POLYMORPHISM OF SOUTHERN PINE SITE INDEX CURVES RESULTING FROM DIFFERENT CULTURAL TREATMENTS

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EXECUTIVE SUMMARY

An analysis was conducted to determine if silvicultural treatments caused an anamorphic or polymorphic change in the dominant height growth curves of slash and loblolly pines. Data from the PMRC slash pine site preparation study, SAGS loblolly pine site preparation study, and the PMRC loblolly pine improved planting stock-vegetation control study were used to evaluate a variety of cultural treatments on dominant height growth of both loblolly and slash pine. Intensive cultural treatments were compared to standard treatments at measured ages to calculate proportional and absolute differences in the dominant height growth curves. These methods were compared to common methods of adjusting site index for cultural treatments to determine the most accurate way to account for dominant height changes due to intensive cultural treatments.

In loblolly pines, only one cultural treatment, improved genetics, appears to cause an anamorphic change in the height growth curve. All other tested cultural treatments caused an increase in dominant height growth at a young age and then maintained that height difference throughout the observed ages. This indicates that simply adjusting site index and using existing non-intensive site index curves cannot accurately account for the effect of cultural treatments on height growth. Instead, new equations that account for changes in rate and shape of the dominant height growth curve are required. The resulting curves are thus polymorphic with required inputs of dominant height, age, and cultural treatment needed to estimate site index.

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1 INTRODUCTION

Site index or dominant height is a major component of yield prediction systems for southern pine plantations. Designed studies indicate that cultural treatments such as vegetation control and fertilization affect yield through impacting height and basal area per acre (Pienaar and Rheney, 1995). One common way that yield models are adjusted to account for intensive cultural treatments is to elevate site index. Most southern pine site index equations are anamorphic. Elevating site index for anamorphic equations implies that the shape is not changed. This would only be true if the height of the treated stand at any age were a constant proportion of the height of the untreated stand at the same ages (Clutter *et*. al, 1983). Since most measurements for site index are not made until after crown closure, the assumption is that cultural treatments that result in larger gains at early ages continue those gains proportionally throughout the life of the stand. If the height gains do not continue at a proportional rate over the life of the stand, then the change in the curve is polymorphic, and simply adjusting site index is not an accurate way to account for cultural treatments.

If site index is elevated for sets of polymorphic curves, this implies that the change in the dominant height curve due to the cultural treatment is the same as the change in the dominant height curve due to increasing site index. This assumption has not been tested, and could lead to under or over prediction of dominant height.

The objective of this paper is to evaluate whether the dominant height development curves of stands of loblolly and slash pines subjected to varying cultural treatments are anamorphic or polymorphic. If cultural treatments are found to cause a polymorphic change in dominant height growth, new dominant height models will be built to account for the effects of various site preparation treatments.

2 METHODS

Several Plantation Management Research Cooperative (PMRC) designed studies were used to test the effects of site preparation, weed control, fertilization and genetic improvement on the shape of dominant height curves. The slash pine site preparation study, the loblolly pine site preparation study and the loblolly improved planting stock/vegetation control studies were old enough to evaluate dominant height growth.

2.1 Slash Pine Site Preparation Study

Data from the PMRC slash pine site preparation study were used to evaluate height-age relationships for planted slash stands subjected to various cultural treatments. For more information on the slash pine site preparation study see PMRC Technical report 2000-4 (Shiver et. al., 1990; Shiver and Harrison, 2000). Measurements at ages eight, eleven, fourteen, seventeen, and twenty were used in the analysis. The following eleven treatments from the PMRC study were used in this study:

1. Control (harvest and plant, no site preparation)
2. Chop (single pass with a rolling drum chopper)
3. Chop, fertilize
4. Chop, burn (chop followed by a broadcast burn)
5. Chop, burn, fertilize
6. Chop, burn, bed
7. Chop, burn, bed, fertilize
8. Chop, burn, herbicide (treatment 4 followed by complete vegetation control)
9. Chop, burn, herbicide, fertilize
10. Chop, burn, bed, herbicide (treatment 6 followed by complete vegetation control)
11. Chop, burn, bed, herbicide, fertilize

All herbicide treatments were complete vegetation control for the life of the stand. Practically, little control work has been needed since crown closure. The fertilization treatment was 250 lbs. di-ammonium phosphate (DAP) after the first growing season, 200 lbs. elemental N and 25 lbs. P from DAP and urea and 100 lbs. elemental K from KCL at age 12, and 200 lbs elemental N plus 25 lbs. P from DAP and urea at age 18.

For the purposes of this analysis treatments one, two and four were considered to be control plots. This was done because previous analyses have indicated that neither chopping nor burning significantly influenced height development (Shiver and Harrison, 2000). All other treatments were grouped as bedded, fertilized, herbicide or combinations of the three. Differences between spodosol and nonspodosol soils were not significant at the alpha=0.05 level with an F statistic of 0.9578. The study originally had ten locations in each soil group, but by age 20, there were nine spodosol and seven nonspodosol locations remaining.

2.2 Loblolly Site Preparation Study

Data from the SAGS loblolly pine site preparation study were used to evaluate height-age relationships for planted loblolly stands subjected to various cultural treatments. For more information on the loblolly pine site preparation study see PMRC Technical report 2000-1 (Martin and Shiver, 2000; Shiver and Martin, 2002). Measurements at ages nine, twelve and fifteen were used in the analyses. The following treatments were used in this study.

1. Chop, burn
2. Shear, pile, disk
3. Chop, herbicide, burn
4. Herbicide, burn
5. Herbicide, burn, herbicide

The chop and burn treatment was used as the control in our analyses because some surviving overtopping hardwoods have negatively influenced pine height development on the burn only treatment. This study had plots in the Upper Coastal Plain and Piedmont physiographic regions. Physiographic regions were not significant at the alpha=0.05 level with an F statistic of 0.1624.

2.3 The Improved Planting Stock/ Vegetation Control Study

The PMRC loblolly pine improved planting stock-vegetation control study was used to evaluate the shape of the height-age curves for differences between unimproved, bulk lot improved, and single family improved genetic stock for loblolly pine with and without vegetation control. For more information on the loblolly pine improved planting stock-vegetation control study see PMRC Technical report 1999-5 (Martin and Shiver, 1999; Martin and Shiver, 2002). Measurements at ages nine, twelve, and fifteen were used in this study. The unimproved genetic stock with no vegetation control was considered the control. Physiographic regions were separated into Upper Coastal Plain and Piedmont. Physiographic region was not significant at the alpha =0.05 level with an F statistic of 0.5044.

3 ANALYSIS AND RESULTS

3.1 Significance of Treatments and Soils

A mixed model approach incorporating repeated measures analysis was used to test significance levels in this study. Installations and all installation interactions were treated as random factors of the experiment. Treatment, soil or physiographic region, age, and any interactions between these three were considered fixed effects. Tables one, two and three give the results of the tests of fixed effects on the slash pine site preparation study, loblolly pine site preparation study, and loblolly improved planting stock-vegetation control study, respectively.

Table 1. Test of fixed effects for average dominant height on the slash site preparation study.

Source	Numerator Degrees of Freedom	Denominator Degrees of Freedom	Type III F	Pr>F
Treatment	7	64	59.3	<.0001
Soil	1	14	0.33	0.5724
Treatment*Soil	7	64	1.65	0.1373
Age	4	56	984.56	<.0001
Treatment*Age	28	383	7.17	<.0001
Soil*Age	4	56	0.16	0.9578
Treatment*Soil*Age	28	383	0.41	0.9969

Table 2. Test of fixed effects for average dominant height on the loblolly site preparation study.

Source	Numerator Degrees of Freedom	Denominator Degrees of Freedom	Type III F	Pr>F
Treatment	5	25	43.01	<.0001
Region	1	23	0.07	0.7935
Treatment*Region	5	25	0.69	0.6376
Age	2	45	883.14	<.0001
Treatment*Age	10	219	3.17	0.0008
Region*Age	2	45	1.89	0.1624
Treatment*Region*Age	10	219	1.31	0.2271

Table 3. Test of fixed effects for average dominant height on the loblolly improved planting stock-vegetation control study.

Source	Numerator Degrees of Freedom	Denominator Degrees of Freedom	Type III F	Pr>F
Treatment	5	61	42.72	<.0001
Region	1	29	0.07	0.7983
Treatment*Region	5	61	1.24	0.3033
Age	2	58	672.72	<.0001
Treatment*Age	10	276	3.15	0.0008
Region*Age	2	58	0.69	0.5044
Treatment*Region*Age	10	276	0.95	0.4904

3.2 Proportionality of Height Curves

To see if various cultural treatments cause an anamorphic or polymorphic change as compared to the shape of the untreated site index curves, the observed dominant heights at every measured age for each treatment were compared to the control treatment average height at the same age. Proportional differences were calculated for individual treatments for the range of measured ages. Figure 1 shows the results of the slash pine comparison. There are significant differences in the proportionality of each treatment curve over the measured time span. This indicates that the height growth curves are polymorphic for all tested treatments on slash pine. As expected, the more intensive treatments vary by the largest percentage at young ages and then begin to decrease. The percentage is still decreasing at age twenty on all but the treatments with fertilizer. This could be due to the timing of fertilization. These treatments were fertilized at a young age, and then fertilized again at age twelve, and finally at age eighteen. Due to the repeated fertilization, these results cannot be directly compared to the other treatments that were only treated at time of planting. From the shape of the fertilization curves between the ages of eight and fourteen, it is likely that had the fertilizer treatment been applied only once, all the treatments would exhibit the same shape over the range of measured ages. It appears that nutrition has become the limiting factor on all of the treatments. The lowest intensity treatment which included fertilizer, the fertilizer only treatment, shows a response from the age twelve fertilization. No other fertilizer treatments show this reaction to the age twelve fertilization, indicating that the nutrition level on the fertilizer only treatment was negatively impacted by competition. Both the fertilizer and bedding treatment and the fertilizer and herbicide treatment show little to no response from the age twelve fertilization, but both seem to respond to the age eighteen fertilization. It appears the addition of bedding or herbicide to the fertilization treatment prolongs the duration of the fertilizer effect. The most intensive treatment, fertilization with both bedding and herbicide, does not exhibit a positive response from either mid-rotation fertilization. It appears that nutrients has not become a limiting factor on this treatment by age twenty.

Figure 2 shows the results of the loblolly site preparation treatment comparison. All treatments show a decrease in their curves over time. The chop, herbicide and burn and the shear, pile, and disk treatments only show a very slight decrease over time, but both of these treatments' dominant heights were within five percent of the control's dominant height even at age nine. This is in contrast to the complete control and the herbicide and burn treatments that had 26 and 13 percent greater dominant heights at age nine, respectively.

Figure 3 show the results of the loblolly pine improved planting stock-vegetation control study. Treatments with competition control show a decreasing trend as age increases, indicating that competition control is causing a polymorphic change in the dominant height curve. Treatments without competition control have curves that are approximately even or increasing. From this early data, improved genetics appears to result in an anamorphic change in the dominant height curves.

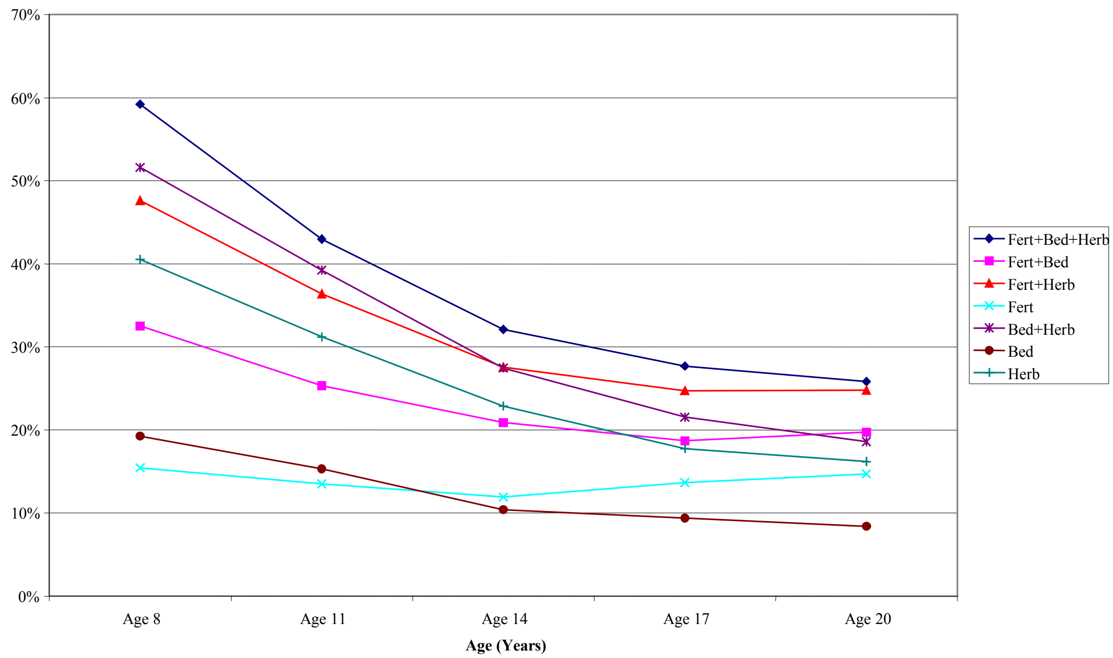

Figure 1. Percent dominant height difference of treatment plots versus control for the slash pine site preparation study over five measurement ages.

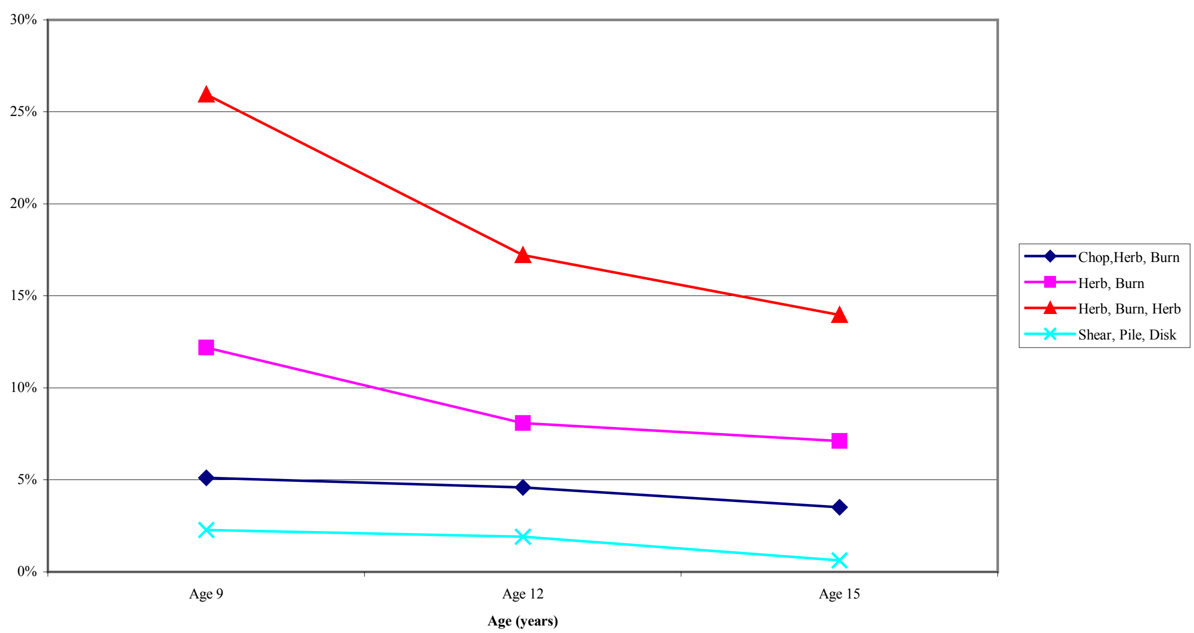

Figure 2. Percent dominant height difference of treatment plots versus control for the loblolly pine site preparation study over three measurement ages.

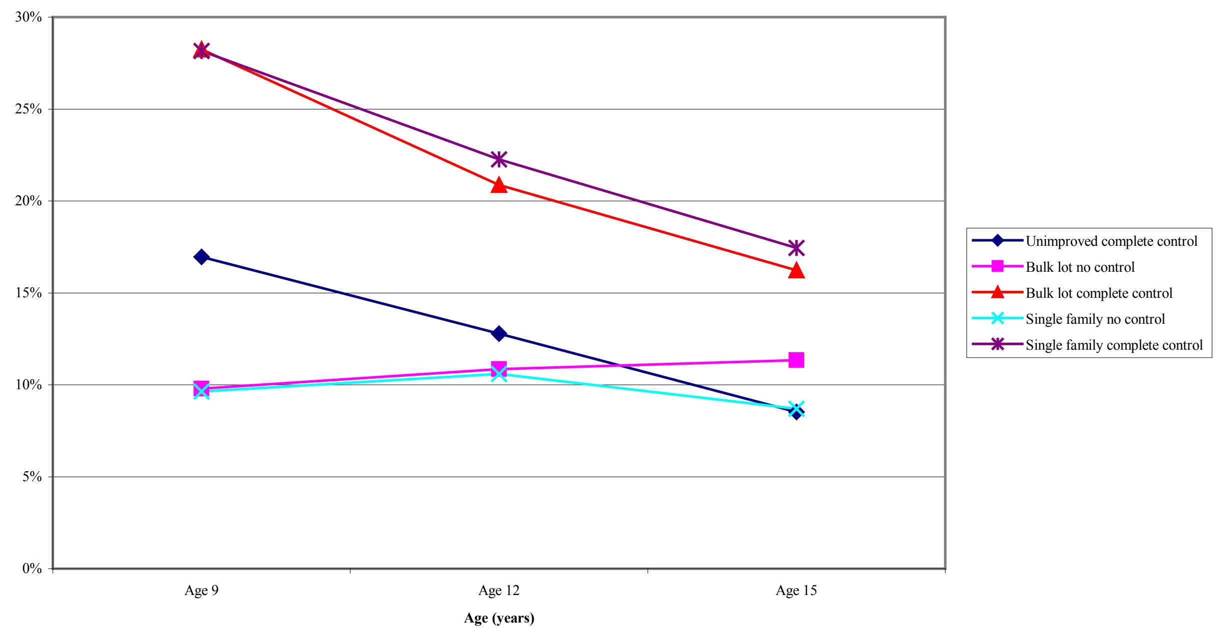

Figure 3. Percent dominant height difference of treatment plots versus control for the loblolly pine improved planting stock-vegetation control study over three measurement ages.

3.3 Absolute Difference in Dominant Height Curves

After establishing that all of treatments, with the exception of genetics, caused a polymorphic change in the dominant height curve compared to the control plots, the absolute dominant height difference (ft.) between the treated plots and the control plots at each age was calculated. Figure four shows the absolute dominant height difference relationship for the slash site preparation study. All non-fertilized treatments maintain a fairly constant dominant height difference compared to the control plots throughout the range of measured ages. This indicated that all gains in dominant height were complete by age eight, and then the absolute difference has been maintained. Treatments that were fertilized were flattening from age eleven to fourteen, but then increased again. This reversal was probably due to the fertilization at age twelve.

Figure five shows the absolute dominant height difference relationship for treatments in the loblolly site preparation study. Results are similar to the slash site preparation study. The dominant height difference between the treated plots and the control plots changes less than 0.5 percent after age 9.

Figure six shows the absolute dominant height difference relationship for the loblolly improved planting stock-vegetation control study. Treatments that had competition control varied less than one percent over the range of measured ages. This agrees with what we have seen in the previous two studies. The improved planting stock treatments with no competition control increased the absolute difference as age increased. Since the proportional curves were anamorphic for these treatments, this was to be expected. The dominant height difference would have to increase as age increases in order for the curves to be anamorphic.

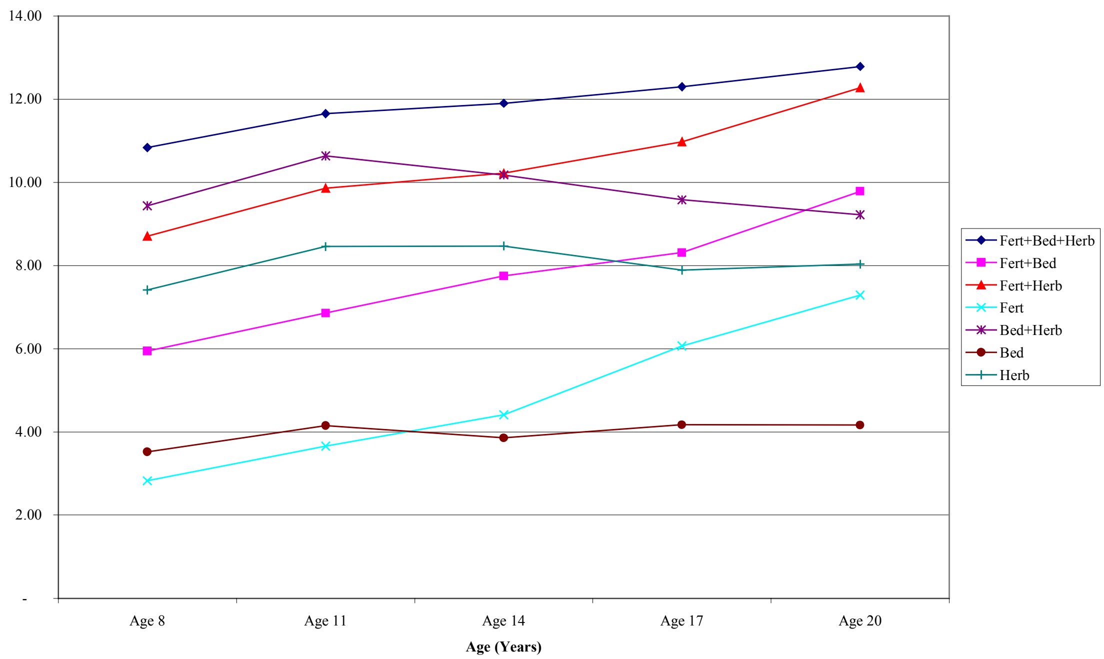

Figure 4. Absolute difference (ft.) of dominant height between control plots and treatments on the slash site preparation study over five measurement ages.

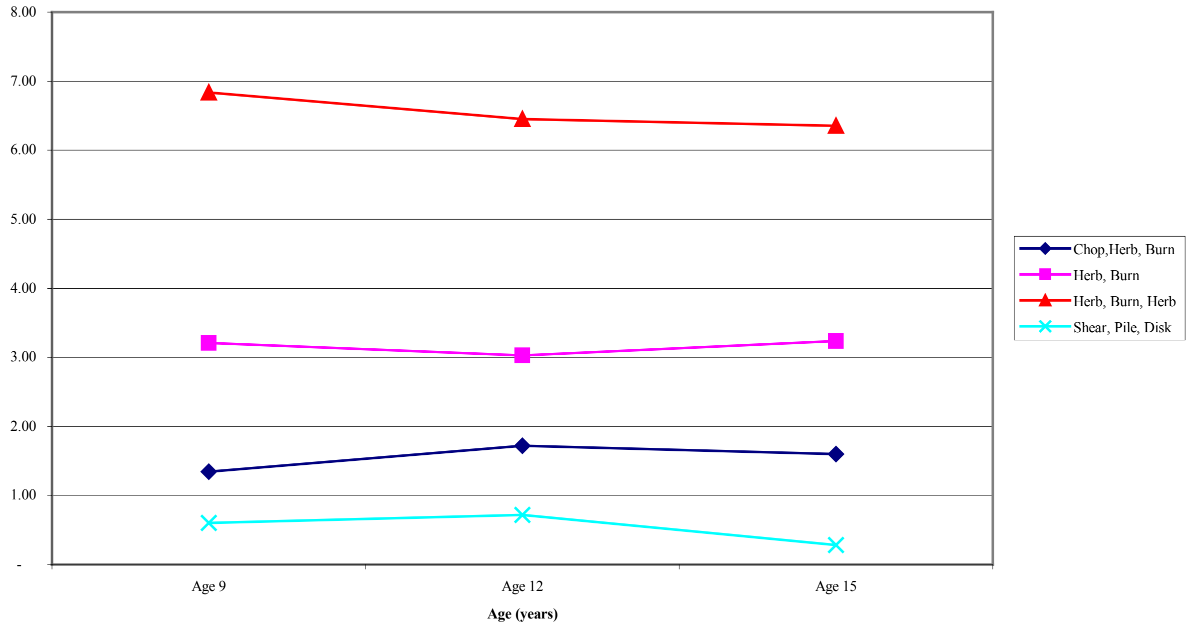

Figure 5. Absolute difference of dominant height (ft.) between control plots and treatments on the loblolly site preparation study over three measurement ages.

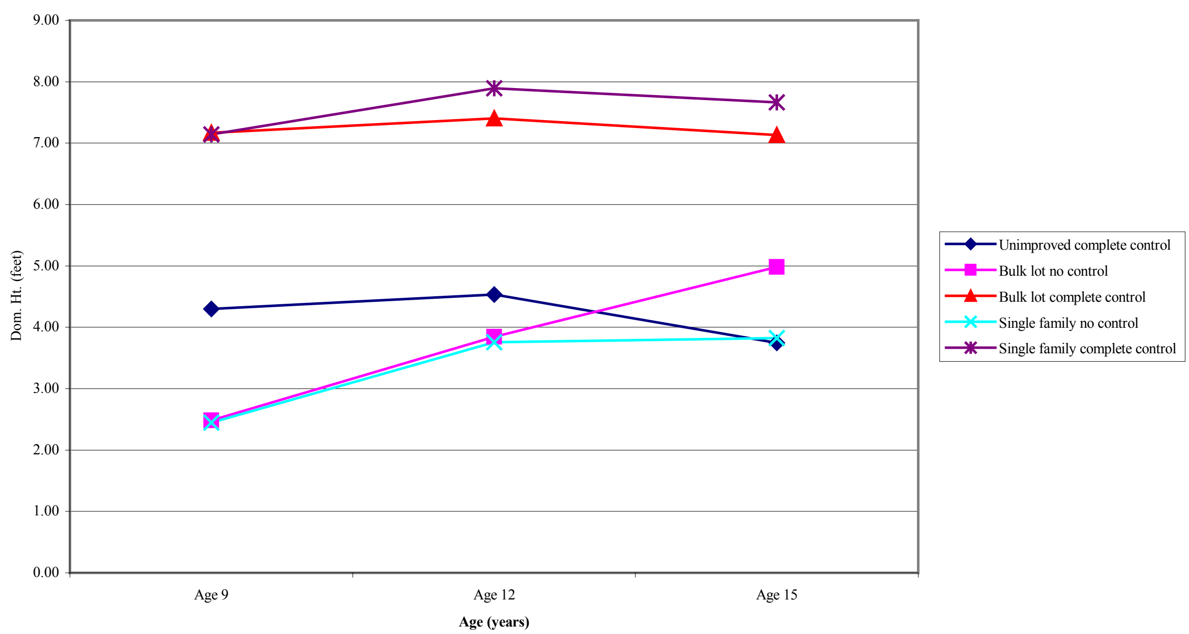

Figure 6. Absolute difference of dominant height (ft.) between control plots and treatments on the loblolly improved planting stock-vegetation control study over three measurement ages.

3.4 Dominant Height Curve Prediction

Due to the polymorphic change in dominant height curves caused by treatments in both the slash site preparation study and the loblolly site preparation study, new dominant height equations are required to accurately model the changes caused by cultural treatments. A Chapman-Richards equation with an additional response term to account for site preparation treatment was used to fit a regression to the height-age data. It has the following general form:

$$HD = b_0(1 - e^{b_1 * Age})^{b_2} + Z(1 - e^{b_3 * Age})$$

Where *HD* = average dominant/codominant height (ft.);

b_0 =asymptote parameter estimated from the data;

b_1 = rate parameter estimated from the data;

b_2 = shape parameter estimated from the data;

Z =maximum cumulative dominant height response of site preparation treatment, estimated from the data;

b_3 =rate of additive response term estimated from the data.

Equations developed from the slash site preparation study and loblolly site preparation study are shown below.

3.4.1 Slash pine dominant height equation development

The following model was developed from the slash pine site preparation data:

$$HD = 69.97(1 - e^{-0.1016 * Age})^{2.3253} + \left[\left(3.70Z_b + 4.79Z_f + 8.51Z_h - 2.46Z_{hf} - 1.84Z_{hb}\right)\left(1 - e^{-0.21783 * Age}\right)\right]$$

Where *HD* = average dominant/codominant height (feet);

Z_b = 1 if bedded, 0 otherwise;

Z_f = 1 if fertilized, 0 otherwise;

Z_h = 1 if herbicide, 0 otherwise;

Z_{hf} =1 if herbicide and fertilized, 0 otherwise;

Z_{hb} =1 if herbicide and bedded, 0 otherwise.

Three treatments, bedding, fertilizer and herbicide were included in the additive response term. The parameter on each term represents the maximum response expected for the given site preparation treatment. The herbicide and fertilizer, as well as the herbicide and bedding treatments, were less than additive when used in combination. The bedding and fertilizer treatments were additive when used together. Burning or chopping did not significantly affect dominant height growth.

Observed and predicted average dominant heights at age 20 for various site preparation treatments are shown in Table 4. Figure 7 shows observed and predicted average dominant heights for bedding, fertilization and herbicide treatments over the range of measured ages.

Table 4. Observed and predicted average dominant height (ft.) for slash pines at age 20 by treatment.

Treatment	Observed	Predicted
CNTL	49.56	50.45
FBHB	62.35	62.99
FCBB	59.35	58.83
FCBH	61.84	61.15
FERT	56.85	55.18
UBHB	58.78	60.69
UCBB	53.72	54.1
UCBH	57.59	58.85

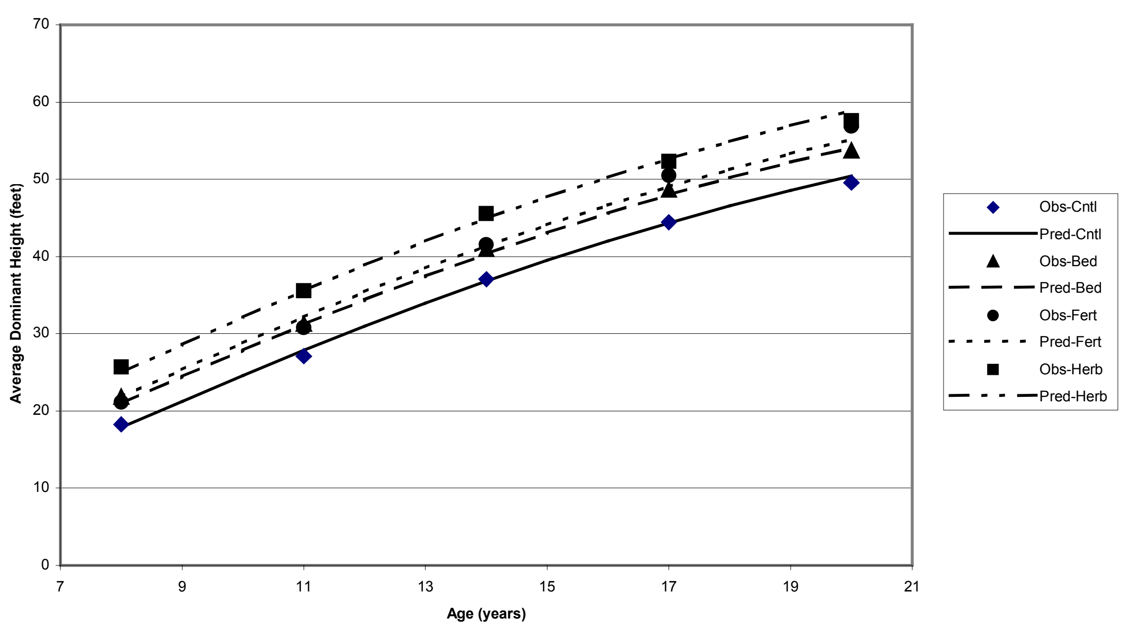

Figure 7. Observed and predicted average dominant height for four treatments on slash pine.

3.4.2 Loblolly pine dominant height equation development

The following model was developed from the loblolly pine site preparation data:

$$HD = 70.1(1-e^{-0.10961*Age})^{2.129} + \left[\left(5.17Z_h\right)\left(1-e^{-0.24476*Age}\right)\right]$$

Where *HD* = average dominant/codominant height;

Z_h = 1 if herbicide, 0 otherwise.

This model includes herbicide in the additive response term. The base model assumes only mechanical site preparation treatment, such as chopping and burning were performed. The 5.17 on the herbicide indicator variable is the maximum expected response from performing chemical site preparation.

Observed and predicted average dominant heights at age 15 for herbicide and mechanical site preparation treatments are shown in Table 5. Figure 8 shows observed and predicted average dominant heights for mechanical and herbicide treatments over the range of measured ages.

Table 5. Observed and predicted average dominant height (ft.) for loblolly pines at age 15 by treatment.

Treatment	Observed	Predicted
C&B	45.51	44.38
Herb	48.74	49.42

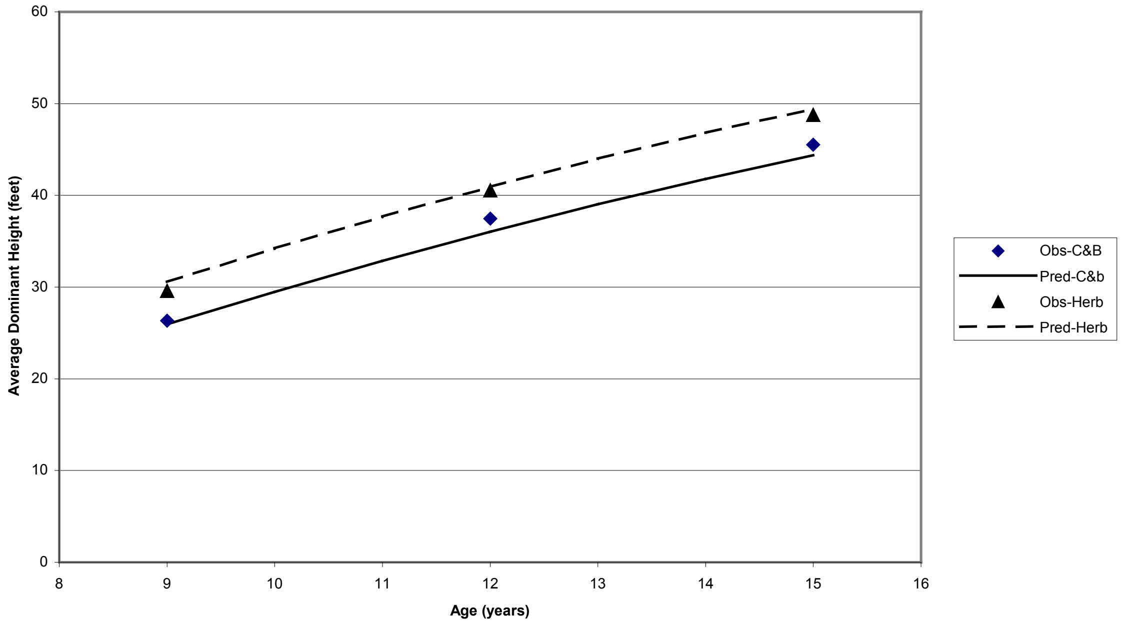

Figure 8. Observed and predicted average dominant height for two treatments on loblolly pine.

4 DISCUSSION

The two models in the previous section use an additive asymptotic response curve that reaches a maximum response and then maintains the additional dominant height increase for the remainder of the stand's life. The general shape of the additive response can be seen in Figure 9. A comparison of a stand with and without the additive response can be seen in Figure 10.

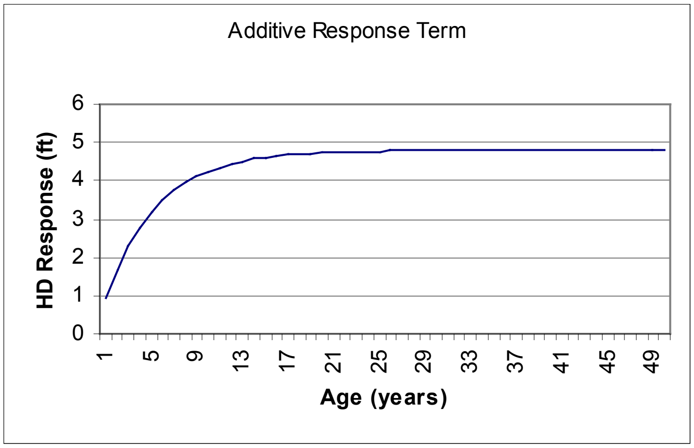

Figure 9. Additive dominant height response of fertilizer.

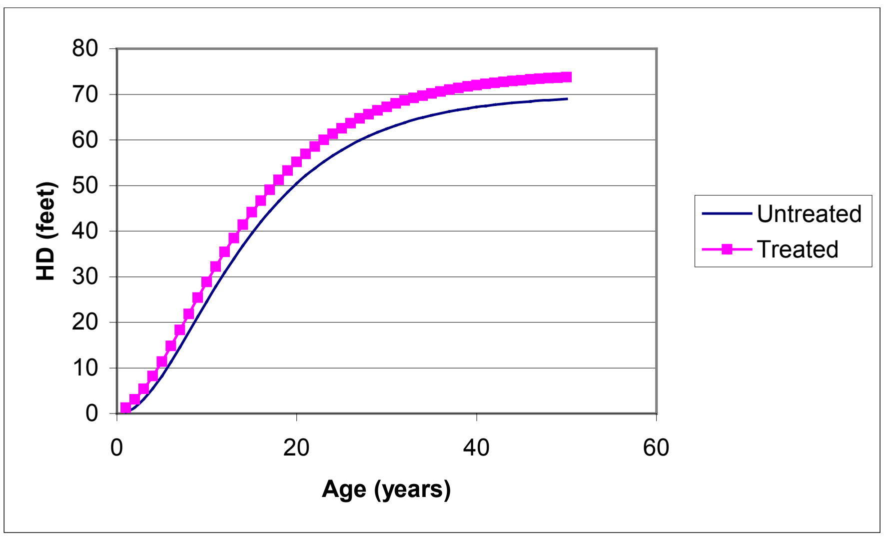

Figure 10. Comparison of treated and untreated stand using an asymptotic treatment response.

Treatment response is 90% complete by approximately age ten. This is consistent with findings by others (NCSFNC, 1996). The treatment response is then maintained. There is no significant difference in the rate of increase between treatments for either loblolly or slash pines.

5 CONCLUSIONS

All cultural treatments except improved genetics were found to cause a polymorphic change in the height growth curve on both loblolly and slash pine. With the exception of improved genetics, the included site preparation treatments appear to cause an increase in dominant height at early ages, and then maintain the additional height, at least over the range of measured ages. The implication is that raising site index to account for cultural treatments will not accurately model the observed change in the height growth curve. New polymorphic models need to be used to account for varying treatment height response. Using the knowledge that the gains in dominant height are maintained after the initial response, an asymptotic additive term was added to model what is being seen on the designed studies.

6 LITERATURE CITIED

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