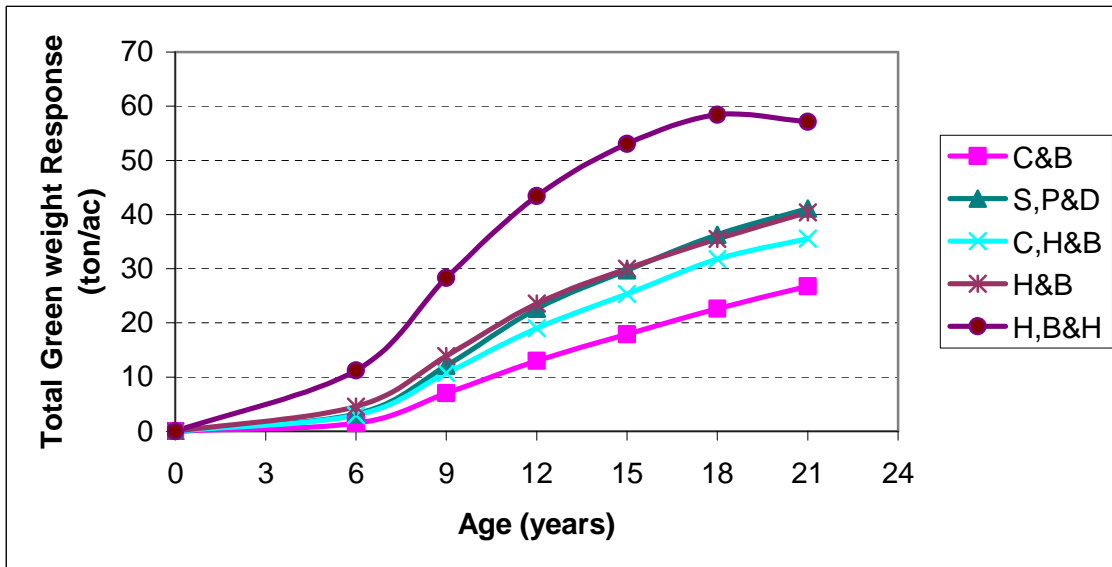


Figure 14. Total stem green weight response as measured by the difference between burn treatment (B) and chop and burn (C&B), shear, pile and disk (S,P&D), chop, herbicide and burn (C,H&B), herbicide and burn (H&B), or herbicide, burn and herbicide (H,B&H) treatments.

#### 4.1.8 Merchantable Green Weight per Acre

The results for merchantable stem green weight follow identical trends as for total stem green weight (Table 9 and Figure 15). The chop and burn treatment (C&B) had 27.1 ton/ac more merchantable green weight than the burn only treatment (B) at age 21, which was greater than the 23.2 ton/ac difference at age 18 and the 18.5 ton/ac difference at age 15. The herbicide and burn treatment (H&B) increased merchantable green weight by 40.6 ton/ac over the burn only treatment at age 21, which was greater than the 36.1 ton/ac difference at age 18 and the 30.6 ton/ac difference at age 15. Complete vegetation control (H,B&H) resulted in an increase of 16.8 ton/ac over the herbicide and burn treatment (H&B) at age 21 which was smaller than the 23.0 ton/ac difference at age 18, the 23.0 ton/ac difference at age 15, and the 20.2 ton/ac difference at age 12. The burn only treatment continued to fall further behind all other treatments.

The operational chemical treatments increased merchantable stem green weight over the operational mechanical treatments. The differences in merchantable green weight between them were significant only at age 9.

Compared with the burn only (B) treatment, merchantable green weight responses to site preparation treatments are presented in Figure 16. The merchantable green weight maximum responses to the C&B, S,P&D, C,H&B, and H&B treatments were 27.1, 41.3, 35.8, and 40.6 ton/ac at age 21 years with Type A response, respectively; The maximum response to H,B&H treatment was 59.1 ton/ac at age 18 years with Type B response.

**Table 9. Least square means for merchantable stem green weight (ton/ac) by site preparation treatment and measurement age.**

| Treatment | Age 6 |   | Age 9 |    | Age 12 |    | Age 15 |   | Age 18 |   | Age 21 |    |
|-----------|-------|---|-------|----|--------|----|--------|---|--------|---|--------|----|
| B         | 0.3   | a | 9.4   | a  | 26.9   | a  | 46.1   | a | 70.1   | a | 90.1   | a  |
| C&B       | 0.7   | a | 17.2  | b  | 40.8   | b  | 64.6   | b | 93.3   | b | 117.2  | b  |
| S,P&D     | 1.8   | a | 22.4  | bc | 50.6   | bc | 76.5   | b | 107.0  | b | 131.4  | bc |
| C,H&B     | 2.0   | a | 21.1  | bc | 47.0   | bc | 72.1   | b | 102.5  | b | 126.0  | b  |
| H&B       | 3.0   | a | 24.3  | c  | 51.4   | c  | 76.7   | b | 106.2  | b | 130.7  | bc |
| H,B&H     | 11.7  | b | 39.6  | d  | 71.7   | d  | 100.0  | c | 129.2  | c | 147.6  | c  |

**Note: For a given age, different letters indicate significant differences between site preparation treatments.**

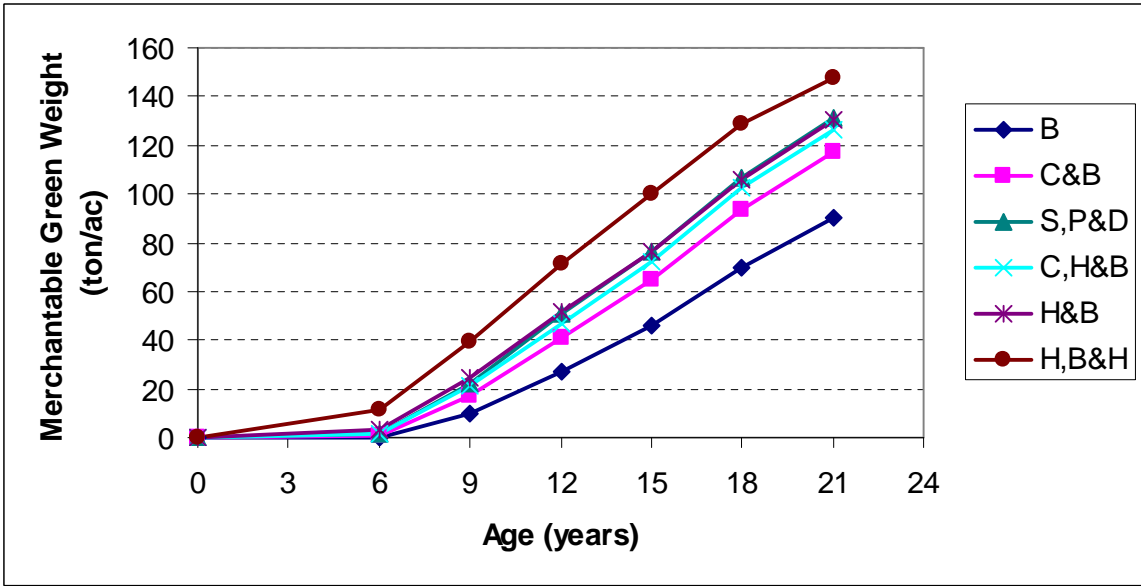


Figure 15. Average merchantable stem green weight growth trends by site preparation treatment.

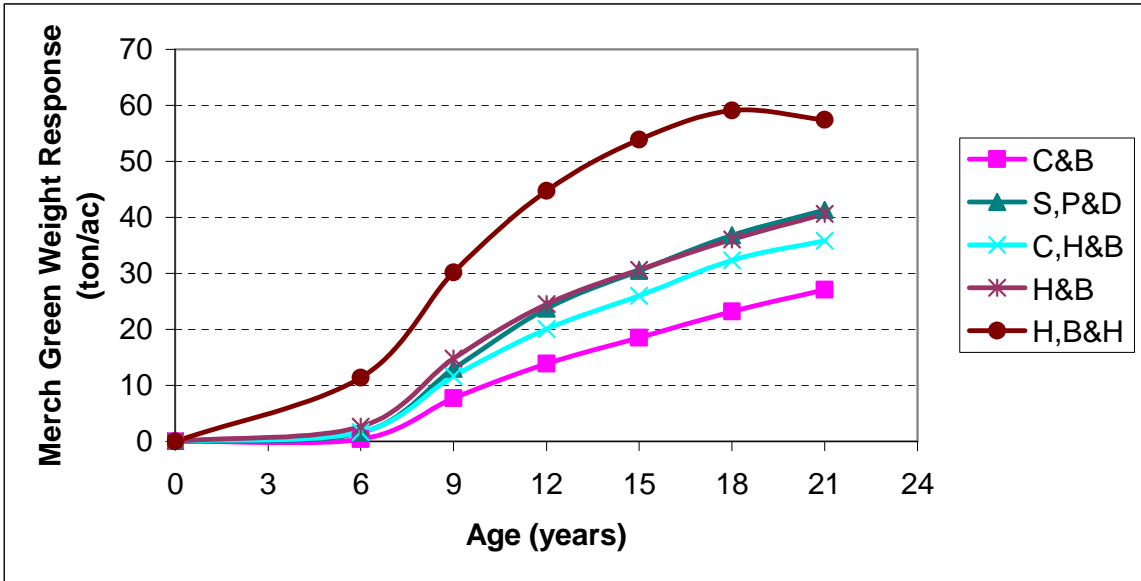


Figure 16. Merchantable stem green weight response as measured by the difference between burn treatment (B) and chop and burn (C&B), shear, pile and disk (S,P&D), chop, herbicide and burn (C,H&B), herbicide and burn (H&B), or herbicide, burn and herbicide (H,B&H) treatments.

#### 4.1.9 Summary of Treatment Response Patterns

Characteristics of response patterns for the different stand attributes to the different treatments as compared to the burn only treatment are shown in Table 10. The age of maximum response varied markedly with response attribute; Dbh response peaked at an early age, followed by height response whereas per acre basal area, volume, and weight responses were, for all treatments with the exception of H,B&H, increasing throughout the 21 year period.

**Table 10. Attributes of temporal patterns in response in average Dbh (in.), average height (H, ft), average dominant height (HD, ft), basal area per acre (BA, ft<sup>2</sup>/ac), total volume per acre (TVOB, ft<sup>3</sup>/ac), merchantable volume per acre (MVOB, ft<sup>3</sup>/ac), total stem green weight per acre (TGW, ton/ac), and merchantable stem green weight per acre (MGW, ton/ac) for different site preparation treatments, compared with the burning only treatment.**

| TRT   | Response                   | DBH | H    | HD   | BA   | TVOB | MVOB | TGW  | MGW  |
|-------|----------------------------|-----|------|------|------|------|------|------|------|
| C&B   | Response Type <sup>a</sup> | B   | A    | B    | A    | A    | A    | A    | A    |
|       | Maximum response           | 1.0 | 5.5  | 4.2  | 28.0 | 957  | 971  | 26.8 | 27.1 |
|       | Age at maximum response    | 9   | 21   | 12   | 21   | 21   | 21   | 21   | 21   |
| S,P&B | Response Type <sup>a</sup> | C   | B    | B    | A    | A    | A    | A    | A    |
|       | Maximum response           | 1.2 | 6.3  | 4.9  | 43.8 | 1477 | 1488 | 41.1 | 41.3 |
|       | Age at maximum response    | 9   | 18   | 12   | 21   | 21   | 21   | 21   | 21   |
| C,H&B | Response Type <sup>a</sup> | C   | B    | C    | B    | A    | A    | A    | A    |
|       | Maximum response           | 1.2 | 6.2  | 5.2  | 38.3 | 1271 | 1284 | 35.6 | 35.8 |
|       | Age at maximum response    | 9   | 18   | 12   | 18   | 21   | 21   | 21   | 21   |
| H&B   | Response Type <sup>a</sup> | C   | B    | C    | B    | A    | A    | A    | A    |
|       | Maximum response           | 1.2 | 7.1  | 6.3  | 41.3 | 1437 | 1449 | 40.4 | 40.6 |
|       | Age at maximum response    | 9   | 18   | 12   | 15   | 21   | 21   | 21   | 21   |
| H,B&H | Response Type <sup>a</sup> | C   | C    | C    | C    | B    | B    | B    | B    |
|       | Maximum response           | 2.3 | 11.2 | 10.0 | 66.0 | 2094 | 2123 | 58.4 | 59.1 |
|       | Age at maximum response    | 9   | 12   | 12   | 15   | 18   | 18   | 18   | 18   |

<sup>a</sup> Type A – response magnitude increase with time; Type B – response peak is attained and maintained; Type C – response peaks and diminishes somewhat with time; Type D – response peaks and with time diminishes to zero or negative.

#### 4.1.10 Trees per Acre

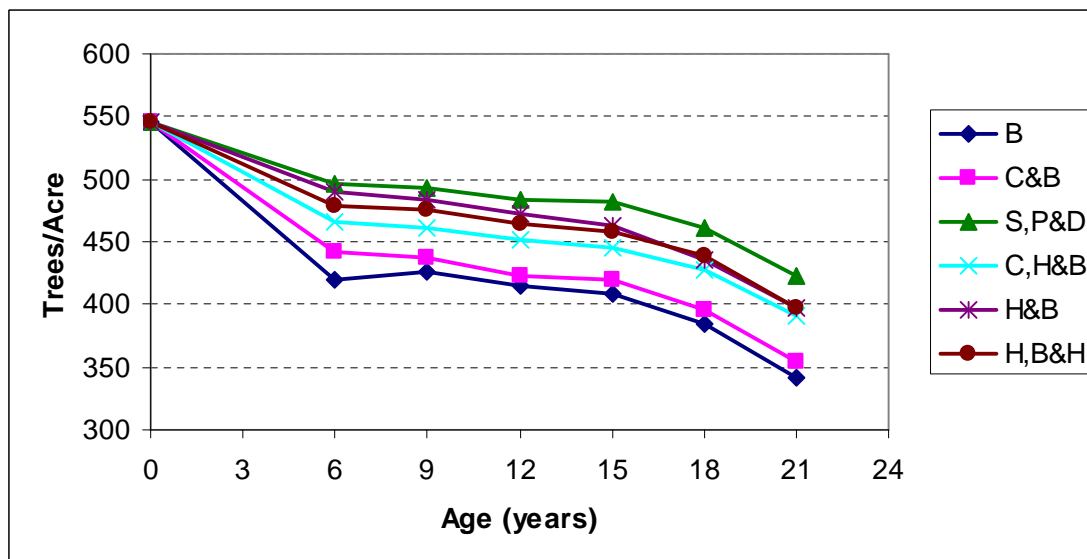
Site preparation treatment significantly affected survival at all measurement ages (Table 1). At age 21, average trees per acre ranged from 342 for the burn only treatment (B) to 423 for the most intensive mechanical treatment (S,P&D) (Table 11). The burn only

treatment (B) and chop and burn treatment (C&B) were not significantly different through age 21 years. A significant survival difference due to an herbicide application over the burn only treatment still exists after 21 growing seasons. The burn only treatment and chop and burn treatment had significantly lower survival than all other treatment which were not significantly different from one another (also see Figure 17).

**Table 11. Least square means for tree per acre by site preparation treatment and measurement age.**

| Treatment | Age 6 |    | Age 9 |    | Age 12 |    | Age 15 |    | Age 18 |    | Age 21 |    |
|-----------|-------|----|-------|----|--------|----|--------|----|--------|----|--------|----|
| B         | 419   | a  | 427   | a  | 415    | a  | 408    | a  | 385    | a  | 342    | a  |
| C&B       | 442   | ac | 437   | a  | 423    | ac | 419    | a  | 396    | a  | 355    | ac |
| S,P&D     | 496   | b  | 492   | b  | 484    | b  | 482    | b  | 460    | b  | 423    | b  |
| C,H&B     | 465   | bc | 461   | ab | 451    | bc | 445    | ac | 427    | ab | 391    | bc |
| H&B       | 490   | b  | 484   | b  | 472    | b  | 463    | bc | 435    | b  | 397    | b  |
| H,B&H     | 479   | b  | 476   | b  | 465    | b  | 459    | bc | 439    | b  | 397    | b  |

**Note: For a given age, different letters indicate significant differences between site preparation treatments.**



**Figure 17. Survival trends by site preparation treatment.**

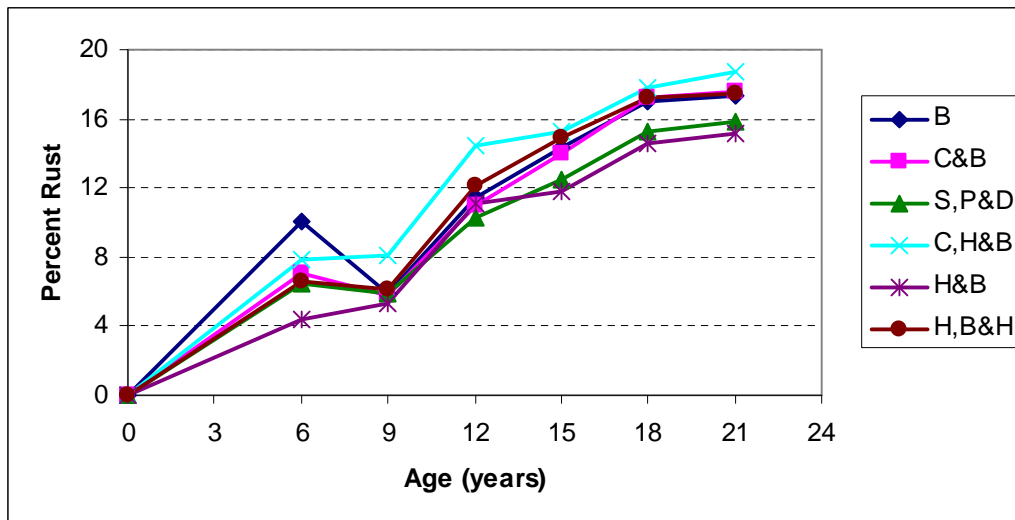
#### 4.1.11 Percent Rust Infection

No significant differences among site preparation treatments for percent of trees with stem rust infection were detected through age 21 years (Table 1). Infection rates ranged from 15.1% for the H&B treatment to 18.7% for the C,H&B treatment at age 21 years (Table 12). 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. Percent rust infection trends by treatment over time are illustrated in Figure 18.

**Table 12. Least square means for percent of trees with stem rust infection by site preparation treatment and measurement age.**

| Treatment | Age 6 |   | Age 9 |   | Age 12 |   | Age 15 |   | Age 18 |   | Age 21 |   |
|-----------|-------|---|-------|---|--------|---|--------|---|--------|---|--------|---|
| B         | 10.1  | a | 5.9   | a | 11.4   | a | 14.3   | A | 17.0   | a | 17.3   | a |
| C&B       | 7.0   | a | 5.8   | a | 11.0   | a | 14.0   | A | 17.2   | a | 17.6   | a |
| S,P&D     | 6.5   | a | 5.9   | a | 10.3   | a | 12.5   | A | 15.2   | a | 15.9   | a |
| C,H&B     | 7.9   | a | 8.1   | a | 14.4   | a | 15.2   | A | 17.8   | a | 18.7   | a |
| H&B       | 4.4   | a | 5.4   | a | 11.1   | a | 11.8   | A | 14.6   | a | 15.1   | a |
| H,B&H     | 6.6   | a | 6.1   | a | 12.1   | a | 14.9   | A | 17.3   | a | 17.5   | a |

Note: For a given age, different letters indicate significant differences between site preparation treatments.



**Figure 18. Percent fusiform rust infection trends by site preparation treatment.**

## 4.2 Periodic Growth

An analysis was carried out to examine the periodic growth between ages 0-6, 6-9, 9-12, 12-15, 15-18, and 18-21 years in terms of average Dbh, average height, basal area per acre, total volume and merchantable volume per acre, total stem green weight and merchantable green weight per acre. The objective of this analysis was to determine how growth rates during specific periods differed among treatments and assess growth rate differences among treatments over time. Note that the more intensive treatment plots are further along in stand development. The stand level growth on these more intensive treatment plots should, therefore, be slowing down in comparison to the less intensive treatment plots, given the lack of thinning. Note that all plots were fertilized at typical operation rates at age 13.

### 4.2.1 Periodic Average and Periodic Annual Dbh Growth

The average Dbh growth values by treatment and growth period are shown in Table 13 and illustrated in Figure 19. Periodic annual increments of average Dbh are illustrated in Figure 20. There were significant differences in average Dbh growth between the burn only treatment and the most intensive treatment (H,B&H) during the life of study except for the 6-9 year period. During the first six years, Dbh growth increased with the increasing intensity of site preparation treatment. After age 9 years, the B and C&B treatments had more periodic Dbh growth and the most intensive treatment grew less than all other treatments. The differences among treatments are decreasing over time. During the 18-21 year period, Dbh growth was not significantly different among the S,P&D, C,H&B, H&B and H,B&H treatments.

**Table 13. Average Dbh growth (inches) by growth period and treatment.**

| Period   | B       | C&B     | S,P&D     | C,H&B     | H&B       | H,B&H     |
|----------|---------|---------|-----------|-----------|-----------|-----------|
| 0 to 6   | 1.9 (a) | 2.5 (b) | 2.8 (b,c) | 2.8 (b,c) | 3.1(c)    | 4.2 (d)   |
| 6 to 9   | 1.7 (a) | 2.0 (b) | 2.0 (b)   | 1.9 (b,c) | 1.8 (a,c) | 1.8 (a,c) |
| 9 to 12  | 1.3 (a) | 1.3 (a) | 1.3 (a)   | 1.2 (a)   | 1.2 (a)   | 1.0 (b)   |
| 12 to 15 | 0.9 (a) | 0.9 (a) | 0.8 (a,c) | 0.9 (a,b) | 0.8 (b,c) | 0.6 (c)   |
| 15 to 18 | 0.9 (a) | 0.9 (a) | 0.7 (b,c) | 0.8 (a,b) | 0.8 (a,b) | 0.6 (c)   |
| 18 to 21 | 0.9 (a) | 0.9 (a) | 0.7 (b)   | 0.7 (b)   | 0.7 (b)   | 0.6 (b)   |

**Note: For a given period, different letters indicate significant differences between site preparation treatments.**

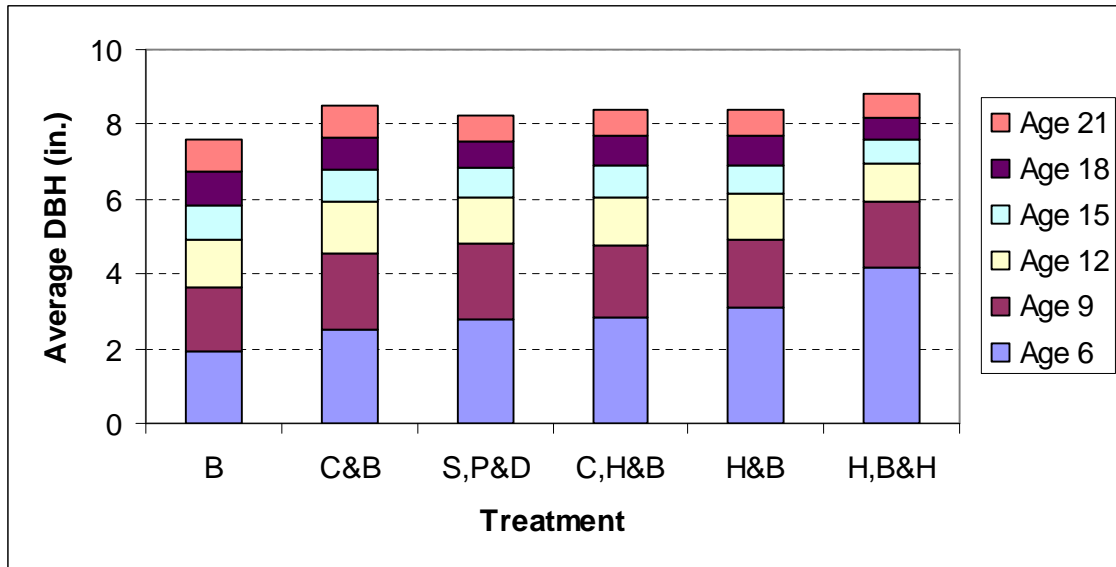


Figure 19. Least-squares means for average Dbh (inches) by age and site preparation treatment.

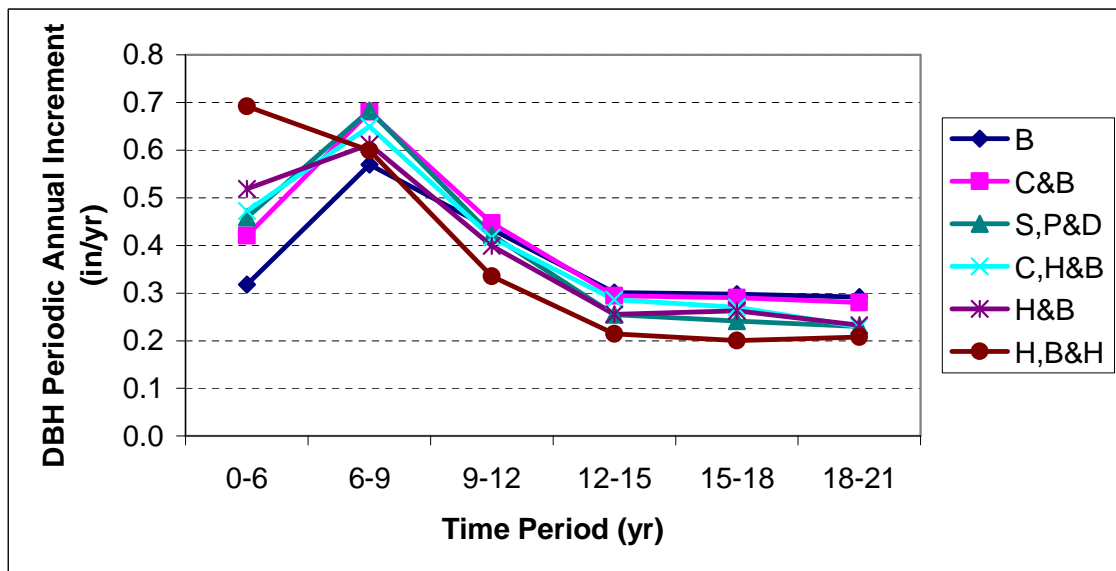


Figure 20. Periodic annual increment of Dbh (inches/yr) by site preparation treatment.



#### 4.2.2 Periodic Average and Periodic Annual Height Growth

The different site preparation treatments resulted in distinct patterns of mean height increments over time (Table 14, Figures 21 and 22). For the 0-6 year and 6-9 year periods, 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 for the less intensive treatments continued to increase between 9 and 12 years of age, while the growth rates for the more intensive treatments increased slowly; thus the differences among treatments decreased, only the difference between the burn only treatment (B) and the most intensive treatment (H,B&H) was significant during that period. In the period between 12 to 15 years, the height growth rates for all treatments decreased and were nearly equal. For the 15 to 18 year period, height growth was again very similar for all treatments, but this period height growth was higher than the 12 to 15 year periodic growth perhaps due to the fertilization treatment at age 13 or improved climatic conditions. The annual height increment decreased again after the age 15-18 period, although it did not decline substantially for all treatments except for the most intensive treatment. From age 18 to 21 years, mean annual height increment was significantly lower for the H,B&H treatment than for all other treatments.

**Table 14. Average height growth (feet) by growth period and treatment.**

| Period   | B        | C&B        | S,P&D      | C,H&B      | H&B        | H,B&H    |
|----------|----------|------------|------------|------------|------------|----------|
| 0 to 6   | 12.8 (a) | 15.3 (b)   | 16.0 (b,c) | 16.4 (b,c) | 17.5 (c)   | 21.0 (d) |
| 6 to 9   | 9.1 (a)  | 10.7 (b)   | 10.6 (b)   | 10.6 (b)   | 10.7 (b)   | 11.0 (c) |
| 9 to 12  | 10.3 (a) | 11.1 (a,b) | 11.5 (b)   | 11.1 (a,b) | 11.0 (a,b) | 11.4 (b) |
| 12 to 15 | 7.7 (a)  | 7.7 (a)    | 7.7 (a)    | 8.0 (a)    | 7.7 (a)    | 7.8 (a)  |
| 15 to 18 | 9.0 (a)  | 9.5 (a)    | 9.5 (a)    | 9.2 (a)    | 9.2 (a)    | 8.3 (a)  |
| 18 to 21 | 8.2 (a)  | 8.5 (a)    | 8.3 (a)    | 7.9 (a)    | 8.0 (a)    | 6.6 (b)  |

**Note: For a given period, different letters indicate significant differences between site preparation treatments.**

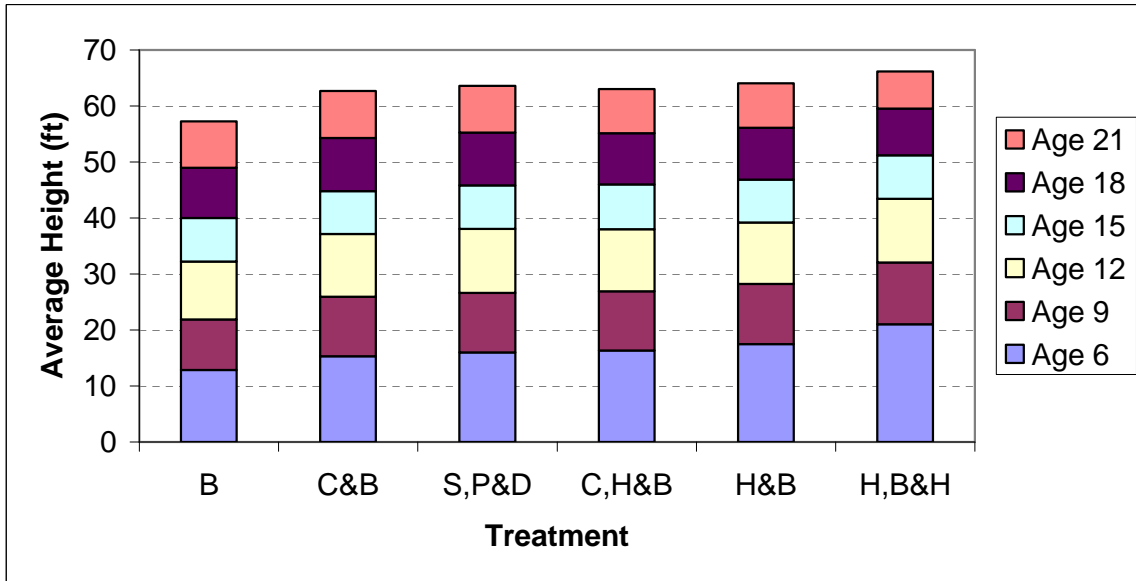


Figure 21. Least-squares means for average height (feet) by age and site preparation treatment.

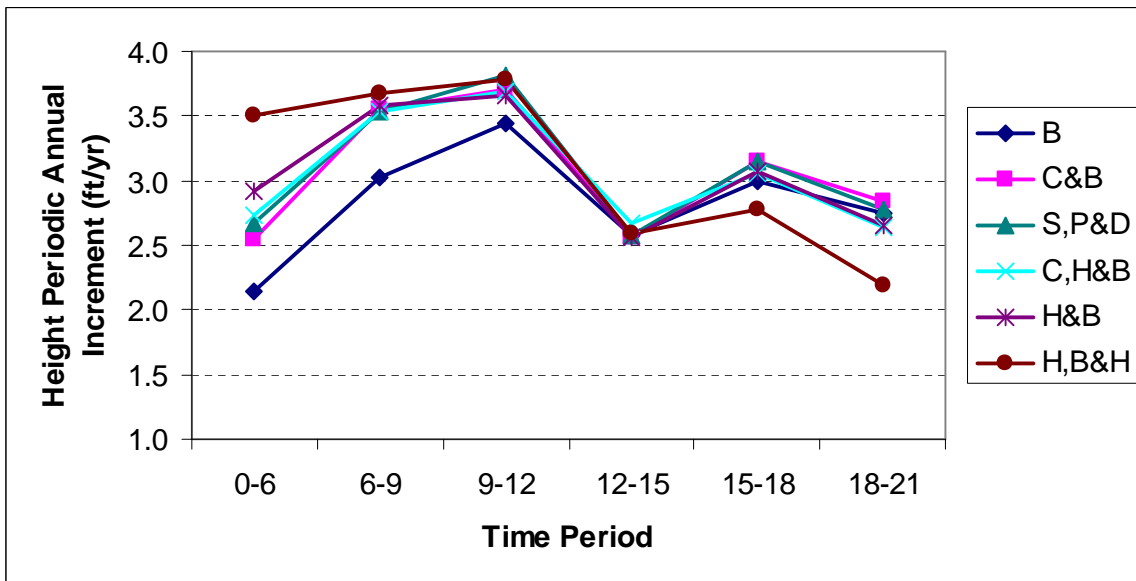


Figure 22. Periodic annual increment of average height (ft/yr) by site preparation treatment.

### 4.2.3 Periodic Average and Periodic Annual Dominant Height Growth

The average dominant height growth by treatment and growth period is shown in Table 15 and illustrated in Figure 23; periodic annual dominant height growth is illustrated in Figure 24. Average dominant height closely resembles the trends found in average height. During the first six years, the most intensive treatment (H,B&H) achieved the greatest rate of dominant height growth. The differences in dominant height among treatments decreased after age 6 years. There were no significant differences between the B treatment and S,P&D treatment, and all other four treatments resulted in similar dominant height growth rates in the period between 6 and 9 years of age. During the 9-12 year period, a significant difference in dominant height growth was only found between the B treatment and S,P&D treatment; in the 12-15 and 15-18 year periods, there were no significant differences among all treatments. As found in average height, dominant height growth rate in the 15-18 year period was higher than the 12 to 15 year periodic growth. The annual height increment decreased again after the age 15-18 year period, and it declined substantially for the most intensive treatment (H,B&H). From age 18 to 21 years, mean annual dominant height increment was significantly lower for the H,B&H treatment than for all other treatments.

**Table 15. Average dominant height growth (feet) by growth period and treatment.**

| Period   | B        | C&B        | S,P&D      | C,H&B      | H&B        | H,B&H      |
|----------|----------|------------|------------|------------|------------|------------|
| 0 to 6   | 14.7 (a) | 16.9 (b)   | 17.7 (b,c) | 18.0 (b,c) | 19.2 (c)   | 22.6 (d)   |
| 6 to 9   | 10.2 (a) | 11.3 (b)   | 10.9 (a)   | 11.1 (b)   | 11.3 (b)   | 11.3 (b)   |
| 9 to 12  | 10.6 (a) | 11.5 (a,b) | 11.8 (b)   | 11.6 (a,b) | 11.3 (a,b) | 11.6 (a,b) |
| 12 to 15 | 8.6 (a)  | 8.2 (a)    | 8.2 (a)    | 8.3 (a)    | 8.1 (a)    | 8.2 (a)    |
| 15 to 18 | 9.5 (a)  | 9.7 (a)    | 9.8 (a)    | 9.5 (a)    | 9.3 (a)    | 8.8 (a)    |
| 18 to 21 | 8.5 (a)  | 8.8 (a)    | 8.4 (a)    | 8.1 (a)    | 8.3 (a)    | 6.9 (b)    |

**Note: For a given period, different letters indicate significant differences between site preparation treatments.**

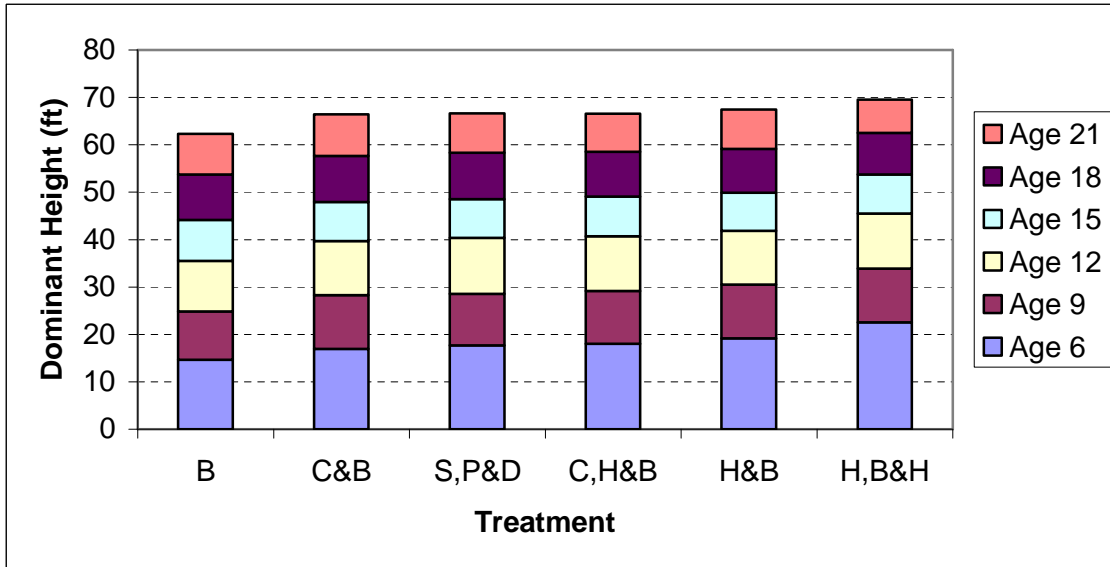


Figure 23. Least-squares means for average dominant height (feet) by age and site preparation treatment.

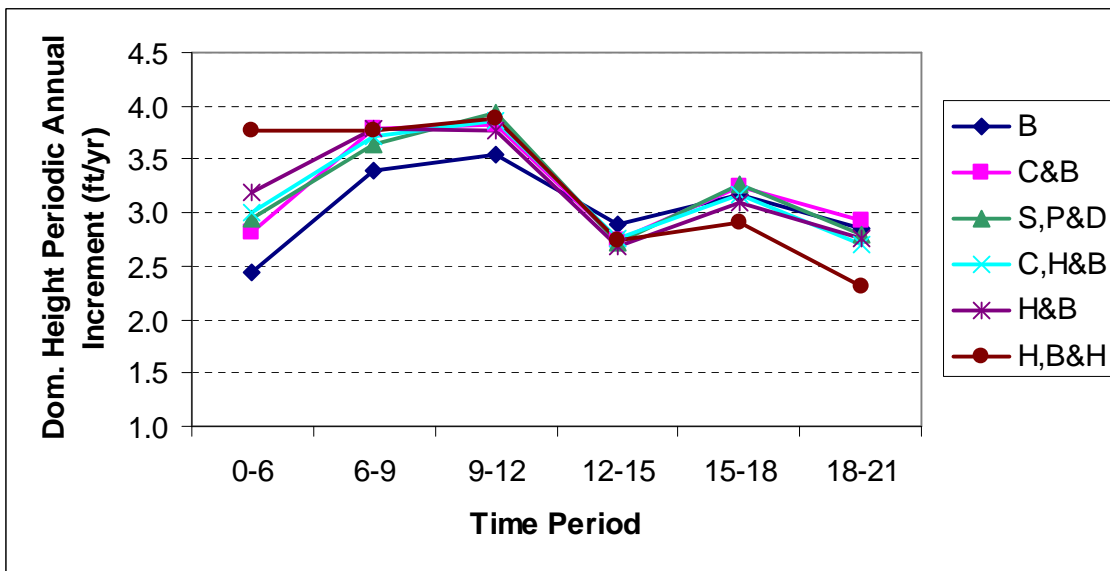


Figure 24. Periodic annual increment of average dominant height (ft/yr) by site preparation treatment.

#### 4.2.4 Periodic Average and Periodic Annual Basal Area Growth

Patterns of periodic mean basal area increment differ markedly by site preparation treatment (Table 16, Figures 25-26). For the 0-6 and 6-9 year periods, 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 9 and 12, the burn only treatment (B) had lower per-acre basal area growth rate than all other treatments. After age 12 years, the most intensive treatment had the lowest basal area growth rate, and there were no significant differences in basal area per acre growth among site preparation treatments for the two periods between 15 and 21 years of age. In general, after age 12 years the most intensive treatment had less basal area growth than other treatments, which implies the less intensive treatments were on a trajectory to approach the most intensive treatment in terms of stand basal area (Figures 7 and 25). Recall Table 5, the trend that the most intensive treatment (H,B&H) significantly increased basal area per acre over the burn only (B), and chop and burn (C&B) treatments still holds after 21 growing seasons, but the differences among the most intensive treatment, the shear, pile and disk treatment (S,P&D), the chop, herbicide and burn treatment (C,H&B), and the herbicide and burn treatment (H&B) were no longer significant.

**Table 16. Average basal area growth (ft<sup>2</sup>/ac) by growth period and treatment.**

| Period   | B        | C&B        | S,P&D      | C,H&B      | H&B        | H,B&H      |
|----------|----------|------------|------------|------------|------------|------------|
| 0 to 6   | 12.2 (a) | 18.2 (a,b) | 24.2 (b,c) | 23.6 (b,c) | 28.6 (c)   | 48.2 (d)   |
| 6 to 9   | 24.6 (a) | 36.1 (b)   | 42.6 (b,c) | 39.1 (b)   | 40.0 (b)   | 48.0 (c)   |
| 9 to 12  | 25.3 (a) | 31.0 (b)   | 35.2 (b)   | 32.3 (b)   | 32.9 (b)   | 31.6 (b)   |
| 12 to 15 | 22.4 (a) | 25.7 (a,b) | 25.8 (b)   | 25.8 (a,b) | 24.4 (a,b) | 22.7 (a,b) |
| 15 to 18 | 20.1 (a) | 21.6 (a)   | 20.4 (a)   | 23.0 (a)   | 20.1 (a)   | 16.5 (a)   |
| 18 to 21 | 11.8 (a) | 11.2 (a)   | 11.9 (a)   | 11.1 (a)   | 11.2 (a)   | 5.2 (a)    |

**Note: For a given period, different letters indicate significant differences between site preparation treatments.**

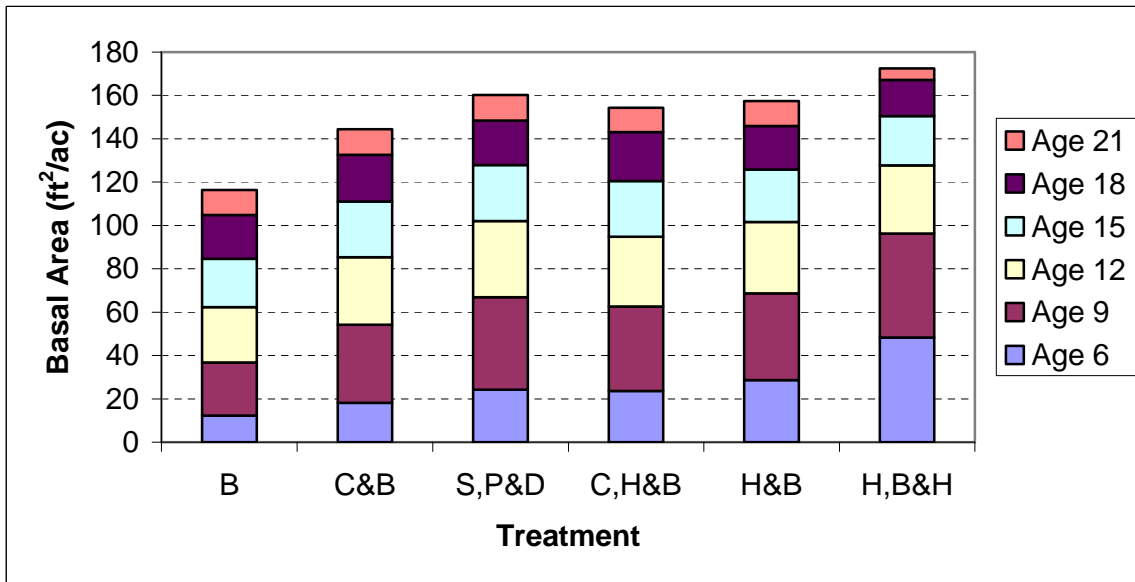


Figure 25. Least-squares means for basal area (ft<sup>2</sup>/ac) by age and site preparation treatment.

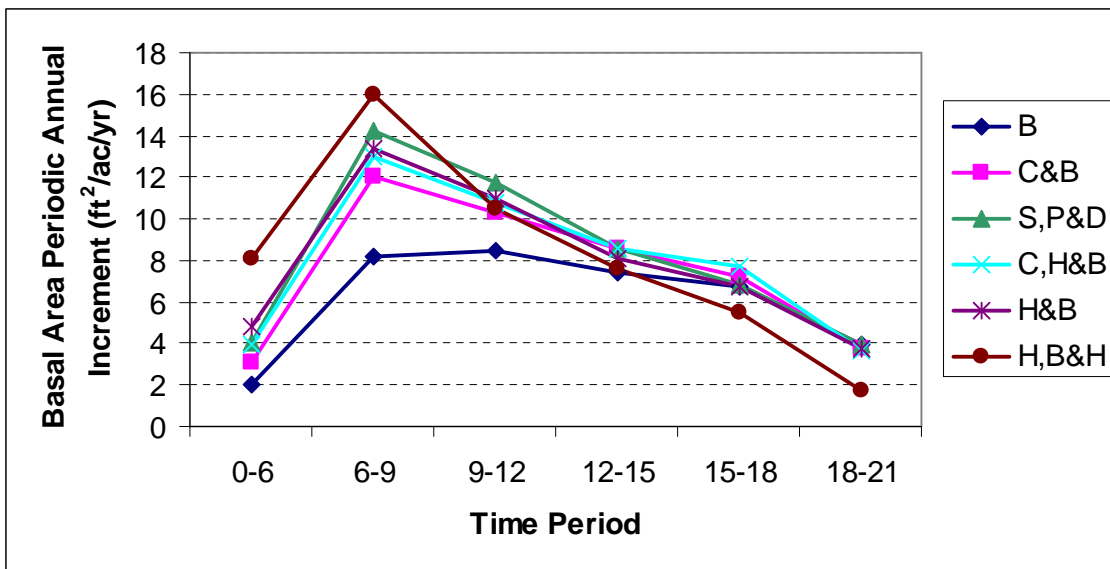


Figure 26. Periodic annual increment of basal area (ft<sup>2</sup>/ac/yr) by site preparation treatment.

#### 4.2.5 Periodic Average and Periodic Annual Total Volume Growth

Site preparation treatment had a marked impact on the temporal pattern of periodic mean and periodic annual total volume growth (Table 17 and Figures 27-28). For the four periods between 0 and 15 years of age, total volume growth increased with increasing site preparation intensity. For the 0-6, 6-9, and 9-12 year periods, the H,B&H treatment grew significantly more volume than all other treatments. For the 12-15 year period, the H,B&H treatment still grew significantly more volume than the burn only (B) treatment and the chop and burn (C&B) treatment, but had no significant differences in total volume growth from the S,P&D, C,H&B and H&B treatments. For the last two periods between 15 and 21 years of age, the differences in total volume growth among site preparation treatments were not significant.

For the more intensive treatments, the periodic annual volume growth in the 12-15 year period decreased from the previous period (Figure 28). The fertilization treatment at age 13 or improved climatic conditions increased periodic annual volume growth in the 15-18 year period for all treatments except for the most intensive treatment (H,B&H). After age 18, periodic annual volume increment decreased again for all treatment.

**Table 17. Average total volume growth (ft<sup>3</sup>/ac) by growth period and treatment.**

| Period   | B       | C&B       | S,P&D      | C,H&B     | H&B       | H,B&H    |
|----------|---------|-----------|------------|-----------|-----------|----------|
| 0 to 6   | 113 (a) | 177 (a,b) | 249 (b,c)  | 240 (b,c) | 305 (c)   | 578 (d)  |
| 6 to 9   | 391 (a) | 612 (b)   | 742 (b)    | 696 (b)   | 752 (b)   | 1038 (c) |
| 9 to 12  | 642 (a) | 859 (b)   | 1024 (b,c) | 941 (b)   | 989 (b)   | 1163 (c) |
| 12 to 15 | 689 (a) | 860 (b)   | 930 (b,c)  | 906 (b,c) | 904 (b,c) | 999 (c)  |
| 15 to 18 | 839 (a) | 1005 (a)  | 1059 (a)   | 1065 (a)  | 1017 (a)  | 992 (a)  |
| 18 to 21 | 672 (a) | 786 (a)   | 831 (a)    | 781(a)    | 809 (a)   | 592 (a)  |

**Note: For a given period, different letters indicate significant differences between site preparation treatments.**

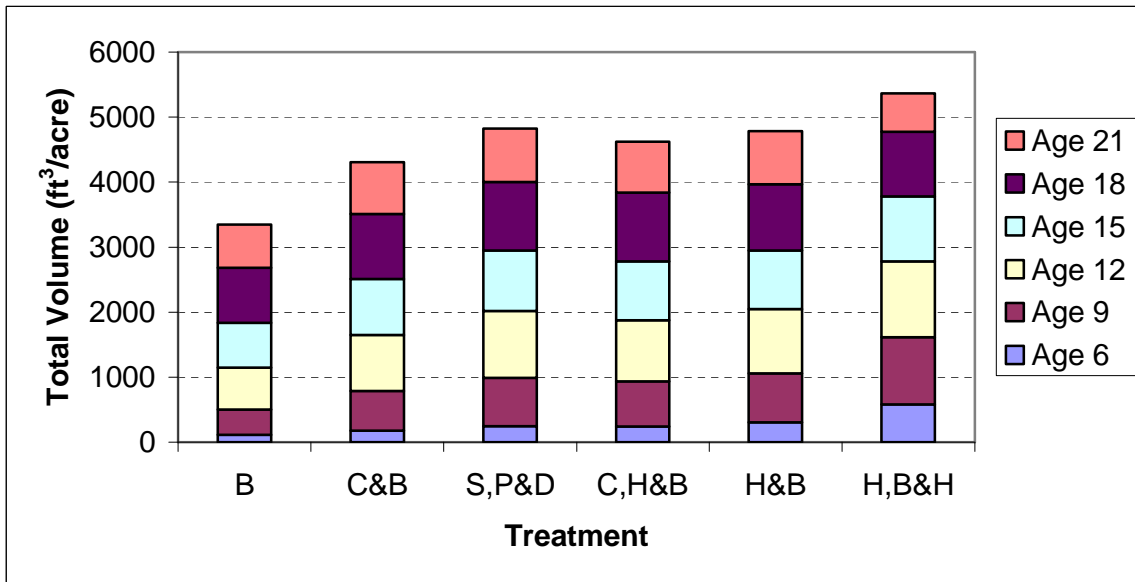


Figure 27. Least-squares means for total volume (ft<sup>3</sup>/ac) by age and site preparation treatment.

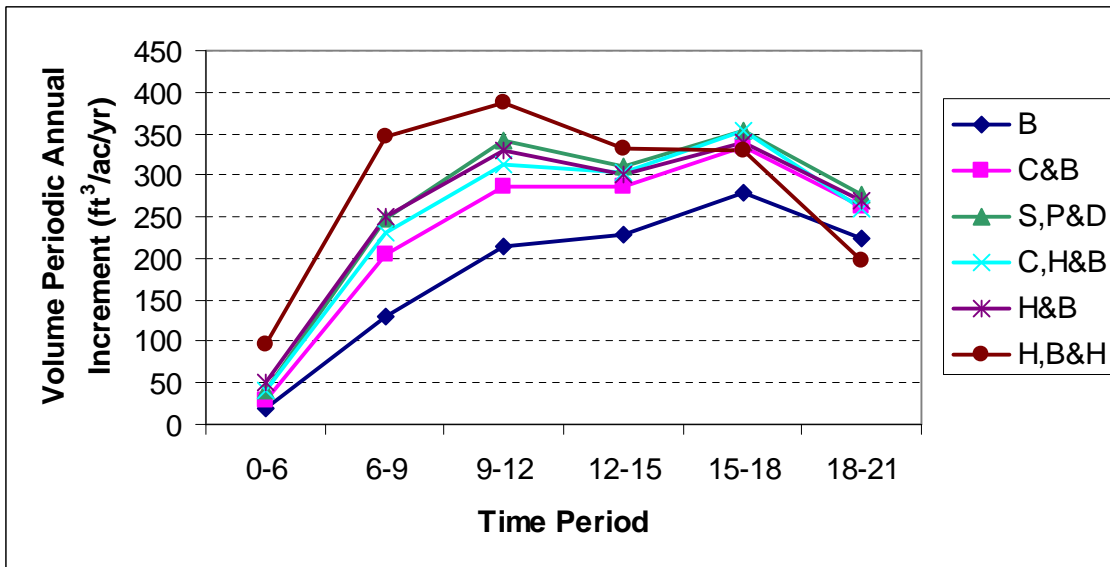


Figure 28. Periodic annual increment of total volume (ft<sup>3</sup>/ac/yr) by site preparation treatment.



#### 4.2.6 Periodic Average and Periodic Annual Merchantable Volume Growth

The average merchantable volume growth per acre values by treatment and growth period are shown in Table 18 and illustrated in Figure 29, and periodic annual merchantable volume increments are illustrated in Figure 30. The results for merchantable volume are comparable to the results for total volume. For the first four periods, merchantable volume growth increased with increasing site preparation intensity. For the 0-6, 6-9 and 9-12 year periods, the H,B&H treatment grew significantly more merchantable volume than all other treatments. For the 12-15 year period, the H,B&H treatment still grew significantly more merchantable volume than the burn only (B) treatment, but already had no significant differences in merchantable volume growth from the C&B, S,P&D, C,H&B, and H&B treatments. For the last two periods between 15 to 21 years, there were no significant differences in merchantable volume growth among site preparation treatments.

**Table 18. Average merchantable volume growth (ft<sup>3</sup>/ac) by period and treatment.**

| Period   | B       | C&B      | S,P&D      | C,H&B    | H&B        | H,B&H    |
|----------|---------|----------|------------|----------|------------|----------|
| 0 to 6   | 26 (a)  | 32 (a)   | 67 (a)     | 71 (a)   | 123 (a)    | 465 (b)  |
| 6 to 9   | 356 (a) | 672 (b)  | 841 (b)    | 789 (b)  | 858 (b)    | 1117 (c) |
| 9 to 12  | 671 (a) | 894 (b)  | 1062 (b,c) | 972 (b)  | 1016 (b,c) | 1168(c)  |
| 12 to 15 | 710 (a) | 867 (b)  | 938 (b)    | 912 (b)  | 911 (b)    | 1000 (b) |
| 15 to 18 | 851 (a) | 1013 (a) | 1063 (a)   | 1072 (a) | 1026 (a)   | 994 (a)  |
| 18 to 21 | 691 (a) | 797 (a)  | 836 (a)    | 789 (a)  | 817 (a)    | 596 (a)  |

**Note: For a given period, different letters indicate significant differences between site preparation treatments.**

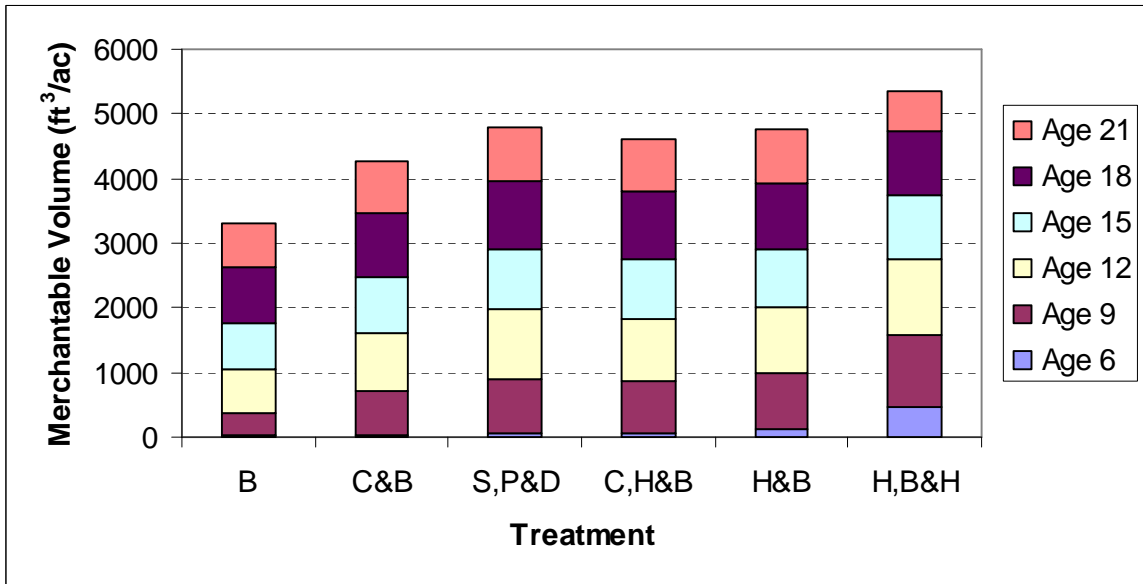


Figure 29. Least-squares means for merchantable volume (ft<sup>3</sup>/ac) by age and site preparation treatment.

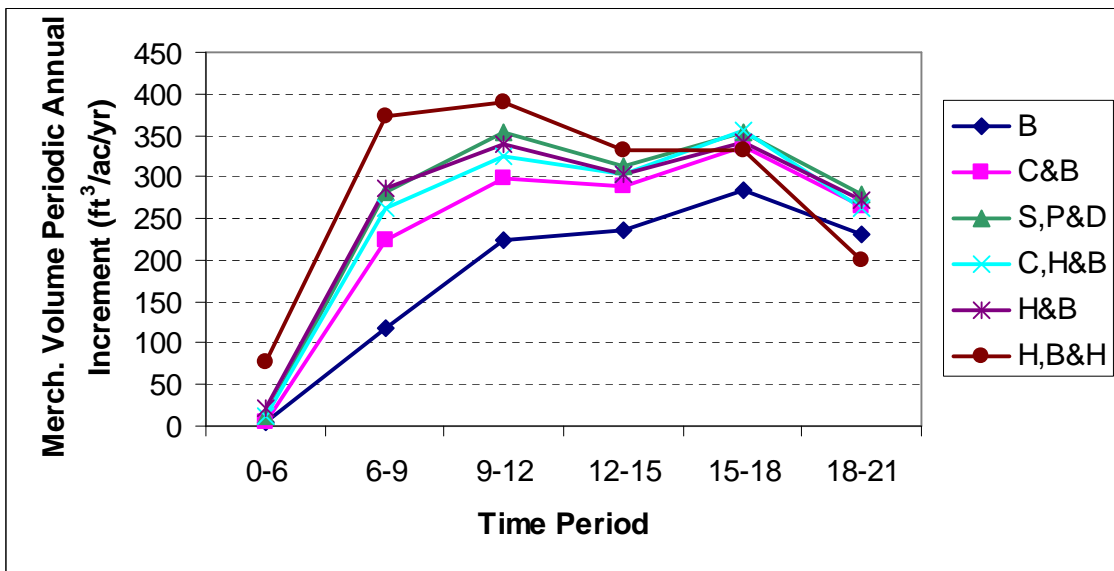


Figure 30. Periodic annual increment of merchantable volume (ft<sup>3</sup>/ac/yr) by site preparation treatment.

#### 4.2.7 Periodic Average and Periodic Annual Total Stem Green Weight Growth

As with other growth measures, site preparation treatment had a marked impact on the temporal pattern of periodic mean and periodic annual total stem green weight growth (Table 19 and Figures 31-32). Before age 15, total green weight growth increased with increasing site preparation intensity. For the 0-6, 6-9, and 9-12 year periods, the H,B&H treatment grew significantly more weight than all other treatments. For the 12-15 year period, the H,B&H treatment still grew significantly more weight than the burn only (B) treatment and the chop and burn (C&B) treatment, but had no significant differences in total stem green weight growth from the S,P&D, C,H&B and H&B treatments. For the periods between 15 and 21 years of age, the differences in total green weight growth among site preparation treatments were no longer significant.

For the more intensive treatments, the periodic annual green weight growth in the 12-15 year period decreased from the pervious period (Figure 32). The fertilization treatment at age 13 or improved climatic conditions increased periodic annual weight growth in the 15-18 year period for all treatments except for the most intensive treatment (H,B&H). After age 18, periodic annual weight increment decreased again for all treatments.

**Table 19. Average total stem green weight growth (ton/ac) by period and treatment.**

| Period   | B        | C&B       | S,P&D      | C,H&B      | H&B        | H,B&H    |
|----------|----------|-----------|------------|------------|------------|----------|
| 0 to 6   | 2.6 (a)  | 4.1 (a,b) | 5.8 (b,c)  | 5.6 (b,c)  | 7.2 (c)    | 13.8 (d) |
| 6 to 9   | 9.7 (a)  | 15.3 (b)  | 18.6 (b)   | 17.5 (b)   | 19.0 (b)   | 26.8 (c) |
| 9 to 12  | 16.9 (a) | 22.9 (b)  | 27.4 (b)   | 25.2 (b)   | 26.6 (b)   | 32.0(c)  |
| 12 to 15 | 18.7 (a) | 23.6 (b)  | 25.7 (b,c) | 25.0 (b,c) | 25.1 (b,c) | 28.3 (c) |
| 15 to 18 | 23.6 (a) | 28.7 (a)  | 30.5 (a)   | 30.4 (a)   | 29.3 (a)   | 29.1 (a) |
| 18 to 21 | 19.6 (a) | 23.4 (a)  | 24.6 (a)   | 23.3 (a)   | 24.1 (a)   | 18.2 (a) |

**Note: For a given period, different letters indicate significant differences between site preparation treatments.**

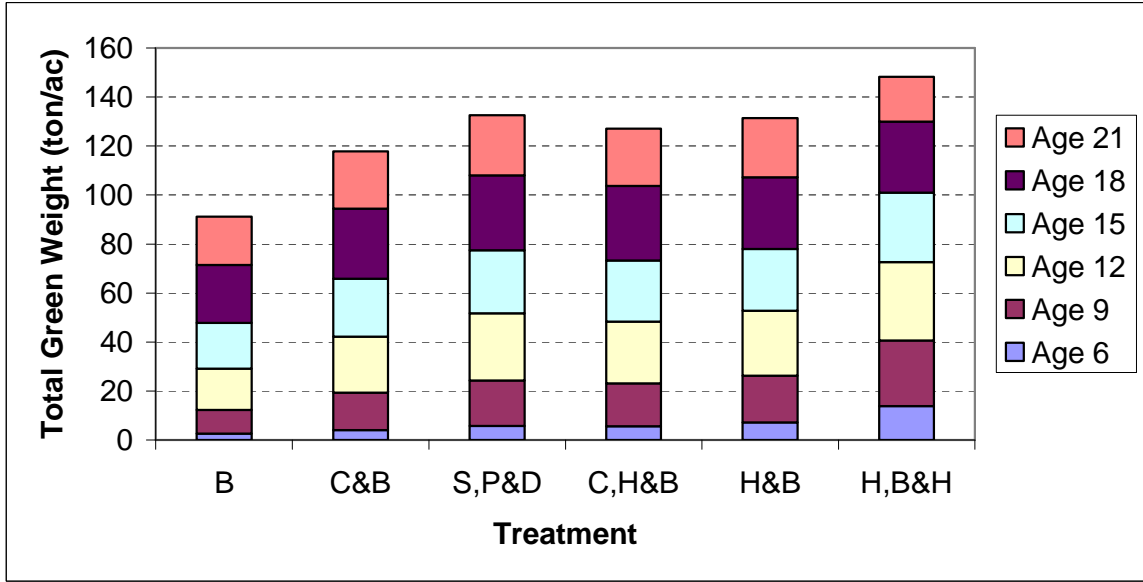


Figure 31. Least-squares means for total stem green weight (ton/ac) by age and site preparation treatment.

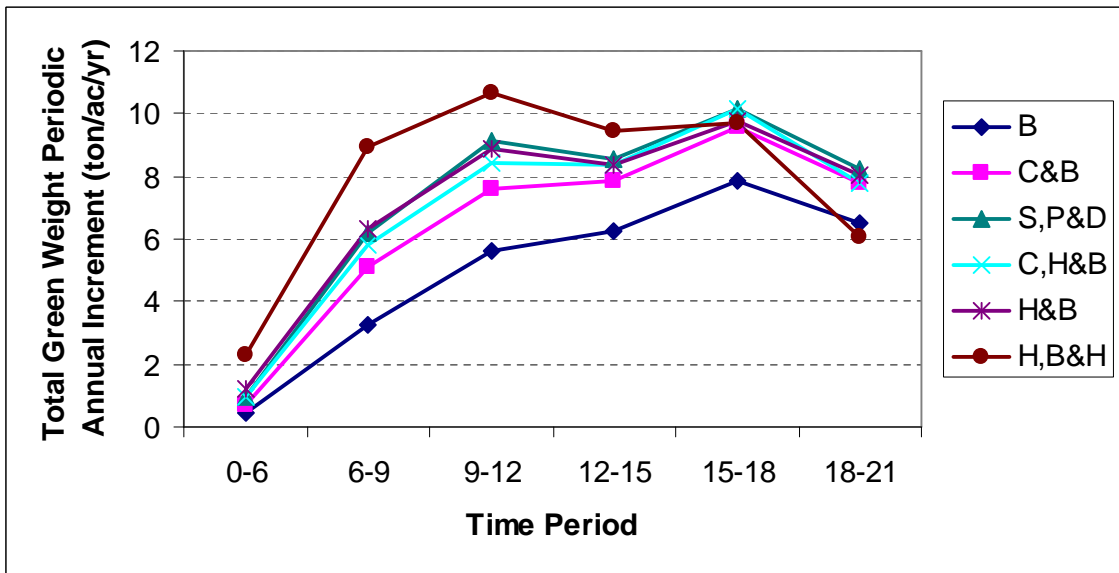


Figure 32. Periodic annual increment of total stem green weight (ton/ac/yr) by site preparation treatment.

#### 4.2.8 Periodic Average and Periodic Annual Merchantable Green Weight Growth

The periodic growth trends for merchantable stem green weight were similar to those for total stem green weight (Table 20 and Figures 33-34). Before age 12, the merchantable green weight growth increased with both site preparation intensity and age. For the 0-6, 6-9 and 9-12 year periods, the H,B&H treatment grew significantly more merchantable weight than all other treatments. For the 12-15 year period, the H,B&H treatment still grew significantly more merchantable weight than the burn only (B) treatment and the chop and burn (C&B) treatment, but already had no significant differences in merchantable green weight growth from the S,P&D, C,H&B, and H&B treatments. After age 15, there were no significant differences in merchantable weight periodic growth among site preparation treatments.

For the more intensive treatments, the periodic annual green weight growth in the 12-15 year period decreased from the previous period (Figure 34). The fertilization treatment at age 13 or improved climatic conditions increased periodic annual weight growth in the 15-18 year period for all treatments except for the most intensive treatment (H,B&H). After age 18, periodic annual merchantable weight increment decreased again for all treatments.

**Table 20. Average merchantable stem green weight growth (ton/ac) by period and treatment.**

| Period   | B        | C&B      | S,P&D      | C,H&B      | H&B        | H,B&H    |
|----------|----------|----------|------------|------------|------------|----------|
| 0 to 6   | 0.3 (a)  | 0.7 (a)  | 1.8 (a)    | 2.0 (a)    | 3.0 (a)    | 11.7 (b) |
| 6 to 9   | 10.7 (a) | 18.1 (b) | 24.4 (b)   | 21.8 (b)   | 21.3 (b)   | 29.3 (c) |
| 9 to 12  | 17.5 (a) | 23.6 (b) | 28.2 (b)   | 25.9 (b)   | 27.2 (b)   | 32.1(c)  |
| 12 to 15 | 19.2 (a) | 23.7 (b) | 25.8 (b,c) | 25.1 (b,c) | 25.3 (b,c) | 28.3 (c) |
| 15 to 18 | 23.9 (a) | 28.9 (a) | 30.5 (a)   | 30.5 (a)   | 29.5 (a)   | 29.1 (a) |
| 18 to 21 | 20.1 (a) | 23.6 (a) | 24.7 (a)   | 23.5 (a)   | 24.3 (a)   | 18.3 (a) |

**Note: For a given period, different letters indicate significant differences between site preparation treatments.**

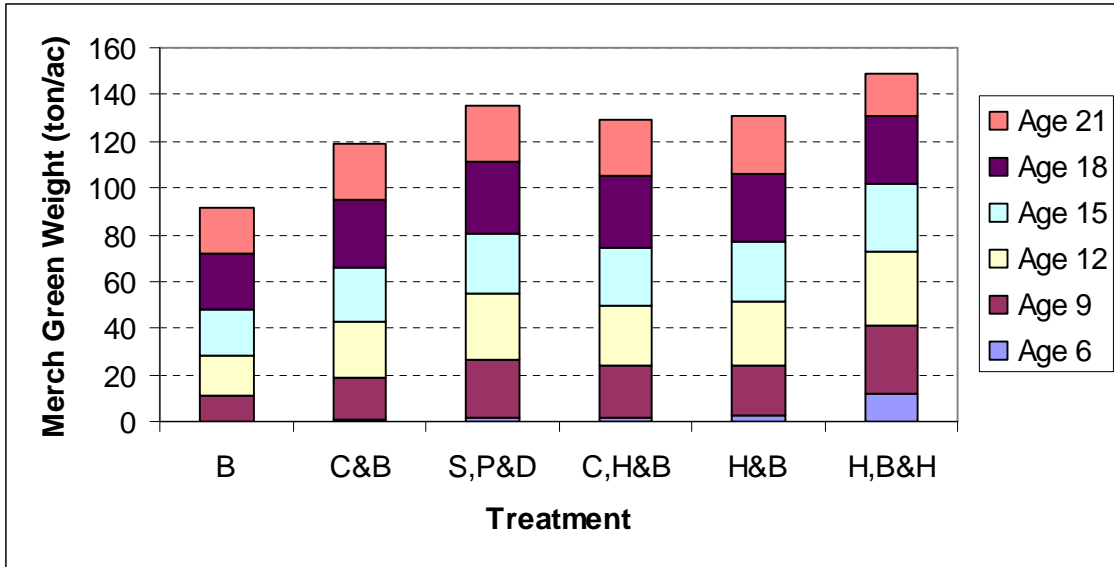


Figure 33. Least-squares means for merchantable stem green weight (ton/ac) by age and site preparation treatment.

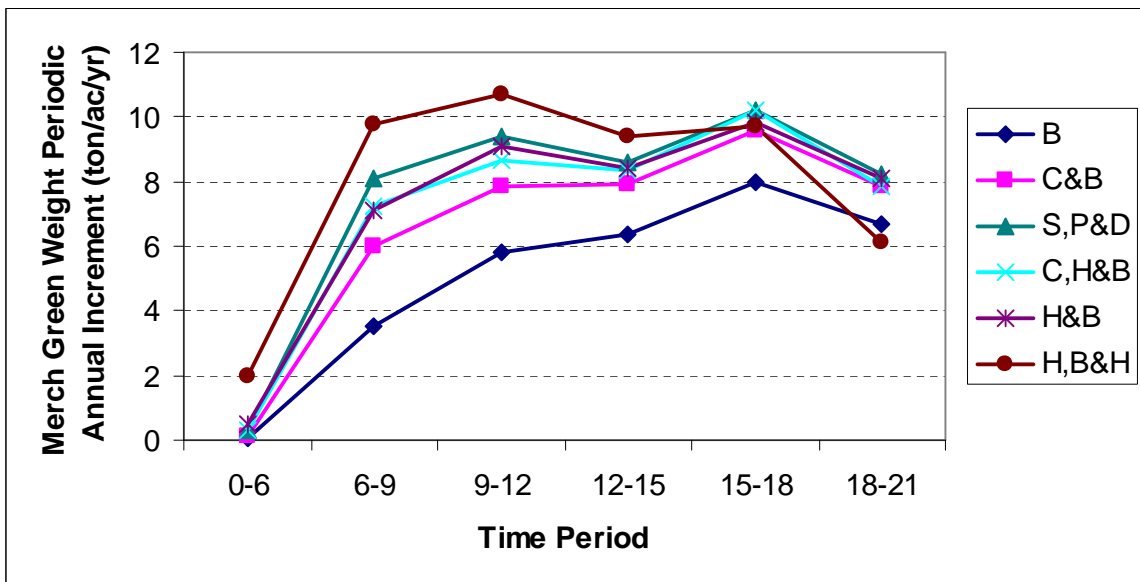


Figure 34. Periodic annual increment of merchantable stem green weight (ton/ac/yr) by site preparation treatment.

## 5 DISCUSSION AND CONCLUSIONS

Site preparation treatment significantly affected average Dbh, average height, dominant height, basal area per acre, total volume per acre, merchantable volume per acre, total stem green weight and merchantable green weight per acre and survival at ages 6, 9, 12, 15, 18 and 21. For all variables where treatment was significant, the addition of either a chop or an herbicide treatment to the burn only treatment achieved significant improvement at the ages from 6 to 21 years; except for survival where an additional herbicide treatment rather than an additional chop treatment to the burn only treatment provided significant improvement. An additional chop or herbicide treatment to the burn only treatment reduced the effect of large hardwoods that overtop the pines and impact growth.

Compared to other treatments, the burn only treatments always had the lowest average Dbh, average height and dominant height, basal area per acre, total volume and merchantable volume per acre, and total stem green weight and merchantable green weight per acre at all the ages from 6 to 21 years.

Compared to the operational mechanical treatments (C&B and S,P&D), the operational chemical site preparation treatment (H&B) had significantly greater average Dbh at age 6, greater merchantable green weight at age 9, greater average height, basal area per acre, merchantable volume per acre and total green weight per acre at ages of 6 and 9 years, greater dominant height at ages of 6, 9, 12 and 15 years, and greater total volume per acre at ages of 6, 9 and 12 years. For all these variables at other ages and survival at all ages, there were no significant differences between the operational chemical and operational mechanical treatments. Chopping two months prior to the operational chemical treatment was not an effective treatment. Chopping this soon prior to chemical site preparation probably reduced the foliar area and thus herbicide effectiveness.

The addition of complete vegetation control to the herbicide + burn treatment resulted in significantly increased average Dbh, average and dominant height, basal area per acre, total and merchantable volume per acre, and total and merchantable stem green weights per acre at ages of 6, 9, 12, 15 and 18 years. However, after 21 growing seasons there

were no significant differences in these variables between the most intensive treatment (H,B&H) and the herbicide + burn treatment (H&B).

Total and merchantable volumes, and total and merchantable stem green weights for the most intensive treatments were still diverging from less intensive treatments through 15 years, but after age 15 the most intensive treatment is slowing down relative to less intensive treatments and they are now producing about the same amount of yield per year. Growth on all treatments was slowing after age 18 (the volume growth rate from 18 to 21 years was lower than the previous period's growth), but this growth reduction was most marked on the most intensive treatment; most likely because the most intensive treatment is approaching its carrying capacity, which implies that stands with this treatment would benefit from a thinning at an earlier age than stands established with less intensive culture.

The intensive mechanical treatment achieved the best survival over the life of the study. The burn only treatment had significantly lower surviving trees per acre than the treatments with herbicide application (C,H&B, H&B, and H,B&H) and the intensive mechanical treatment (S,P&D). The improvement of survival due to an additional chop treatment to the burn only treatment was not significant, and there were no significant differences in survival between the C&B and C,H&B treatments over the life of the study.

Site preparation intensity had a marked effect on periodic rates of growth. The most intensive treatment (H,B&H) exhibited significantly higher growth at earlier ages, and thereafter resulted in similar or significantly less periodic growth as compared to that of other treatments. During the two periods between 15 and 21 years of age, no significant differences were detected for basal area, total and merchantable volumes, and total and merchantable green weights. This indicates that the most intensive treatment was approaching its carrying capacity and the production started to slow relative to other treatments.

The evaluations of periodic growth and treatment response trends over time illustrate that the different tree and stand variables show different temporal responses. Compared to the burn only treatment, mean responses in Dbh and dominant height followed Type B or C patterns and peaked at 9 and 12 years for all treatments; mean response in basal



area per acre for the C&B and S,P&B treatments followed a Type A pattern, through 21 years, for the C,H&B treatment followed a Type B pattern and peaked at 18 years, and for H&B and H,B&H treatments followed Type B and C patterns, respectively, peaking at 15 years; mean response in volumes and green weights followed a Type A pattern through the 21 year period for all treatments, except the H,B&H treatment that exhibited a Type B response peaking at age 18 years.

Periodic annual Dbh increment approached its maximum at age 6 years for the H,B&H treatments and at age 9 years for other treatments. Periodic annual increments of height and dominant height approached their maximum at age 12 years for all treatments. Periodic annual increments of basal area, total and merchantable volumes, and total and merchantable green weights per acre peaked at age 12 years for the H,B&H treatment and at age 18 years for other treatments.

These response trends will be used in developing response models for the PMRC growth and yield system. While these trends reflect mean response, these results will be investigated in greater detail to determine if response magnitude and patterns vary substantially by “base” site index, soil class, and competing vegetation class. If significant class differences are found, classes will be used to improve response model precision.

The observed decline in “absolute” response for the most intensive treatment (H,B&H) as these stands reach greater maturity indicates the importance of appropriately timed silvicultural treatments (thinning, fertilization, and/or release) to capture early gains and to maintain optimum growth trajectories for the management objectives.

The fertilization at age 13 should have provided good nutritional status through at least age 18. After age 18, nutrition limitations probably developed.

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